United States Department of Agriculture
Forest Service
Research & Development
Southern Research Station

General Technical Report
SRS-178

The Southern Forest Futures Project

TECHNICAL REPORT







David N. Wear and John G. Greis, Editors

The Editors:

David N. Wear, Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695; and **John G. Greis**, Resource Analyst, State and Private Forestry, Southern Region, U.S. Department of Agriculture, Forest Service, Tallahassee, FL 32399.

Cover images: TOP TO BOTTOM: (1) Tellico-Robbinsonville Road scenic vista, USDA Forest Service; (2) Chipping by David J. Moorhead, University of Georgia; (3) Kids playing in the forest, USDA Forest Service; (4) Palmetto and hardwood hammock, USDA Forest Service; (5) Forest river scenic vista by Chris Evans, Illinois Wildlife Action Plan; (6) Kudzu by R. Kindlund, USDA Forest Service; FAR RIGHT: Long leaf pine in the fog, USDA Forest Service.

August 2013

Southern Research Station
200 W. T. Weaver Blvd.
Asheville, NC 28804

www.srs.fs.usda.gov

The Southern Forest Futures Project: Technical Report

David N. Wear and John G. Greis

ACKNOWLEDGMENTS

The Southern Forest Futures Project was a cooperative and highly complex effort requiring contributions from many organizations, public agencies, universities, and individuals. We wish to express our grateful appreciation to all who provided the ideas, guidance, and technical support needed to make the project both technically sound and useful, especially the following:

The leaders of the USDA Forest Service, Peter Roussopoulos, Director, Southern Research Station (Ret.) and Charles Myers, Regional Forester, Southern Region (Ret.), who recognized the importance of looking into the future of southern forests so that they might be best managed and conserved. James Reaves and Rob Doudrick, Directors, Southern Research Station and Liz Agpaoa, Regional Forester, Southern Region, who continued to support the effort to its conclusion after the retirements of their predecessors. Ken Arney, USDA Forest Service, Southern Region, who provided consultation and continuous support throughout the process.

The Chairmen of the Southern Group of State Foresters, John Burwell (Ret.) and Charlie Morgan, who agreed to co-sponsor the effort and provided strong support on behalf of the 13 State forestry agencies.

The Futures Project team, authors, and co-authors of all of the individual chapters of the Technical Report and the five subregional reports, who worked tirelessly, cooperatively, and patiently throughout the process to make the final product both valuable to the public and one of technical excellence. Their work is indeed the foundation of the project. Peer reviewers of chapter and report drafts, who contributed technical review and constructive criticism to make the final products as valuable and technically sound as possible.

Nancy Walters, who guided public and team meetings and consulted with the project's co-leaders to build a process that benefitted from and was responsive to public input and issues of concern.

The Science Delivery and Public Affairs teams of the Southern Research Station and Southern Region, who worked from project origination to completion to ensure the project's process and results were accessible to the public and the media and reports met high publication standards. In particular, Jennifer Plyler, Stevin Westcott, Michael Robinson, Zoe Hoyle, Patricia Matteson, Maureen Stuart, Gary Kuhlmann, and Helen Robinson of the Southern Research Station, and Stephanie Johnson and Steve Bekkerus of the Southern Region, USDA Forest Service.

Michaela Foster, who maintained and managed process records for the project.

Carol Whitlock, Altamont Professional Services LTD., who expertly edited all chapters and reports.

Shawna Reid, who patiently coordinated the development of map products across the chapters of the Technical Report and various phases of the project.

The interested public, who participated in the 15 public meetings conducted around the South and contributed the foundation of their ideas, expertise, and opinions upon which the project was built.

The Wear and Greis families, whose patience, understanding, and support enabled the co-leaders to concentrate on the Futures Project and travel widely to ensure its successful conclusion.

David Wear and ***John Greis***
Southern Forest Futures Project Co-Leaders

PREFACE

The Southern Forest Futures Project was initiated in 2008 as an effort to study and understand the various forces reshaping forests across the 13 Southeastern States. Chartered by the USDA Forest Service Southern Region and Southern Research Station along with the Southern Group of State Foresters, the effort built from the Southern Forest Resource Assessment (Wear and Greis 2002a, 2002b), which had identified and explored the implications of several forces of change reshaping the region's forests including land development, new forest pests, and increasing timber demands. These and other changes have continued apace or accelerated since 2002, warranting another look at the implications for southern forests and the many services and values that they provide.

The Futures Project was launched with a set of 15 public meetings from across the South to gather a broad range of insights into ongoing changes and anticipated trends affecting forests in the region and local areas. In contrast to public involvement processes for resource planning or administrative decision making—where input focuses on deducing values held by the public and their preferences regarding outcomes—we simply sought information regarding the range of issues, questions, and uncertainties regarding the future of forests and their various goods, services, and values in the South. We sought broad participation from all "stakeholders," including landowners, researchers, nongovernmental organizations, and forestry agencies and information from the public meetings was used to help organize the design of the project (Wear and others 2009).

After compiling public input, Phase I of the Futures Project was initiated. This involved constructing forecasts of future forest conditions to the extent possible using a set of future scenarios describing, among other factors, changes in populations, economics, and climate to the year 2060. A set of resource issues (meta-issues) developed from the public input sessions defined a set of questions that needed to be addressed. A lead scientist was identified for each of these meta-issues, research teams were convened, and study plans were developed and thoroughly reviewed. The detailed results of the forecasting and meta-issue teams are described in this technical report. A summary report (Wear and Greis 2012) provides a synthesis and identifies a set of key findings from the technical report.

A second phase of the Futures Project, ongoing as this report is being completed, examines the findings of the Technical Report from the perspective of each of five separate subregions. We contend that because of the diversity of resource settings in the South, the implications of the Futures Project for management, restoration, and potential policy would vary by subregion. Separate subregional reports are now being completed for the five subregions: (1) Appalachian-Cumberland, (2) Piedmont, (3) Coastal Plain, (4) Mississippi Alluvial Valley, and (5) Mid-South.

In addition to soliciting public input, we have sought expert input from the study team (more than 50 scientists and analysts have been involved) and through peer reviews from many specialists across the region. In addition, we shared the peer reviewed drafts of the summary report and this technical report with the public for their review. All of the reports produced in the Futures Project have greatly benefited from this thorough vetting process.

From its inception, the Southern Forest Futures Project has sought to provide an information foundation for evaluating the future of the region's forests and consequences for its people, and a platform for discussing how to negotiate the future. The ultimate measure of our success will be the extent to which our findings advance these discussions.

LITERATURE CITED

Wear, D.N.; Greis, J.G., eds. 2002a. The Southern Forest Resource Assessment: technical report. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 635 p.

Wear, D.N.; Greis, J.G. 2002b. The Southern Forest Resource Assessment: summary report. Gen. Tech. Rep. SRS-54. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 103 p.

Wear, D.N.; Greis, J.G. 2012. The Southern Forest Futures Project: summary report. Gen. Tech. Rep. SRS-159. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 54 p.

Wear, D.N.; Greis, J.G.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS–115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

CONTENTS

ABSTRACT

The Southern Forest Futures Project provides a science-based "futuring" analysis of the forests of the 13 States of the Southeastern United States. With findings organized in a set of scenarios and using a combination of computer models and science synthesis, the authors of the Southern Forest Futures Project examine a variety of possible futures that could shape forests and the many ecosystem services and values that forests provide. The science findings and modeling results could inform management and policy analysis of the South's forests. In the chapters of this technical report, the authors provide detailed findings and results as well as sets of key findings and implications.

Keywords: Forest conservation, futuring, integrated assessment, Southern Forest Futures Project, sustainability.

CHAPTER 1. Design of the Southern Forest Futures Project

David N. Wear and John G. Greis[1]

INTRODUCTION

The South has a unique human and landscape history and forests that reflect many episodes of change. Spanning the 13 States from Virginia to Texas, the South still contains a widely diverse complement of physical, economic, and ecological conditions; where forests and other native habitats play an important role not only in supporting diversity of native plants and animals but also in providing economic, aesthetic, and cultural values for its residents. Perhaps more so than in any other region of the United States, southern forests continue to change in response to direct human uses and to changes in the physical and biological environment, raising important questions about their potential future. Because these and other forces will dictate the long term sustainability of forest resources, it is important to scientifically assess their consequences so that society can make informed policy and management decisions.

The Southern Forest Futures Project represents a response to this need for a careful, science-based assessment of the South's forests. It was chartered by the Southern Research Station and the Southern Region of the Forest Service, U.S. Department of Agriculture, in cooperation with the Southern Group of State Foresters, to forecast potential changes and to clarify, to the extent possible, how important trends and potential structural changes might affect a variety of forest values, conditions, and uses (Wear and others 2009). The following definition of success shapes the objectives, design, and conduct of the Futures Project: *A successful Southern Forest Futures Project will provide a credible, objective information foundation that helps shape sustainable forests in the South through the informed actions of private and public forest managers and through the design and development of effective land use and forest policies.*

The Futures Project cooperators anticipate a broad audience, one that reflects the diverse population of forest owners and forest users, and recognizes that about 90 percent of southern forests are privately owned. Within this context, sustainability starts with understanding current trends, anticipating changes, and identifying potential future scarcities; and ends with designing and implementing management and policy in response.

The first step in developing questions and issues to be addressed was to engage in discussions with a cross section of forest owners and forest users in a set of workshops conducted in all 13 States. With the public's interests defined through the workshops, we set out to design an assessment process that would target the most important questions and make the most efficient use of available tools and science.

Success also depended on our ability to provide three different types of information. The first was to take a comprehensive "systems science" approach in forecasting change at a scale detailed enough to be meaningful for the analysis of economic and ecological issues and their implications, but also capable of addressing major uncertainties through a set of potential futures. Second was to collect information about issues that are developing rapidly, and are not suited for modeling because of their complexity or their dependence on policy development or other highly uncertain events. Third was to identify the management implications of forecasted changes, which required a tertiary analysis coupling changes and implications with management science to determine how forest management choices might affect—or be affected—by undesirable outcomes.

Satisfying these three sets of information needs defined distinct and necessary phases of the Futures Project (fig. 1.1):

- A **forecasting** phase using a simulation modeling framework to play out the implications of several scenarios for land use, forest conditions, and forest uses in the South. We assembled a forecasting team to deploy a modeling system for forecasting these scenarios of the future.
- A **meta-issue** phase analyzing and predicting the future of several key issues of concern to southern forested landscapes, their functions, and the values that are derived from them. We recruited experts to address specific questions about these meta-issues.

[1] David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695. John G. Greis is a Resource Specialist, Southern Region, U.S. Department of Agriculture Forest Service, Tallahassee, FL 32399.

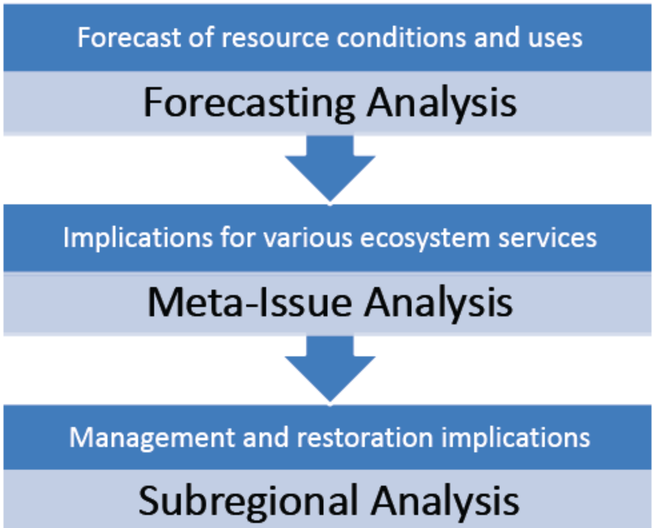


Figure 1.1—The three phases of the Southern Forest Futures Project.

- A **management implications** phase identifying important issues and management implications for five broad subregions (fig. 1.2) of the South (Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, and Mid-South) and the ecological sections within each subregion (fig. 1.3). We recruited scientists and managers to co-lead the analysis of these management implications.

METHODS

Soliciting Public Input on Issues

Before beginning the three phases of analysis described above, we asked for help in identifying the key issues to be analyzed. With a vast number of issues that could potentially be addressed by a project such as this, it was critical to decide where to (and not to) focus attention so as to streamline the project and maximize its usefulness. Because our intent was to address a broad complement of issues relevant to forest managers, landowners, agency specialists, policymakers, science leaders, and the interested public, we sought extensive input from them on the specific issues that should be addressed. Their input provided guidance on content and helped formulate specific plans for all phases of analysis. For the forecasting work, public input helped shape the scenarios to be analyzed with technical models. Public input was the basis for selecting and defining the set of meta-issues. And public input helped frame the analysis of management implications, focusing attention on the potential ecosystem impacts of future changes and the values that participants considered at risk within each of the subregions.

It is important to consider what "the public" represents in the context of this project. In contrast to public involvement processes for resource planning or administrative decision making, where input focuses on deducing the values held by the public and their preferences regarding outcomes, we sought information about the range of issues, questions, and uncertainties surrounding the future of forests and their services in the South. The analysis teams used this information, coupled with their own expertise, to define the most important issues. We sought broad participation from all "stakeholders," but did not have the means to determine whether this was a representative cross section of all demographic subgroups within the region. No weighting or voting was applied to the comments received, so that the focus was on the complete set of issues, not on a set of aggregate preferences.

Our primary method of eliciting input was to organize public meetings in 14 locations (table 1.1) at sites selected to ensure at least two meetings in each of the five subregions and at least one in each State. This latter criterion was important because State agencies had a strong interest in these meetings and wanted to be sure that their interested citizens had an opportunity to participate. We also reinforced the process of the face-to-face meetings through three "webinars" using Internet and phone access, which allowed people to participate without traveling, no matter their location. Two of these were held in the evening for those who could only participate after work hours. The public was also invited to provide input through the project Web site.

After reading and evaluating all the comments received, the project co-leaders next identified the meta-issues embedded in the public comments and assigned specific comments to their respective issues. A meta-issue was defined as a broad area of concern that was raised region-wide and that involved a complement of interrelated drivers and/or implications. Sorting algorithms grouped comments according to several topical categories with extensive cross-referencing. Finally, we summarized the major points raised within each category.

Taken together, the more than 2,200 comments from some 600 participants define a comprehensive view of natural resource dynamics in the South. They address the social dynamics that reshape forested ecosystems, and they focus attention on the key uncertainties that surround anticipated changes in the interactions between human and ecological systems. We categorized the broad and universally important issues identified by the public into nine meta-issues: socioeconomic factors; plant and animal diversity and sustainability; bioenergy; climate change; land ownership change; water resources; taxes; insects; diseases and invasive plants; and fire.

A thorough and comprehensive analysis of each of these areas would define a broad research program for a community of researchers for years to come, but our

Figure 1.2—The five broad subregions of the South.

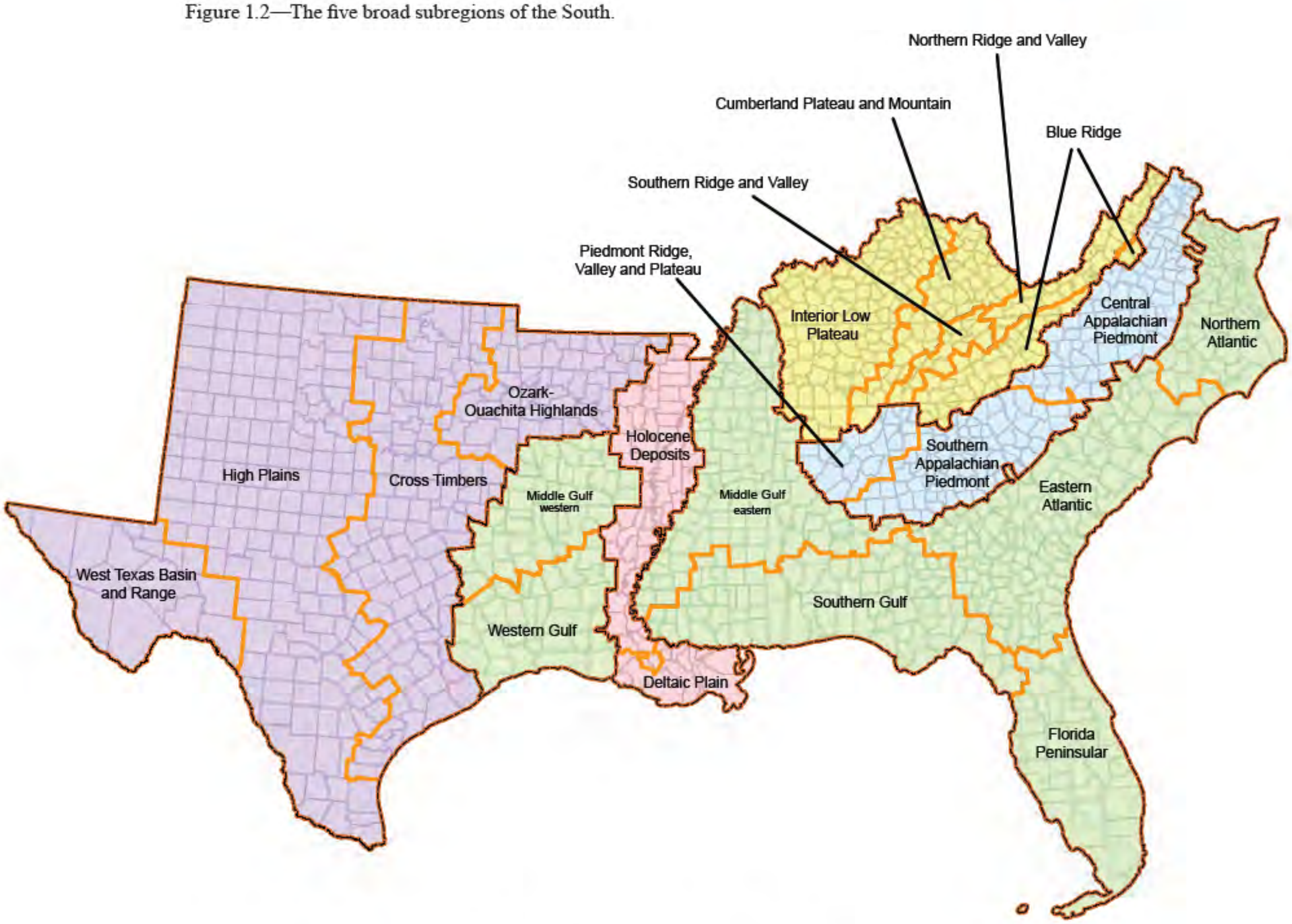


Figure 1.3—The 21 ecological sections of the South. (Source: Rudis 1999)

Table 1.1—Locations, subregions represented, and schedule of public meetings held for the Southern Forest Futures Project in 2008

Meeting location	Subregion represented	Date
Baton Rouge, LA	Coastal Plain/Mississippi Alluvial Valley	January 29
Stoneville, MS	Coastal Plain/Mississippi Alluvial Valley	January 30
Gainesville, FL	Coastal Plain	February 7
Charleston, SC	Coastal Plain	February 8
Little Rock, AR	Mid-South/Mississippi Alluvial Valley	February 13
College Station, TX	Mid-South	February 11
Stillwater, OK	Mid-South	February 12
Lexington, KY	Appalachian-Cumberland	February 19
Nashville, TN	Appalachian-Cumberland	February 21
Raleigh/Durham, NC	Piedmont/Coastal Plain	February 25
Blacksburg, VA	Appalachian-Cumberland	February 26
Asheville, NC	Appalachian-Cumberland	February 27
Athens, GA	Piedmont/Coastal Plain	March 6
Auburn, AL	Piedmont/Coastal Plain	March 7
Webinar #1	All subregions	April 8 evening
Webinar #2	All subregions	April 16 afternoon
Webinar #3	All subregions	April 16 evening

objective was to shape the first planning step of the Southern Forest Futures Project.

For the forecasting phase we enlisted a team of experts to summarize the forces of change and begin shaping a set of alternative futures for analysis using quantitative models (chapter 2). The public's input was the starting point for a structured workshop in which the team developed a manageable number of scenarios that address the issues raised by the public.

For each meta-issue identified through the scoping process, we continued to use public input as we developed research questions and associated important elements to be evaluated. An expert scientist was assigned to manage the analysis of each meta-issue. We also linked specific concerns and questions to their applicable subregions. These would be considered by the team addressing management implications in each of the five subregions.

The meetings clearly showed that the public anticipates (and is concerned about) important changes they believe will occur on the forested landscapes of the South over the next 50 years (Wear and others 2009). Multiple forces will drive these changes, and their effects will span ecological, economic, and social dimensions. The public sessions clearly validated the need to undertake the Futures Project, and the public's input provides the foundation upon which we designed the three analysis phases of the effort.

The Future of Southern Forests: An Ongoing Conversation

1969 > South's Third Forest—Supported by the wood products industry and large private forest landowners, the third forest report used literature reviews and an evaluation of trends to evaluate the future of timber supply in light of increased demands for wood products and perceived underinvestment in private forest lands (Wheeler 1970). Concerned that timber scarcity would limit growth of the wood products sector, the report recommends policies and strategies to encourage planting and increase management on private forests; protect forests from insects, diseases, and fires; and build stronger institutions for forestry training, technology transfer, and research. Its forecasts of population-driven urbanization and expansion of timber growing and production have been realized in the South.

1988 > South's Fourth Forest…alternatives for the future—Nearly 20 years after the third forest report, the Forest Service asked some of the same questions about the potential future of the timber-producing sector in the South (USDA Forest Service 1988), this time using a state-of-the-art timber market model and a technical analysis of various policy alternatives for reversing underinvestment by nonindustrial private forest owners. Their findings anticipate the growth in timber production realized through 2000 and point to a similar suite of programs and policies to encourage reforestation, management, and forest protection. While the report dedicates a few pages to impacts of timber projections on wildlife and water, its emphasis is squarely on the future of timber management and production.

2002 > Southern Forest Resource Assessment—The growth in forest management and timber production largely anticipated by the third and fourth forest reports, coupled with the emergence of satellite chip mills in the late 1990s, raised concerns about the sustainability of forests in the South (Wear and Greis 2002a, 2002b). An interagency effort let by the Forest Service and driven by a set of questions developed from extensive public meetings, the Southern Forest Resource Assessment drew knowledge from extensive literature and data bases to address concerns ranging from imperiled terrestrial and aquatic species to wetlands; from outdoor recreation to the influence of policies, regulations, and laws; from air pollution to the future course of timber markets and land use changes. The assessment identifies urbanization as a key threat to forest sustainability and raises additional concerns about the effects of increased management intensity on wildlife and water, and about an increasing scarcity of recreational opportunities in parts of the South.

Today > Southern Forest Futures Project—Six years after the completion of the Southern Forest Resource Assessment, new issues and questions have arisen. Forest industry has largely divested its land holdings, science has provided new insights into potential future climates, and questions about water sustainability are on the horizon. To address these and other questions—again deriving from extensive public involvement—the Forest Service and Southern Group of State Foresters commissioned the Southern Forest Futures Project. Where the earlier assessment relied mostly on literature reviews and stand-alone analysis of future impacts for its forecast of a most-likely future, this new effort is focused on forecasting the future under a variety of scenarios and uses these scenarios to integrate findings. The Futures Project builds from the knowledge foundation of its predecessor, updates some topical areas, and lays out a range of futures for consideration by policymakers and forest managers.

Forecasting Forest Conditions and Uses

Forecasting forest conditions and uses required a determination of the variables that could change the world surrounding future forests, including the physical environment (such as climate change), the social environment (number of people, their relative wealth, and how they use land), and the economic environment (relative scarcity of timber and other forest amenities). Following evaluations of the input from public workshops to sort out the variables to be addressed, our next step was to conduct a scenario analysis so that combinations of variables could be projected and evaluated. In particular, we developed a set of alternative futures to organize and conduct the forecasting phase of the project. Derived from scenarios constructed for the 2010 Resources Planning Act Assessment conducted by the Forest Service, these alternative futures represent a broad range of internally consistent world possibilities by linking climate, population, income, and technological advances.

Alternative futures were evaluated using the U.S. Forest Assessment System, a modeling system designed to forecast alternative futures for U.S. forests. The Forest Assessment System is a forward-looking adjunct to the Forest Inventory and Analysis (FIA) program implemented by the Forest Service research and development staff. The FIA program provides nationwide monitoring through repeated inventories that provide for consistency over time and a high level of detail. The Forest Assessment System accounts for changes driven by multiple vectors including biological, physical, and human factors to generate forecasts of forest inventories. The modeling approach is designed to address scenarios changing climate, market-driven timber harvesting, and land use changes along with changes driven by a successional transition in forest conditions.

A general schematic of this modeling system (fig. 1.4) starts with internally consistent combinations of social, economic, and technology forecasts defined as Cornerstone Futures for this application of the Forest Assessment System. Linked to the Cornerstones are various through various general circulation models (climate change models), each selected to define a climate forecast that is consistent with the Cornerstone. Also linked are data from a forest inventory server, which defines starting conditions for all plots in the forest inventory.

The modeling framework at the center of this system shows how future forest conditions are driven by biological dynamics—such as growth and mortality—that are affected

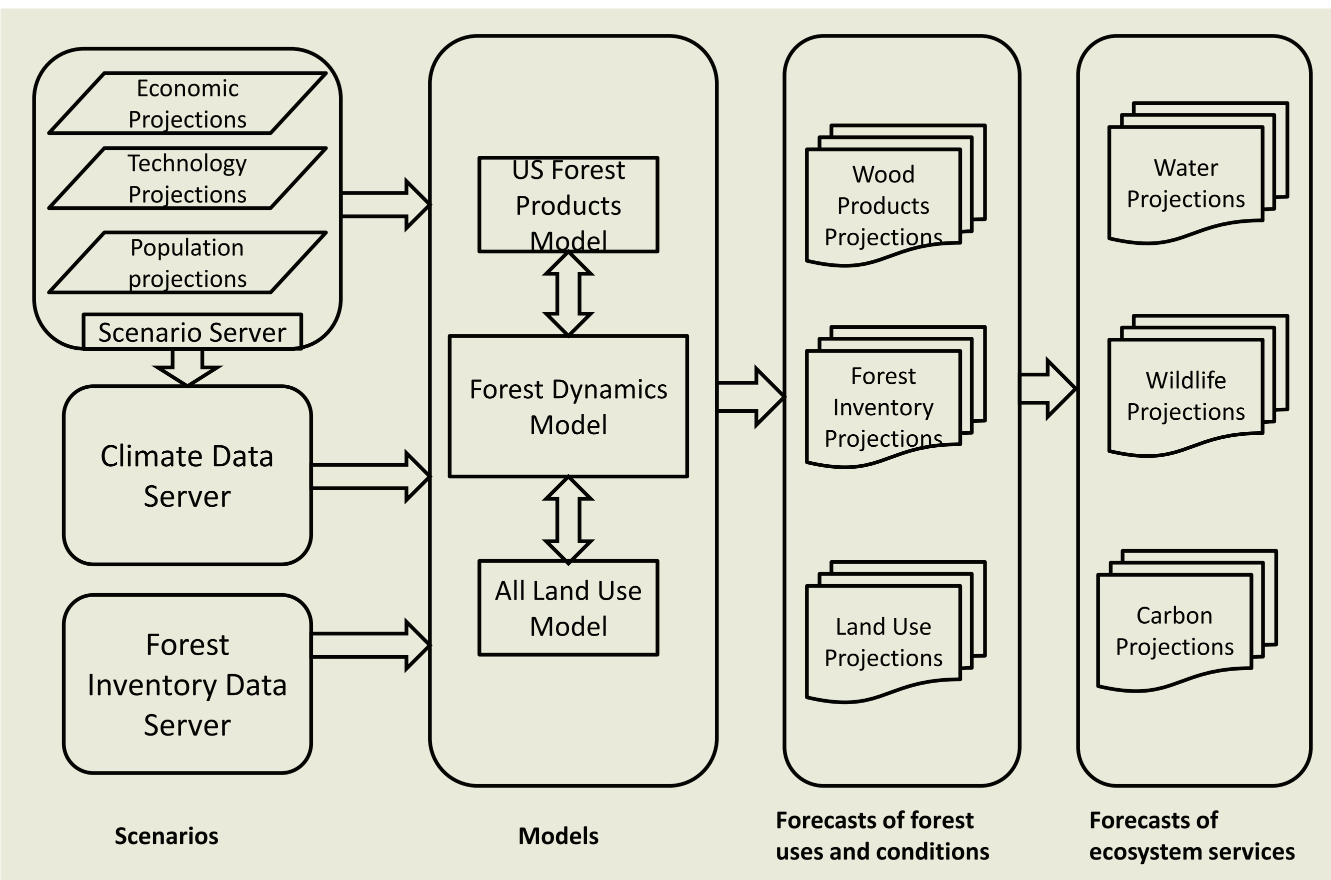


Figure 1.4–General schematic of the U.S. Forest Assessment System. (Source: Wear and others 2013)

by climate factors, allocations among land uses, disposal of forest land, timber harvesting, and forest management. The interplay of all of these factors yields a set of outputs, each of which describes forest projections that are consistent with the flow of forest products and land uses. Changes in water, biodiversity, and other ecosystem services can also be derived from the forecasted changes in forest conditions and land uses. Many of these are described in subsequent chapters.

The forest products module of this framework can be approached in one of two ways. The first is an explicit market simulation of market-clearing wood products and timber production in three regions of the United States (North, South, and West) and all other countries in the world. This approach accounts for a wide variety of demand drivers including energy futures, U.S. housing starts, and changes in paper consumption by households (Ince and others 2011). The second approach, and one that is used for much of the analysis of this Futures Project, is to develop price futures for timber products in the region. Increasing prices are consistent with increased scarcity of timber; decreasing prices indicate a lessening of timber scarcity.

The land use module (fig. 1.4) described in chapter 3 simulates changes in all uses of land and is driven by population and income growth along with the prices of timber products. Projections of forest area from the land use module feed into forecasts of future forest conditions and other analyses described below.

The forest dynamics module of this framework projects the future of every FIA plot in the forest inventory in a multiple stage process. The process begins by determining the point at which the plot is harvested, if ever, and the intensity of the harvest based on timber prices (from the forest products module), and the condition of forests on the plot (Polyakov and others 2010). The age of each plot in the next period is determined, and if harvested, the plot is determined to be naturally regenerated or planted. Forecasted climate including temperature and precipitation is assigned and forest conditions on the plot are inferred based on the harvest/no harvest decision, age, and climate selection (chapter 5).

The Forest Assessment System generated simulation results include forecasts of land use (chapter 4), forest products (chapter 9), and detailed forest conditions (chapter 5) for the forecast period (2010 to 2060). In chapter 5, we generate forecasts on various forest conditions including the volume of forest biomass, the area of forests by type and age class, and the carbon contained in the above- and belowground pools represented. Furthermore, we generate maps forecasting removals from forests determined by harvesting and land use changes. Results of these forecasts are used in the analysis of meta-issues and are summarized for each subregion for evaluation of management implications.

Evaluating Meta-Issues

We defined a meta-issue as a broad area of concern that contains a complement of interrelated drivers and implications. The public input process identified the eleven meta-issues shown in table 1.2. For each meta-issue, we synthesized all of the public input into one central question and an accompanying set of specific issues in need of resolution. The lead analyst and team member assigned to each meta-issue designed a study approach. Study plans are located on the Futures Project Web site (http://www.srs.fs.usda.gov/futures/process/draftplan/). Reporting of each meta-issue analysis comprises one or more chapters in this publication (for example, the meta-issue report for invasive species is divided into two chapters to address invasive plants and invasive insects and diseases). The central meta-issue questions and associated specific issues follow.

Social/economic linkages—How will alternative futures be affected by changing demographics and values, and how will these futures alter certain social and economic benefits in the South?

- How are population, demographics, and values changing; what might these changes mean for forests futures?
- How and where will population growth, changing demographics ownership, and land use affect supply and demand for different types of forest-based recreation?
- How and where might forest-based employment and income be affected by anticipated futures?

Table 1.2—Definition of meta-issues for the Southern Forest Futures Project

Social and economic factors—recreation, jobs, and income
Timber markets
Wildlife, biodiversity, and forest communities
Water and forests
Tax influences on forest management and conservation
Climate change and forest conditions
Fire in southern forests
Forest ownership changes
Invasive plant species and the integrity of forest ecosystems
Forest insects and diseases
Bioenergy and its potential influence on forests

Wildlife and forest communities—How might changes in forest environmental and social conditions affect terrestrial wildlife (birds, mammals, reptiles, and amphibians), their habitats, and forest vegetation communities in the South?

- How would anticipated fragmentation and population growth, urbanization, and related infrastructure affect wildlife habitats?
- How might anticipated futures affect wildlife diversity and where would changes likely be concentrated?
- What are the implications of anticipated futures for imperiled, rare, threatened, and endangered wildlife and plant species?
- How will rare forest communities be affected by anticipated futures?

Water—What roles do forests and forested wetlands play in producing and protecting water resources in the South, and how might future land-management and land-use changes affect these roles?

- What is the relationship between forests and water timing, flow, and quality?
- How will forest conversion and loss affect these relationships?
- What are the implications of intensive forest management for water?
- How do forested wetlands and riparian areas protect water quality, and what are the potential implications of their conversion and loss?
- How will increased demand interact with forest conversion, drought, and climate change?
- What are the known effects of impoundment construction on forests and associated resources?

Taxes—How might taxation influence retention and management of forest land in the South?

- What are the effects of estate, income, severance, and property taxes for nonindustrial forest owners?
- How do differential income taxes affect "C" corporations?
- How can/will the tax structure affect conservation easements or other forms of forest stewardship?

Climate change—How might the environmental conditions associated with climate change affect forest ecosystem health and productivity?

- What are the critical climate change variables and how are southern forests likely to be affected by them?

- Where in the South might forecasted changes in climate-induced environmental conditions be most/least significant?
- How will potential climate-change outcomes, such as severe weather events and drought, interact with forest pests?
- What are the economic consequences of extreme weather events for landowners, forest industry, and local governments?

Fire—How will fire behavior and fire risk change over time, and what are the likely effects on communities and people?

- What is the current and potential fire behavior/fire risk situation in the South, and what factors contribute to potential changes?
- What is the likely future of prescribed burning in the South, including the factors that affect this practice and alternatives to its use as a management tool?
- How will restricted or excluded prescribed fire affect fire-adapted and fire-dependent forest communities and other dependent species, and where will these effects be concentrated?
- What are the economic consequences of reduced prescribed burning, including potential property and structural damage and loss, timber devaluation, liability, and emergency rehabilitation and reforestation costs?
- Do wildfire and prescribed burning differ in carbon cycling, air pollution, forest productivity, and forest health?

Forest ownership change—Describe recent and anticipated changes in forest ownership in the South and the implications of these changes for forest ecosystem conditions, management, and productivity.

- How much and where has forest land ownership changed in recent years and where will changes likely to be concentrated in the future?
- What are the economic determinants for ownership change (all ownership categories), and how might they change in the future?
- How will forest-land use and forest uses likely change as a result of shifts in ownership?
- How are forest management practices influenced by ownership change and what are the ramifications of those influences?
- How will changing forest ownership affect the forest products industry?

Invasive species—How will invasive plants, insects, and diseases likely affect southern forests and related ecosystems in the future?

- What are the factors influencing historical spread and forecasting future spread of significant invasive species?
- What are the expected consequences of the spread of important invasive species for forest composition, riparian

health, and dependent communities?
- What is the likelihood of effective invasive species control in the future, given anticipated fragmentation, parcelization, and urbanization interactions?
- What forest species are likely to be completely lost as a result of the spread of invasive pests?

Bioenergy—What would be the likely effects of the emergence of a mature bioenergy market on southern forests, forest owners, and traditional forest product markets?

- What current and potential technologies are needed to realize large scale production of biofuels from woody biomass, including preferred feedstock (if known)?
- What might be the likely forest management regimes followed to maximize the production of woody biomass?
- How would these regimes affect indicators of forest ecosystem integrity such as habitat quality, biodiversity, and soil productivity?
- How will the emergence of a bioenergy market affect competition with traditional forest product markets and financial returns to landowners?
- What effects will subsidies or other incentives have on landowner behavior and wood product markets?

Discerning Management Implications of Futures Project Findings

The South's regional identity sometimes obscures the substantial diversity of its landscapes. From coastal pine flatwoods to Blue Ridge escarpments, from cedar swamps and hardwood hammocks to High Plains mesquite, the South's forests are varied across longitude and latitude, and the region's diversity of tree species exceeds any other part of the conterminous United States. The findings of the Futures Project or any other regional assessment cannot be meaningfully generalized to the entire South. Rather they warrant evaluation at finer grains where forecasted change can be intersected with specific forest and social conditions.

To address the diversity of the South, we include interpretations of the findings for the subregions shown in figure 1.2 and, where appropriate, for the 21 sections nested within these subregions (fig. 1.3). Throughout our analysis of forecasts and meta-issues, we summarize our findings for the entire region and for each of the subregions, and follow up with management implications of forecasts and issue analyses for each.

The analysis of management implications starts with a thorough examination of current conditions and a summary of findings from the forecasts and the meta-issue analyses. Then a team of experts, coupling forest managers with scientists, interprets forecasting and analysis results into implications for management. Management changes may be directly implied by the forecasts, for example where intensified management is indicated or where specialized management is indicated by expected scarcity of an ecosystem service such as wildlife habitat or water. Other forecasted changes imply constraints on how forest management might be practiced in certain places, most notably where human populations are growing.

By design, the subregional analyses of management implications are staged for completion after the forecasting and meta-issue analysis. Accordingly, the results of these efforts will be published under separate cover at a later date. We also anticipate that the findings of the Futures Project will spawn additional studies of the implications for management and policy across the South. To support such future study, our findings in all other areas will be readily accessible online at the Futures Project Web site.

CONCLUSIONS

The Southern Forest Futures Project was initiated to provide interested publics, including forest managers and policymakers, with insights into the array of possible futures and a better understanding of what those futures would mean for forests and their associated values. Anticipating the future is the first step toward sustainable forest management. The next is developing management and policy approaches that lead to desired outcomes in these complex systems. Our forecasting and meta-issue analyses intend to address the first step. Our analysis of management implications addresses the second. The future is uncertain, as is our understanding of forested ecosystems, the provision of ecosystem services, and possibilities for management design and effects. Sustainability is therein a moving target where objectives, means, and knowledge are all dynamic. The accumulated data and knowledge arrayed by the Futures Project provides a starting point for considering the future of southern forests. Informed management, research, monitoring, and attention to the mechanisms of change will necessarily define the region's path toward forest sustainability.

LITERATURE CITED

Ince, P.J.; Kramp, A.D.; Skog, K.E. [and others]. 2011. U.S. forest products module for RPA forest assessment. Research Paper FPL-RP-662. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 61 p.

Polyakov, M.; Wear, D.N.; Huggett, R. 2010. Harvest choice and timber supply models for forest forecasting. Forest Science. 56(4): 344-355.

Rudis, V.A. 1999. Ecological subregion codes by county, coterminous United States. Gen. Tech. Rep. SRS-36. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 95 p.

U.S. Department of Agriculture (USDA) Forest Service. 1988. The South's Fourth Forest: alternatives for the future. Forest Resource Report No. 24. Washington, DC: U.S. Department of Agriculture Forest Service. 512 p.

Wear, D.N.; Huggett, R.; Li, R. [and others]. 2013. Forecasts of forest conditions in U.S. regions under future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-170. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 101 p.

Wear, D.N.; Greis, J.G., eds. 2002a. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 635 p.

Wear, D.N.; Greis, J.G. 2002b. Southern Forest Resource Assessment: summary report. Gen. Tech. Rep. SRS-54. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 103 p.

Wear, D.N.; Greis, J.G.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS-115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Wheeler, P.R. 1970. The South's third forest. The Journal of Forestry. March: 142-146.

CHAPTER 2.
Constructing Alternative Futures

David N. Wear, Robert Huggett, and John G. Greis[1]

INTRODUCTION

The desired product of the Southern Forest Futures Project is a mechanism that will help southerners think about and prepare for future changes in their forests and the benefits they provide. Because any single projection of the world's (or a region's) biological, physical, and social systems has a high probability of being incorrect, the Futures Project instead examines a range of possibilities–also called scenarios or futures–that describe the forces influencing forests. Its scope is defined by an extensive public input process and insights of an expert panel and then narrowed into a practical number of futures through modeling and analysis.

This chapter describes the development of the alternative futures considered for the Southern Forest Futures Project and the ones selected for detailed analysis. Because they play such a prominent role, we begin with a definition of what is meant by a "future:" each future is a comprehensive and coherent (internally consistent) combination of varying climatic, demographic, and economic changes in the southern region; by simulating these changes, we can forecast likely impacts on the amount and characteristics of forests.

Within the context of this effort, the futures are used to evaluate how forest conditions and interrelated ecosystem services might change over time, and how those changes might affect forest functions, values, management, and policies. Together, the set of futures represents the full range of possible trends and changes to southern forests driven by social, economic, and climatic forces.

The futures are analyzed with the U.S. Forest Assessment System, which is also used for national and regional assessments for modeling responses of land use, forest harvesting, forest development, and forest disturbance to changes in key economic, demographic, and climatic variables. At the national level, the U.S. Forest Assessment System is the primary tool for evaluating several climate and timber-market scenarios for the 2010 Resources Planning Act (RPA) Assessment conducted by the Forest Service, U.S. Department of Agriculture (USDA Forest Service 2012). RPA scenarios describe forecasts of conditions in U.S. counties, most often "downscaled" from published global scenarios (IPCC 2007).

Some important issues could not be analyzed using our modeling framework, either because models were not available within the framework or because available knowledge could not be formalized into an explicit set of model variables. We addressed some of these issues by coupling forecasting work with expert knowledge and results from previous research; for others, we employed models that were outside the framework. Although analyses are informed by the forecasts, these "meta-issues" draw much of their information from a careful synthesis of the scientific literature. Each meta-issue is addressed in a separate chapter of this publication.

METHODS

We used a multi-stage process to choose a practical number of futures that represent a range of factors likely to determine the future conditions in southern forests. Public meetings, conducted in 14 locations to gather input on a broad set of resource issues in the South, drew more than 600 participants (Wear and others 2009) and identified a large number of concerns and issues (chapter 1).

[1]David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695; Robert Huggett is a Research Assistant Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695; John G. Greis is a Resource Specialist, Southern Region, U.S. Department of Agriculture Forest Service, Tallahassee, FL 32399.

A panel of experts distilled and analyzed the public input into the key driving factors that could plausibly affect the South (and southern forests) over the next 50 years. The 10 panel members, all with a broad range of experience in southern resource issues and forest management, met for two days in a structured process that followed these steps:

1. The stage was set by an overview of the Futures Project and its links to other resource assessment efforts [in particular, RPA and the Intergovernmental Panel on Climate Change (IPCC) assessments].

2. The panel was briefed on the public input, which had been organized into broad categories representing seven forces of change: economic, social, institutional, land use, forest management, biological, and physical.

3. The panel discussed, clarified, and expanded on the public input. They were asked to speculate on how each force of change might play out in the future and to define a list of alternatives for each of several influential factors (such as population and bioenergy demands). This list was distilled by combining similar ideas and forming a short list of what the panel deemed to be the most important factors likely to drive change.

We next reviewed the public input and the list of factors from the expert panel meeting to determine how they could be addressed within the Futures Project, given data and model limitations. Some of the factors identified by the expert panel were not suited for quantitative analysis within the modeling framework, but could be addressed using science synthesis and technical analysis through the meta-issue analysis. After careful deliberation, we specified a strategy for addressing each of them.

We then examined scenarios that had been developed for use in other assessments to determine whether any could be applied to the Futures Project, this in recognition of the difficulty and high cost, both in dollars and time, of developing futures for key driving variables. When key variables interact within a constructed future, such as ours, coherence is difficult to maintain; for example, economic futures have implications for energy consumption and therefore for emissions and climate projections. Based on these considerations, we selected the 2010 RPA scenarios, which are in part based on IPCC scenarios, as a starting point for developing futures. Using these scenarios provided "downscaled" and detailed forecasts of key driving variables—including population, income, and climate changes. In some instances, we modified scenarios to address specific issues raised for the Futures Project. The resulting large number of possible futures was impractical for detailed and timely evaluation, so we conducted a preliminary analysis to define a smaller, more manageable set—we call these "Cornerstone Futures"—that represent the range of future conditions from the full set while eliminating essentially redundant ones.

DATA SOURCES

Our primary data source is the set of more than 2,000 comments collected through public meetings, webinars, and online input. These are described and synthesized in Wear and others (2009). Raw data and issue aggregations are also available on the Web at http://www.srs.fs.usda.gov/futures/input/received/.

RESULTS

Strategies for Analyzing Drivers of Change

Several key determinants of the future of forests and forest benefits in the South were identified based on the synthesis of the public input. For each of them, the expert panel defined alternative views of how the future might unfold over time. Each was evaluated as to whether it would be possible to evaluate the alternative views using inputs to the U.S. Forest Assessment System and related models. Four met this criterion: emerging bioenergy demands, land use changes, forest products markets, and climate change. The remaining six (forest insects and diseases, invasive plant species, water, taxes, forest ownership, and fire issues) could not be addressed using the modeling framework but would be evaluated as part of meta-issue analysis. The alternatives considered (where applicable) as well as the analysis strategies chosen for each are listed below.

Bioenergy—The emergence of new markets for renewable energy was expected to have great potential for shifting forest conditions and uses in the South. Driven by various policies, bioenergy uses of wood could be influenced by demands for cellulose in biofuel production or for wood chips to be burned in power plants or to make fuel pellets. Three alternatives for increased biofuels demand were considered: (1) demand grows for wood-based cellulose for liquid fuels, (2) demand for cellulose in liquid fuels is limited to agricultural inputs, and (3) demand grows for wood chips in power plants and for wood pellets in heating.

Demand for wood and agricultural feedstocks as renewable energy sources can be compared within the U.S. Forest Assessment System by adjusting market activity (harvests) to reflect emerging markets. However, bioenergy-focused policies could increase demand to a level that causes broad-scale structural changes in timber markets, resulting in scenarios that exceed the limits of our analytical models. This suggested a combination of approaches. The first was to include a moderate expansion in demand for bioenergy as a part of the package of alternative futures. The second was the use of additional models to address the potential for structural market changes. In addition, the bioenergy analysis needed to examine the various production and policy uncertainties surrounding this issue and to inform additional modeling with insights into technological constraints and alternative demands (chapter 10).

Forest products markets—Although bioenergy represents a new and uncertain element, forest product markets have long influenced the use and condition of southern forests. With the South producing about 60 percent of all wood products in the United States (Prestemon and Abt 2002, Wear and others 2009), the expert panel saw a need to evaluate alternative wood products futures based on the possibility that the retraction of pulp and paper markets and the ongoing shift from lumber and plywood to engineered solid wood products will continue. From these possibilities emerged two alternative scenarios for timber demand: (1) an increase driven by new technologies in engineered wood products, biofuels, and a stable pulp and paper sector; or (2) a decrease driven by declines in paper production or by traditional wood product uses as wood becomes replaced by other materials.

Alternative futures for wood products demands can be evaluated within the U.S. Forest Assessment System by adjusting production levels for the region, using either market models or simple price forecasts. The evolution of the wood products industry in the South documented by Prestemon and Abt (2002) provides a foundation for forecasting alternative market futures within this well-defined marketplace (chapter 9).

Land uses—The scoping process identified population growth, development, and changes in the timber and agricultural sectors as the key driving factors driving land uses in the South. The expert panel viewed these as dynamic and advised analyzing a range of future developments in land use. The analysis yielded two major issues: (1) urban expansion affected by population growth and income changes, and (2) changing demand for cropland driven by bioenergy or food markets.

The land use models in the U.S. Forest Assessment System are designed for forecasting alternative trajectories of urban development in response to population and income forecasts. In addition, changes in rural uses are simulated in response to changes in the values of agricultural and forest values. We incorporated land use forecasts as part of the alternative futures and addressed specific questions regarding the future of land uses in the South. In particular, questions about altered urbanization footprints require an analytical future approach and chapter 4 is dedicated to discussing land use futures and uncertainties.

Climate—The expert panel identified climate change as a key driving factor and a source of uncertainty for the future of southern forests. Alternative climate forecasts from the IPCC analysis provide a range of futures for the key variables (temperature and precipitation) that could be considered within the Futures Project. The panel also raised questions that may not be precisely captured by the U.S. Forest Assessment System models: (1) the effects of climate changes on extreme weather events and fire, and (2) the role of forests in sequestering carbon as part of a national mitigation strategy.

A set of climate forecasts defined by existing models can be examined within our modeling framework: the U.S. Forest Assessment System was designed to address the impacts of climate changes, and the RPA scenarios provide a library of climate scenarios from several general circulation models (GCMs). We also designated climate change as a meta-issue so that key uncertainties and implications beyond those addressed by the U.S. Forest Assessment System could be fully examined (chapter 3). This publication also addresses climate change effects on carbon stored in forests (chapter 5), wildlife (chapter 14), and fire (chapter 17).

Insects, diseases, and invasive plant species—The expert panel identified insects, diseases, and invasive plant species as driving factors in determining the future of southern forests. Insects and diseases have long been the focus of forest health concerns in the South, with increased threats from nonnative species defining a key area of uncertainty for forest sustainability. Over the past 20 years, nonnative invasive plant species have also become a growing concern. The spread of cogongrass, paulownia, Chinese privet and other highly invasive species was raised at public meetings throughout the South. The rate of spread for these species, the potential for new species introductions, and the plausibility of controlling existing and new species are highly uncertain.

Invasive species effects cannot be directly evaluated within the structure of the U.S. Forest Assessment System. They may represent novel structural changes to forest systems. We addressed this issue through two meta-issue analyses: one addressing nonnative invasive plant species (chapter 15), and the other addressing insects and diseases (chapter 16), which updates an earlier analysis of Ward and Mistretta (2002). The former explores the potential influence of climate changes on invasive species spread rates and ranges.

Water—Both the demand for and supply of water in the South was seen as a driving factor for the future, largely through its impact on acceptable forest management practices. Water availability could also have an eventual impact on the scale of urban development and thus would necessarily affect forest extent and condition. The expert panel raised questions about the effects of population growth, urban development, and increased drought frequency and severity; and mitigating effects of new technologies and conservation.

Although water demands as described by the expert panel could eventually have an impact on land uses, for example in metropolitan watersheds, these demands would be localized and are not amenable to developing alternative futures for modeling within the U.S. Forest Assessment System. The primary analysis of these issues is contained in a meta-issue analysis (chapter 13), which included linkages of the U.S. Forest Assessment System model outputs to a water supply and demand model to predict the effects of land use conversion and timber harvesting on southern water supplies (Sun and others 2008).

Taxes—The influences of taxes on forest management, ownership, and parcelization have long been a concern for private forest owners, and this issue was raised consistently at the public meetings. The public asked questions about the design of "conservation-neutral" tax policy and speculated about the impacts of changes to inheritance, property, and income taxes on forest conditions. The future of tax policy was seen as important in determining future ownership and management.

The impacts of various tax policies cannot be directly addressed within the U.S. Forest Assessment System. Instead, tax issues are examined as a meta-issue (chapter 11) using a literature synthesis.

Fire—Fire can be an important management tool and an undesirable occurrence in the forest, depending on timing and location. The public raised concerns about the future feasibility of fire management amid the challenges of urbanization and climate change, and the implications of climate change for future wildfire extent and patterns.

The complex suite of issues surrounding fire is beyond the scope of the U.S. Forest Assessment System. However, the key driving variables of urbanization and climate change, along with forest-area and forest-inventory outputs from the U.S. Forest Assessment System, can be explicitly linked to fire implications for the South. A meta-issue analysis (chapter 17) of fire issues employs wildfire risk models linked to the climate forecasts used in the U.S. Forest Assessment System.

Forest ownership dynamics—Recent changes in forest ownership—especially the shift from forest industry to Timber Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs)—portends changes in forest management and conditions. What is more, several trends in the demographic makeup of nonindustrial private forest owners foreshadow potential changes in ownership and forest uses. All have implications for future forest conditions and sustainability.

Because of the high degree of uncertainty, forest ownership is another area that cannot be directly modeled. Instead a meta-issue analysis examined trends in ownership and owner attributes, the causes of historical changes in broad owner categories, and the range of implications from ongoing changes in ownership (chapter 6). This issue is linked to forest taxes (chapter 11) and land use changes (chapter 4).

Developing Alternative Futures: Linking Scoping Results to Forecasting Models

The expert panel identified nine key driving factors likely to influence the future development of southern forests and proposed alternatives for how they might play out over the next 50 years. Four driving factors (bioenergy, forest products, land uses, and climate) were suitable for formal forecasting analysis using the U.S. Forest Assessment System. Permutations of their alternative projections resulted in too a large number of alternatives for practicality, so we winnowed them to eliminate redundancies. In this section, we describe how we constructed the initial set of futures and then reduced them to a subset of representative "Cornerstone Futures."

The U.S. Forest Assessment System provides the modeling framework for the analysis, and we considered driving factors in terms of this model's inputs. Market futures were driven by price forecasts with prices increasing as timber products became more scarce, decreasing with less scarcity. For constructing the futures we conceptually bundled bioenergy and forest products market futures. That is, expanding demands could reflect strengthened markets either for bioenergy or traditional wood products. Land use models within the U.S. Forest Assessment System are designed to be driven by population and income projections. Climate variables enter the projection of forest conditions affecting forest type distributions and forest productivity.

Since the U.S. Forest Assessment System had originally been designed to develop the RPA Assessment, we began by evaluating whether the existing RPA scenarios were adequate for addressing the issues of the Futures Project. Although based on IPCC worldviews, the RPA scenarios also contain data and detail relevant to conditions in the United States–specifically, climate and socioeconomic projections, downscaled to the county level (USDA Forest Service 2012). The IPCC fourth assessment (IPCC 2007) is the global basis for the RPA Assessment because it provides an internally consistent set of scenarios that offer a broad spectrum of potential futures from which the RPA analysts could select a subset that was most relevant for U.S. forests.

The IPCC directed a special report to generate scenarios of greenhouse gas emissions, set within four broad storylines about future economic, demographic, political, environmental, and technological change (Nakicenovic and others 2000). The A1 storyline describes a future of very rapid economic growth with a global population that peaks in mid-century, and then declines. The A2 storyline describes a continuously increasing global population and economic growth that is more regionally oriented. Population growth for the B1 storyline is the same as A1, but B1's economic future describes a rapid change towards a service and information economy, with a strong emphasis on clean and resource-efficient technologies. The B2 storyline describes a growing population and intermediate economic growth, but a preference for local solutions over global integration. Data compatibility issues limited the RPA scenarios to the A1, A2, and B2 storylines. Furthermore, RPA adopted the A1B storyline with its assumptions regarding energy futures.

For each of the IPCC storylines A1, A2, and B2, the 2010 RPA scenarios provide unique forecasts of population and economic growth, downscaled to the U.S. county level to the year 2060. For the A1 storyline, the IPCC developed several sub-storylines that were used to depict different futures of energy use and technology. For the 2010 RPA analyses, the A1B set was chosen. The storylines were used as input to modeling systems that generate estimates of GHG emissions, which in turn were used to run GCMs that provide alternative climate forecasts. The 2010 RPA analyses used results from three GCMs for each storyline, resulting in nine potential climate futures. The GCM data were downscaled using a statistical approach to the 0.5 arc minute and then aggregated to the county scale (Coulson and others 2010). For the A1B and A2 storyline, the GCMs are the MIROC, CSIRO, and CGCM models, while for the B2 storylines they are the Hadley, CSIRO, and CGCM.

The GCM projections were generated as changes from simulated historical monthly means (1961–90) for each GCM (Joyce and others 2011, Price and others 2011). Basing forecasts on the simulated values corrects for differential biases of the GCMs at the fine scale used for analysis. Change forecasts were then applied to historical data to generate the projections. Monthly mean daily max and min temperatures, precipitation, along with other variables not used in the Futures Project's analysis were generated to the year 2100. Note, however, that Futures Project impact analysis was limited to a 50-year analysis (2010–60).

The RPA scenarios, then, provide a set of futures defined by three GCMs for each of three storylines. Land use models within the U.S. Forest Assessment System define change in forest area (and other uses) in response to the economic variables from the storylines as well as timber and crop prices (Wear 2011). Forest dynamics models forecast changes in forest conditions in response to harvesting (which in turn are influenced by the economic variables) (Polyakov and others 2010), and to changes associated with aging, disturbance, and climate (Wear and others 2013). These RPA scenarios therefore directly address a range of futures identified as important land-use and climate driving factors by the expert panel.

We decided that the RPA climate data provided an adequate (and the only practical) range of climate scenarios for the Futures Project. We also decided that the land use forecasts, driven by alternative population and income forecasts, provided an adequate range of land use scenarios for the Futures Project.

Two other forces of change identified by the expert panel—forest harvesting and management to supply bioenergy and other wood products markets—could be evaluated within the structure of the model. In the U.S. Forest Assessment System, we can address alternative scenarios for wood production in two ways. One is to apply alternative projections of prices for forest products to forecast changes in harvesting. This "price-exogenous" approach, although simple, allows us to simulate increasing and decreasing scarcity in markets without specifically addressing market dynamics and wood-products demand structures. The other approach is to incorporate explicit models of market demands for various forest products within the modeling system, which for the RPA scenarios is the U.S. Forest Products Model (Ince and others 2011). The Forest Products Model was chosen for the RPA scenarios because it can incorporate demands for all classes of U.S. wood products within a global marketing framework (Raunikar and others 2010) and can be driven by variables taken from the same storylines.

For our development of alternative futures, we used exogenous price forecasts, in particular, three "price-exogenous" scenarios: constant timber prices, increasing prices (plus 1 percent per year), and declining prices (minus 1 percent per year). Increasing prices describe an increasing scarcity of timber products and therefore can be applied to two possible futures: a shortage in available timber supplies or an increased demand to satisfy existing uses or emerging uses such as bioenergy. Decreasing prices reflect decreasing scarcity consistent with a contraction in demands for products (such as pulpwood for paper production) or a rapid expansion in supplies derived from intensive management. We use the 1-percent increase and decrease rates to bookend the analysis of markets because they are consistent with real price growth over the expansionary phase of southern timber markets from the 1980s through the 1990s. Layered on the analysis of futures, we also conducted an analysis of future wood products/bioenergy markets to provide insights into how specific market developments might play out and to define additional analytical futures for evaluation.

For our initial set of alternative futures, therefore, we started with the RPA scenarios for forecasts of climatic and socioeconomic conditions, and then applied the three alternative timber market scenarios, three socio/economic storylines, three GCMs, and three timber market scenarios. None of the resulting 27 initial futures were considered more likely than the others. Rather, each was judged to be within the realm of plausibility. While each scenario likely contained some unique insights into future resource uses and conditions, it was necessary to select a smaller subset of the futures for detailed analysis and discussion within the Futures Project.

Selecting the Cornerstone Futures

In this section, we briefly touch on some of the variables forecasted with the U.S. Forest Assessment System to describe the logic behind selecting Cornerstone Futures. Thorough discussions of forecasting approaches and forecast results are contained in chapters 4 and 5 and in several supporting documents.

To begin defining the set of Cornerstone Futures to be used for detailed analysis within the Futures Project, we conducted the U.S. Forest Assessment System land-use, forest-condition, and timber-harvesting simulations for the initial set of 27 alternative futures and applied various metrics to compare the resulting forecasts. This process was complicated because the alternative futures are ranked differently depending on which variable is used to construct the ranking—for example, the same future might forecast the greatest loss of forest land and a median level of future biomass (estimated as growing stock volumes).

Timber prices—We started by dropping the set of futures with constant prices; in every comparison, these futures yielded forecasts that were intermediate between futures with increasing and decreasing prices, meaning that the increasing and decreasing price futures bracketed the constant price futures for all variables evaluated. This step reduced the number of alternative futures to 18.

Biomass volume and land use—We next used two highly aggregate metrics to compare forecasts across the remaining futures: total volume of biomass by broad forest type and total area of forestland. We held the GCM constant (CSIRO) for storyline/timber price scenarios and displayed volume forecasts to 2060 for all growing stock and then for hardwood and softwood growing stock. Total volume follows a broad range of trajectories across futures (fig. 2.1). Increases are only expected for the B2 storyline with low prices (resulting in lower harvesting), which has the lowest urbanization (lower population growth and moderate income growth). All other futures result in expansion of biomass through 2030 or 2040, followed by declines. The future with the lowest biomass in 2060 is defined by the A1B storyline (moderate population growth and high income growth) combined with high timber prices. Figure 2.2 shows that softwood volumes increase to 2030 but then either level off (A1B/high prices) or increase through 2060, with the highest rate of increase for B2/low prices. Hardwood volumes are projected to decline after 2030 for all futures except B2/low prices, with the largest decline for A1B/high prices.

Forest area is forecasted to decline in response to the economic/population forecasts from the storylines and the timber price futures (by construction, land use is not directly responsive to climate). Low population and income growth reduces urbanization and consumption of forest land. In addition, high timber prices discourage deforestation. Therefore, the B2 storyline (moderate income growth) coupled with high prices yields the smallest loss of forest land by 2060, and the A1B storyline (rapid economic growth) coupled with low prices yields the greatest loss of forest land (fig. 2.3). With the storyline held constant, low prices yield more forest loss than high prices. Because the A2 storyline is intermediate to the A1B/high forest loss and B2/low forest loss and was intermediate in the biomass volume forecasts (for all climate projections), it was dropped from the cornerstones.

So an analysis of the range of outcomes for these two variables suggests inclusion of four futures for consideration. A high economic-growth/increasing timber price future (A1B/high price) and a low growth/decreasing price future (B2/low price) bracket the projections of total forest biomass. For forest area change projections, the brackets are a low economic-growth/increasing timber price future (B2/high price), which could reflect less globalization (more isolated nation economies) and increasing U.S. scarcity of wood products in the face of less trade; and a high growth/decreasing price (A1B/low price) future, which could reflect a shift in timber production offshore to support global economic growth (or simply a decline in the demand for forest products).

Climate—The ranking of the futures with respect to total biomass and total forest area does not vary across GCMs, as is shown by a follow-up evaluation of the biomass variable. Figure 2.4 shows forecasts of growing stock volumes for the three GCMs associated with A1B storyline, low and high timber prices (MIROC, CSIRO, and CGCM). Clearly, the trajectories of growing stock volumes cluster strongly around the price futures with much less variation among the GCMs within each price cluster.

We concluded that the timber-price and storyline effects overshadow the effects of climate variation. We were, however, reluctant to eliminate climate variation from consideration, primarily to account for any spatial variations that may be masked by the aggregate outcomes. Accordingly, we introduced climate variation by assigning different GCMs to the four cornerstones identified above: MIROC to A1B/high prices, Hadley to the B2/low prices, and CSIRO to the A1B/low prices and B2/high prices. These models were selected to provide a variety of spatial expressions of the climate projections (MIROC for example, is generally warmer than the other models, but these differences do not significantly affect the projections of aggregate forest conditions). The implications of any spatial variations are

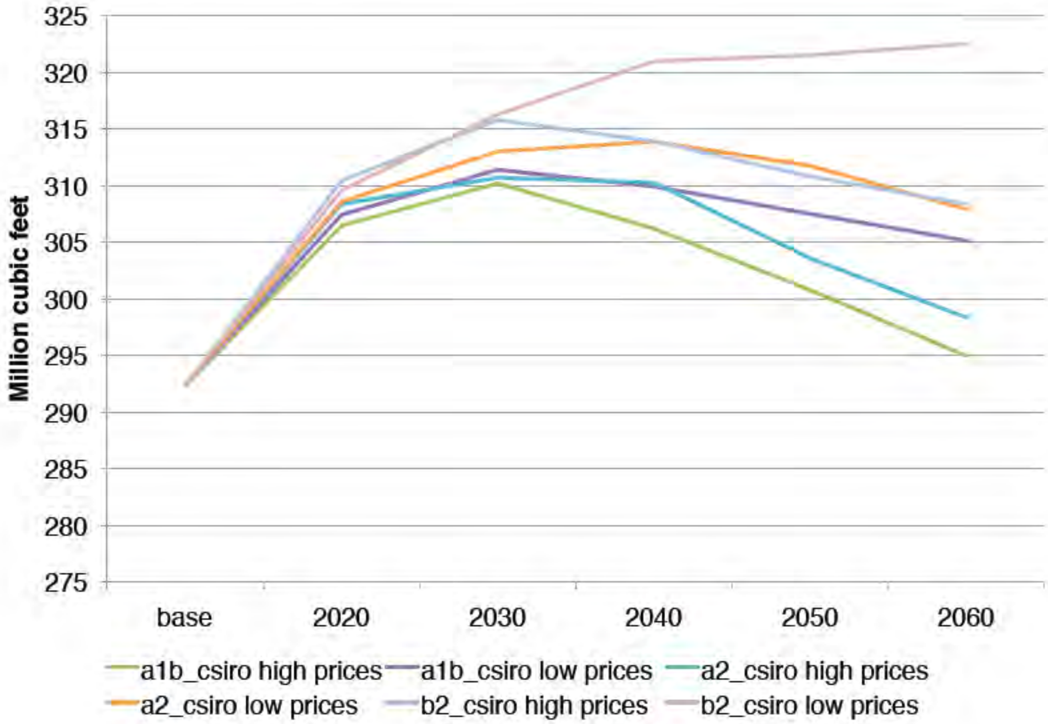


Figure 2.1—Forecasts of total growing stock volume in the South by alternative futures, 2010 to 2060, defined by permutations of storylines (A1B, A2, and B2) from the 2010 Resources Planning Act (RPA) Assessment and increasing and decreasing timber prices. All futures use the CSIRO general circulation model's forecasts of the associated climate.

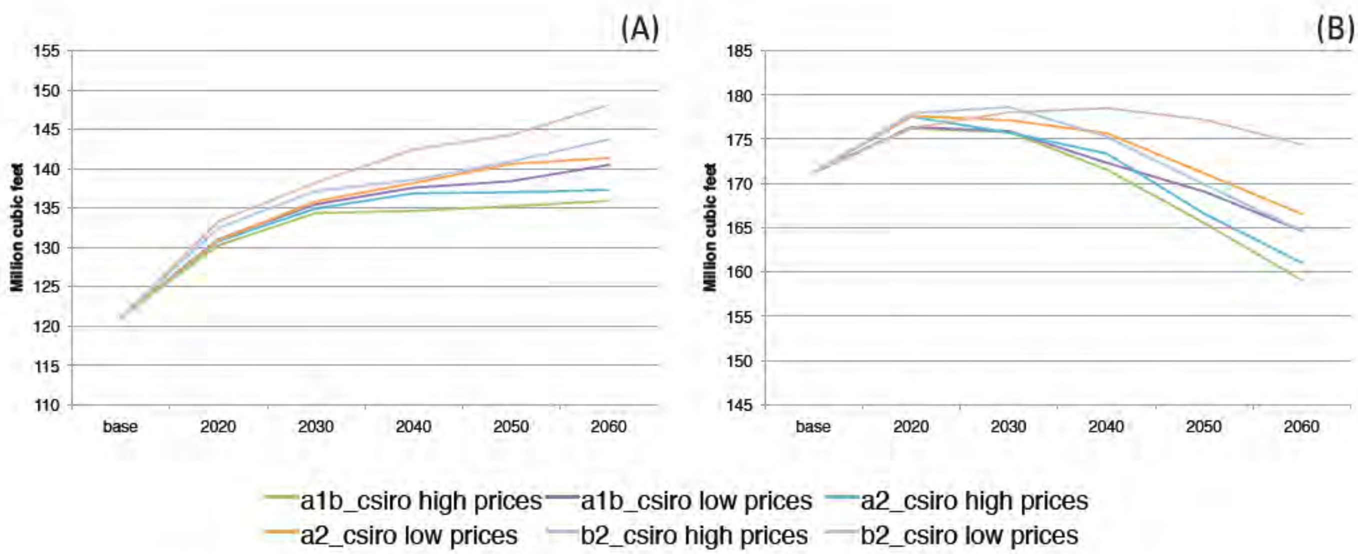


Figure 2.2—Forecasts of (A) softwood and (B) hardwood growing stock volume for the South, 2010 to 2060, defined by permutations of storylines (A1B, A2, and B2) from the 2010 Resources Planning Act (RPA) Assessment and increasing and decreasing timber prices. All futures use the CSIRO general circulation model's forecasts of the associated climate.

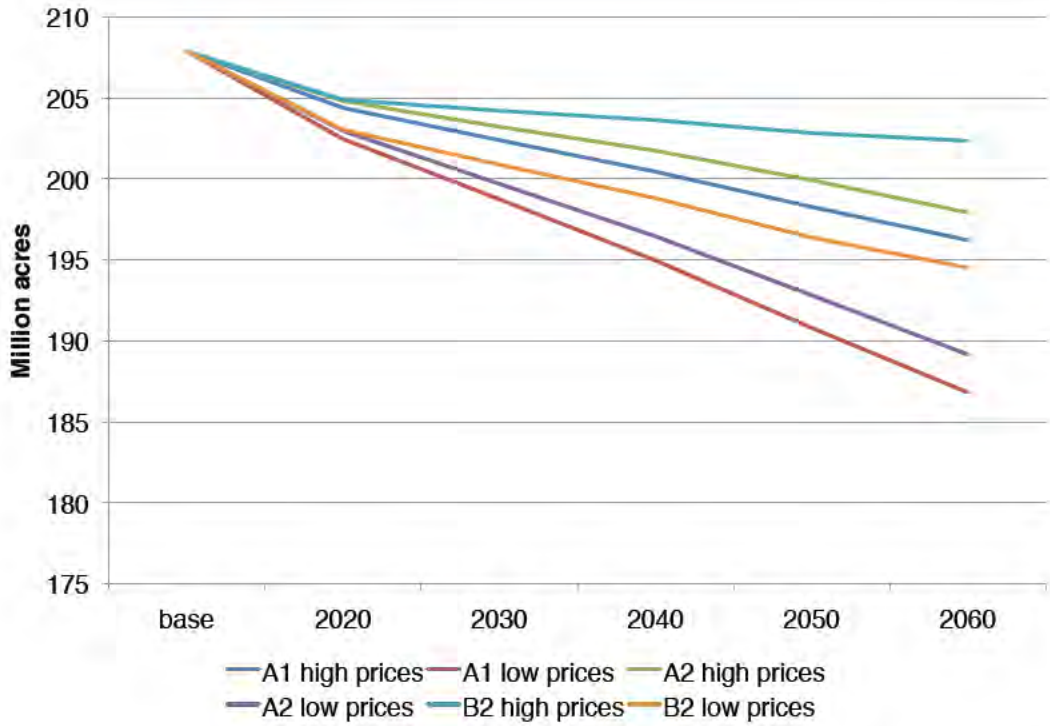


Figure 2.3—Forecasts of total forest area in the South for alternative storylines (A1B, A2, and B2) from the 2010 Resources Planning Act (RPA) Assessment and price scenarios (increasing and decreasing). Note that land use forecasts do not vary across general circulation models.

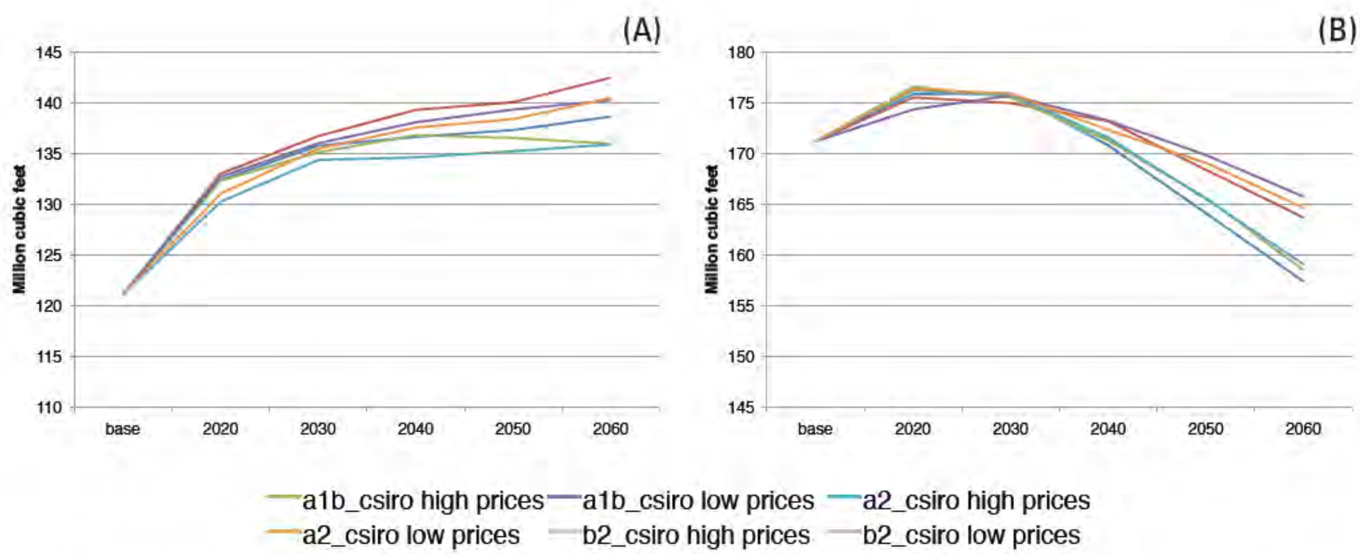


Figure 2.4—Forecasts of (A) softwood and (B) hardwood growing stock volumes for the A1B storyline, 2010 to 2060, defined by the A1B storyline from the 2010 Resources Planning Act (RPA) Assessment and either increasing or decreasing timber prices. Forecasts are generated using CSIRO, CGCM, and MIROC general circulation models.

discussed in the evaluation of various meta-issues, especially for wildlife (chapter 14) and fire (chapter 17).

Tree planting—A review of the four remaining futures indicated that forecasts of forest investment, a key element in the development of the South's forests since the 1950s, did not respond to variations in market futures. This led us to expand our scope to address this dynamic in a way that was consistent with our modeled changes in timber markets.

To address the effects of forest planting, we augmented the U.S. Forest Assessment System with a simple model which assumes that current plantations will be replanted after harvesting and that a specified portion of other harvested forests will be planted. These assumptions derive from historical rates of planting for each of the 13 States and from expert advice on the likely path of future planting. The planting rates adopted for these baseline assumptions are more moderate than the aggressive expansion of plantations in the 1990s, and thereby reflect economic conditions and trends in the 2000s. Because planting rates are tied to harvesting (which controls the availability of forests for planting) and to land use changes, the area planted varies somewhat across simulated futures. We adjusted this baseline projection approach to introduce broader variation in the planting rate and to reflect the assumptions about future timber markets. The result was two additional futures. For the first, we increased forest planting rates in harvested areas by 50 percent from base rates for the A1B/MIROC/high price future; this yields planting rates that are higher than for other futures but not as high as was experienced in the 1990s—they would be plausible in light of observed nursery capacity and forest management. For the second, we decreased planting rates by 50 percent from base rates for the B2/Hadley/low price future; this yields a very moderate increase in forest plantations that level off after about 2030.

What the Cornerstone Futures Say and How They Compare

Figure 2.5 shows the six Cornerstone Futures in a diagram that emphasizes their key variables. Cornerstones A through D are defined by the matrix formed by intersecting RPA/IPCC storylines A1B and B2 with increasing and decreasing timber price futures. Cornerstones E and F depart from these four by either augmenting the planting rates in Cornerstone A (E) or by decreasing the planting rates in Cornerstone D (F).

Storylines vary in their projections of population density (fig. 2.6). A2, the storyline not used within the Cornerstones yields the highest population growth with an 80 percent increase from 2006 to 2060. Lowest population growth is associated

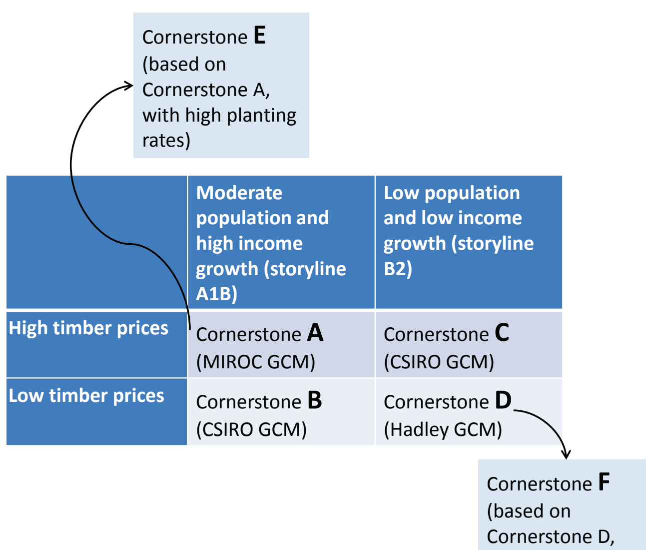


Figure 2.5—The six Cornerstone Futures defined by permutations of storylines from the 2010 Resources Planning Act (RPA) Assessment, three general circulation models (GCMs), and two timber price futures; and then expanded by evaluating increased and decreased forest planting rates.

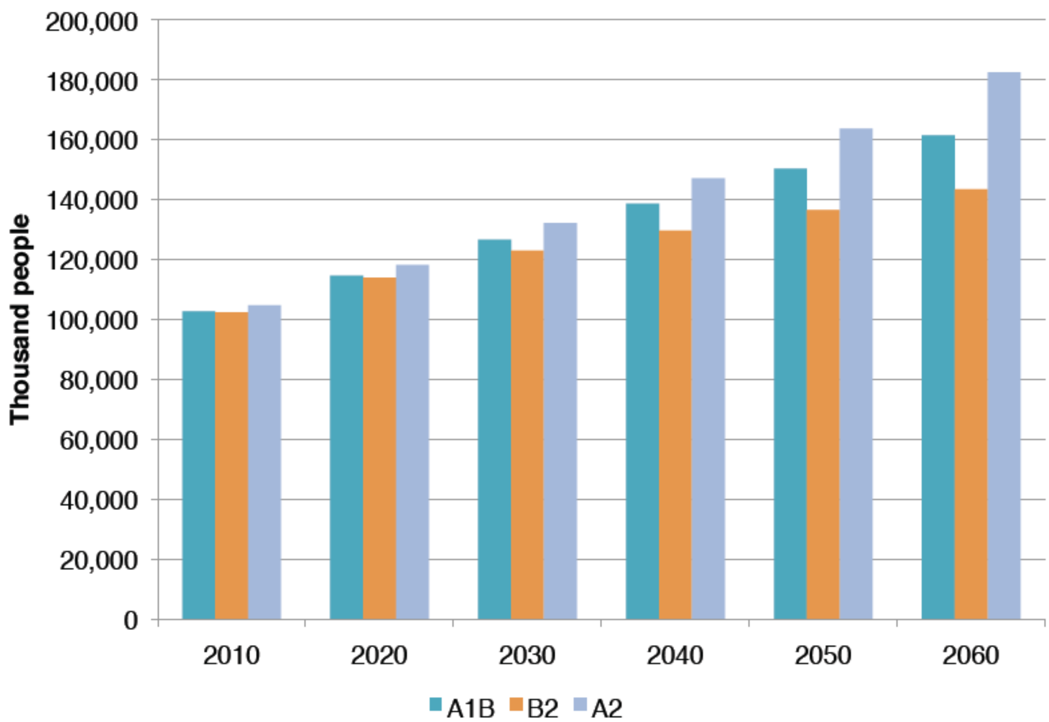


Figure 2.6—Projections of population for A1B, A2, and B2 storylines. (Source: 2010 Resources Planning Act Assessment)

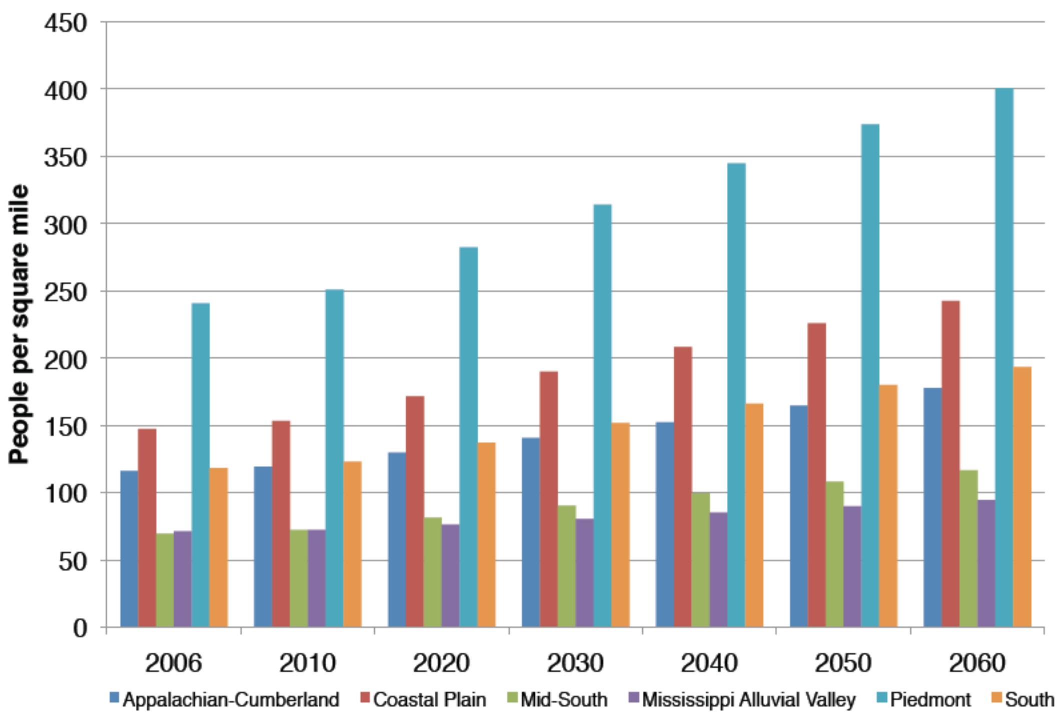


Figure 2.7—Projections of population density, 2006 to 2060, by southern subregions (people per square mile of total land area) for storyline A1B from the 2010 Resources Planning Act (RPA) Assessment.

with B2 (40 percent growth) and A1B is bracketed by the two (60 percent). Because urbanization is also fueled by income levels, A1B, with its strong economic growth actually results in the greatest urbanization and greatest losses of forest area (chapter 4); B2 results in the lowest urbanization and forest losses.

Figure 2.7 shows population density growth, by subregion, for the A1B storyline. In 2006, the Piedmont had the greatest population density (about 250 people per square mile or ppsm), followed by the Coastal Plain and Appalachian-Cumberland subregions with intermediate densities (100 to 150 ppsm) and the Mid-South and Mississippi Alluvial Valley with the lowest densities (75 ppsm). This general trend continues over the projection period, with growth strongest on the Piedmont (an additional 150 ppsm). By 2060, the population density in the Coastal Plain would be as high as current population densities in the Piedmont.

Even within the subregions, population change is not evenly spread. Forecasted population growth from 2006 and 2060 (fig. 2.8) shows that several areas are expected to experience population declines. This includes parts of the High Plains in Texas and Oklahoma, much of the Mississippi Alluvial Valley, and parts of southern Alabama and Mississippi. Population growth in the South is clearly organized around major metropolitan centers—especially Atlanta; Miami; Houston; Dallas; Washington, DC; Nashville, TN; and Charlotte and Raleigh, NC.

Cornerstone Futures are also framed by timber market projections over the next 50 years. These projections do not account for short run business cycles or the pattern of economic recovery from the recent recession but attempts to capture some long-run potentials for market development beyond this period of adjustment. Price forecasts defined by the Cornerstone Futures anticipate an orderly progression, either increasing or decreasing in real terms at 1 percent per year from a 2005 base. That year, prices were below their peak values from the late 1990s, especially for pulpwood-sized material (fig. 2.9). We also held the real returns to agricultural crops constant through the period. Because future markets could depart from these assumptions, we used additional analyses to examine the sensitivity of future forest conditions to general market conditions (chapter 5) and to address alternative bioenergy futures (chapter 10). In this case the Cornerstone Futures define a framework for evaluating forest product/bioenergy market possibilities.

Also embedded in the Cornerstone Futures is the climate forecasted using various GCMs, including changes in temperature, precipitation, and derived potential evapotranspiration. For example, figure 2.10 displays changes in the 10-year average annual temperatures from 2000 to 2060 for Cornerstones A through D. Under Cornerstone A (A1B with MIROC) nearly the entire South is forecasted to experience an increase of at least a 1° C and the northern portions of the High Plains and Cross Timbers sections of Texas and Oklahoma are forecasted to experience 2.5-3° C increases. Other Cornerstone Futures are consistently warmer but less warm than A1B/MIROC and show greater spatial variation in temperature increases. Forecasted changes in precipitation vary across the South and across the Cornerstone Futures (fig. 2.11). Under Cornerstone A, precipitation declines across the entire region while all other Cornerstones show variation from strong declines to strong increases. These forecasts vary across the Cornerstones (figs. 2.10 and 2.11) and define variations in future growing conditions for forests across the South. They may prove important for determining wildfire impacts over the next 50 years. The use of three different GCMs in constructing the Cornerstone Futures should address potential variability in spatial distributions. More detail on climate inputs to the forecasts is contained in chapter 3.

Our use of discrete Cornerstone Futures with different climate futures does not allow for isolating the effects of climate versus all of the other driving forces behind the scenario, e.g., population or land use. The complete factorial analysis of futures based on emissions scenarios and GCMs required for this type of analysis was beyond the capacity of the Futures Project to evaluate secondary and tertiary effects. However, forest forecasts for the full factorial were the basis for the selection of the Cornerstone Futures and are described in detail in Wear and others (2013).

DISCUSSION AND CONCLUSIONS

Public meetings provided the initial input on issues needing attention in the Futures Project. These issues were further synthesized and distilled to define a set of driving factors to be examined in the course of the study. Some could not be formalized using quantitative models and have been examined as meta-issues and through science synthesis. Four driving factors could be modeled and were used to organize a set of 27 alternative futures. We reduced this initial set to the six Cornerstone Futures (shown in table 2.1 and figure 2.5) that were used to organize our forecasts of forest conditions and to evaluate long-term implications for a variety of resource values throughout this publication.

In sum, Cornerstones A-D are defined by the matrix formed by intersecting low and high population and income forecasts with increasing and decreasing timber price futures as described above.

- **Cornerstone A**: High population/income growth along with increasing timber prices and baseline tree planting rates.
- **Cornerstone B**: High population/income growth along with

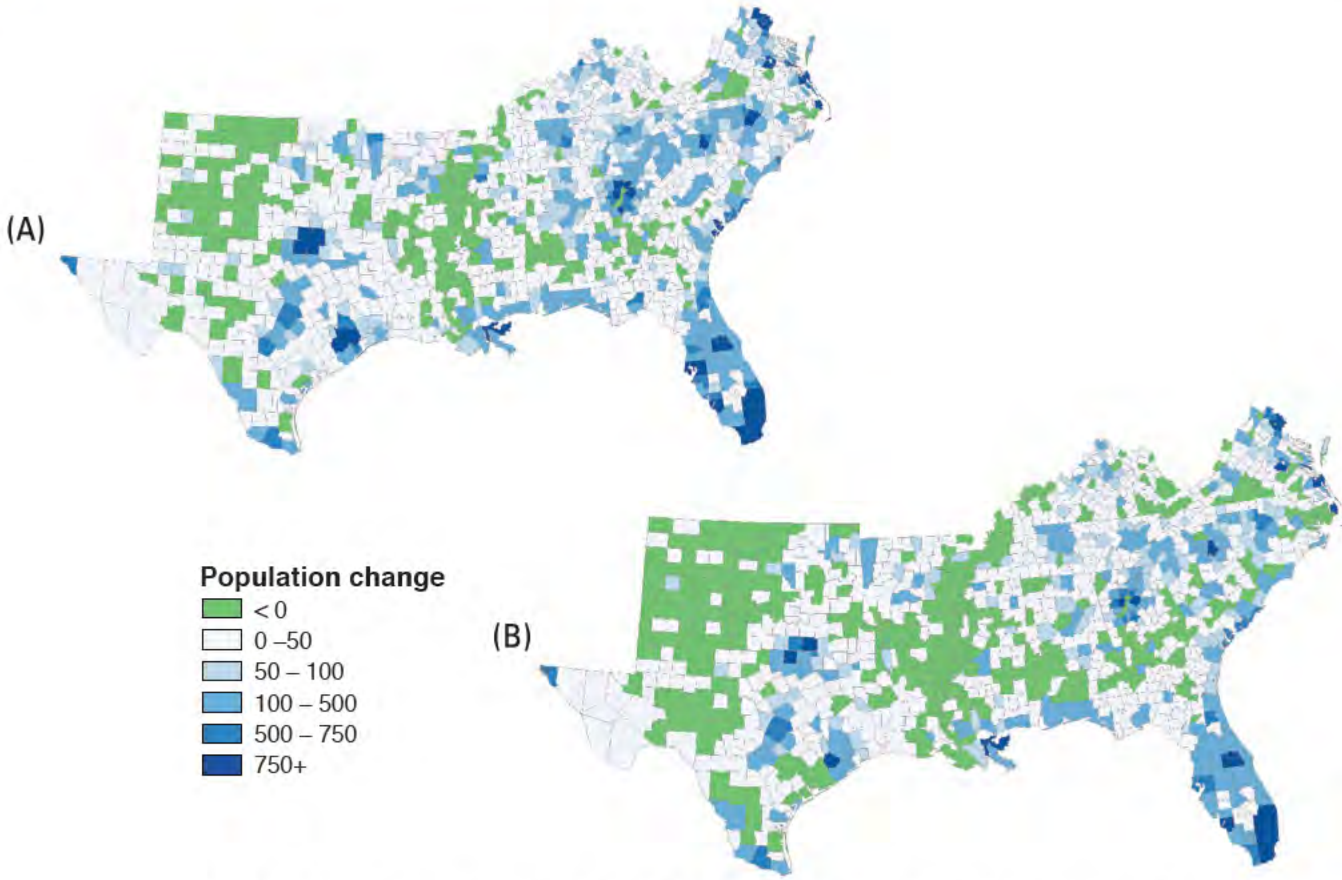


Figure 2.8—Projection of population change for the (A) A1B and (B) B2 storylines (change in people per square mile) from the 2010 Resources Planning Act (RPA) Assessment. Note that counties in green have forecasted population losses.

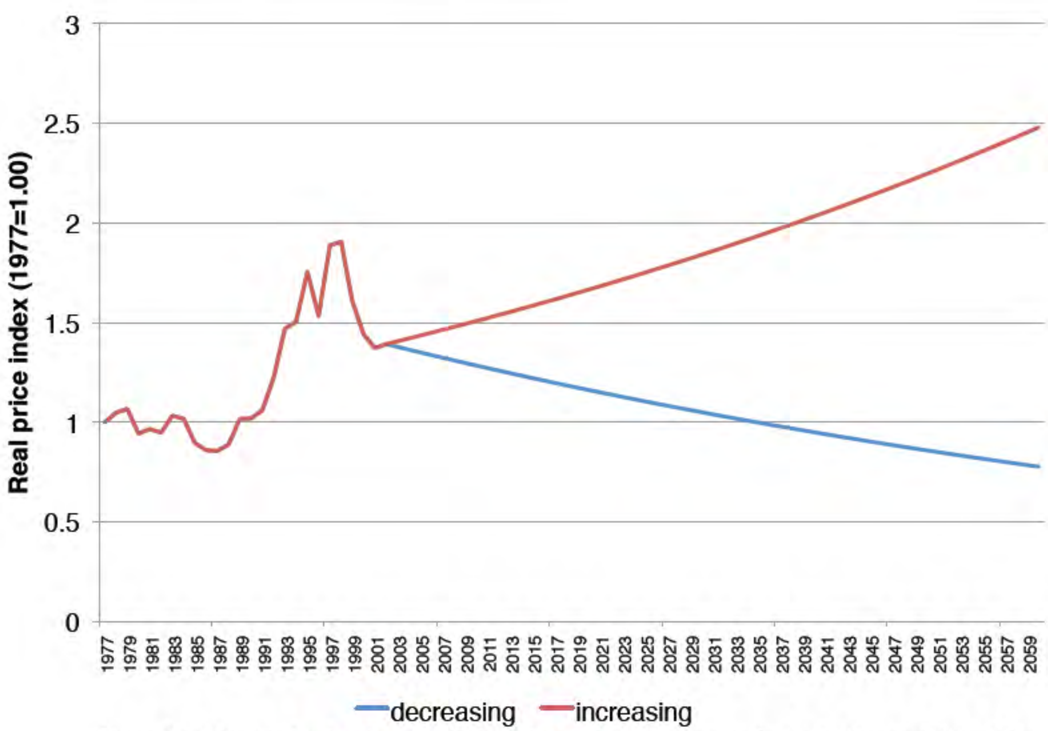


Figure 2.9—Historical and projected real price index for timber products in the South. (Sources: Timber Mart South for historical data, 2010 Resources Planning Act Assessment total product output charts)

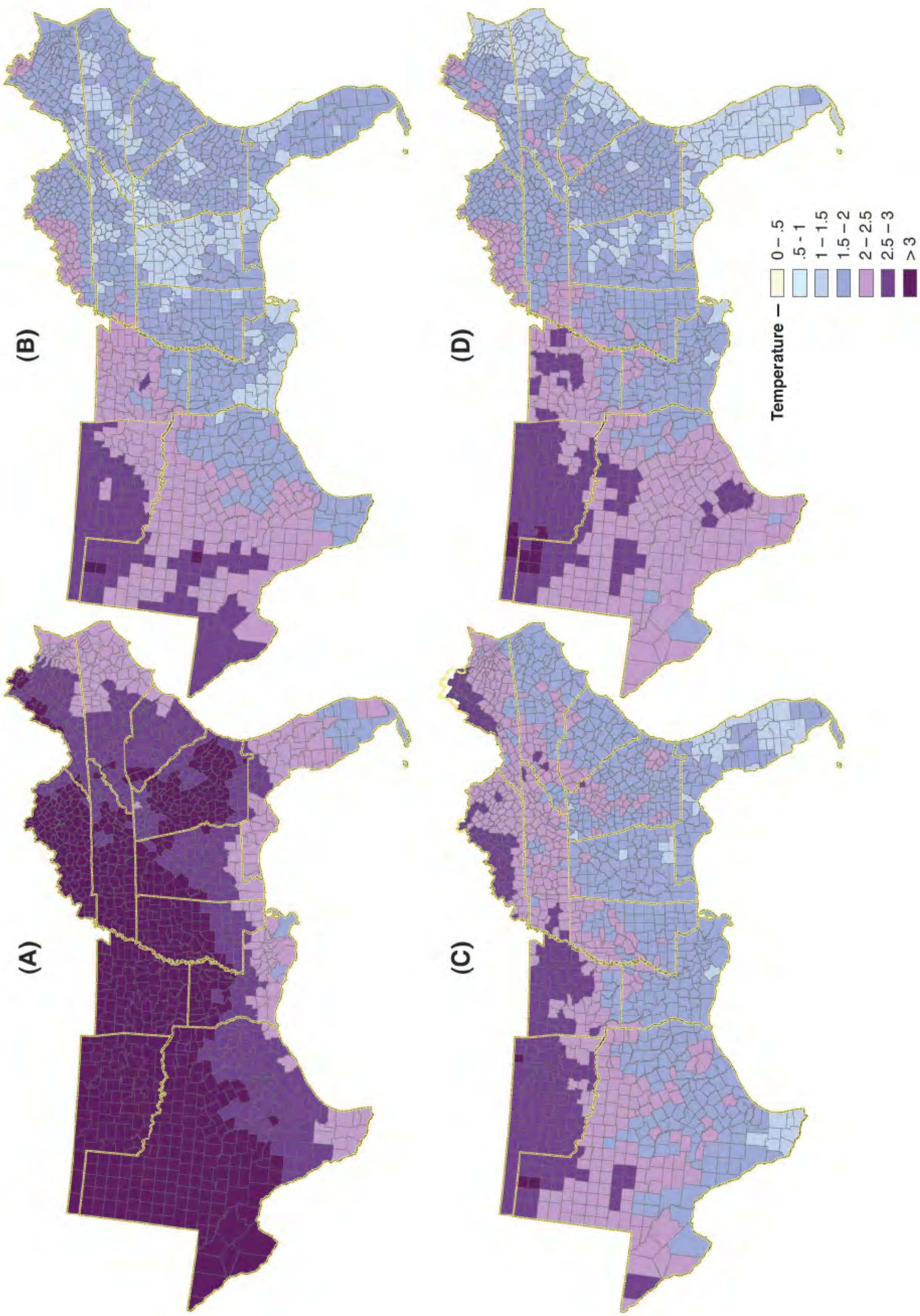


Figure 2.10—Change in average annual temperature for 10-year periods ending in 2010 and 2060 under Cornerstone Futures A, B, C, and D.

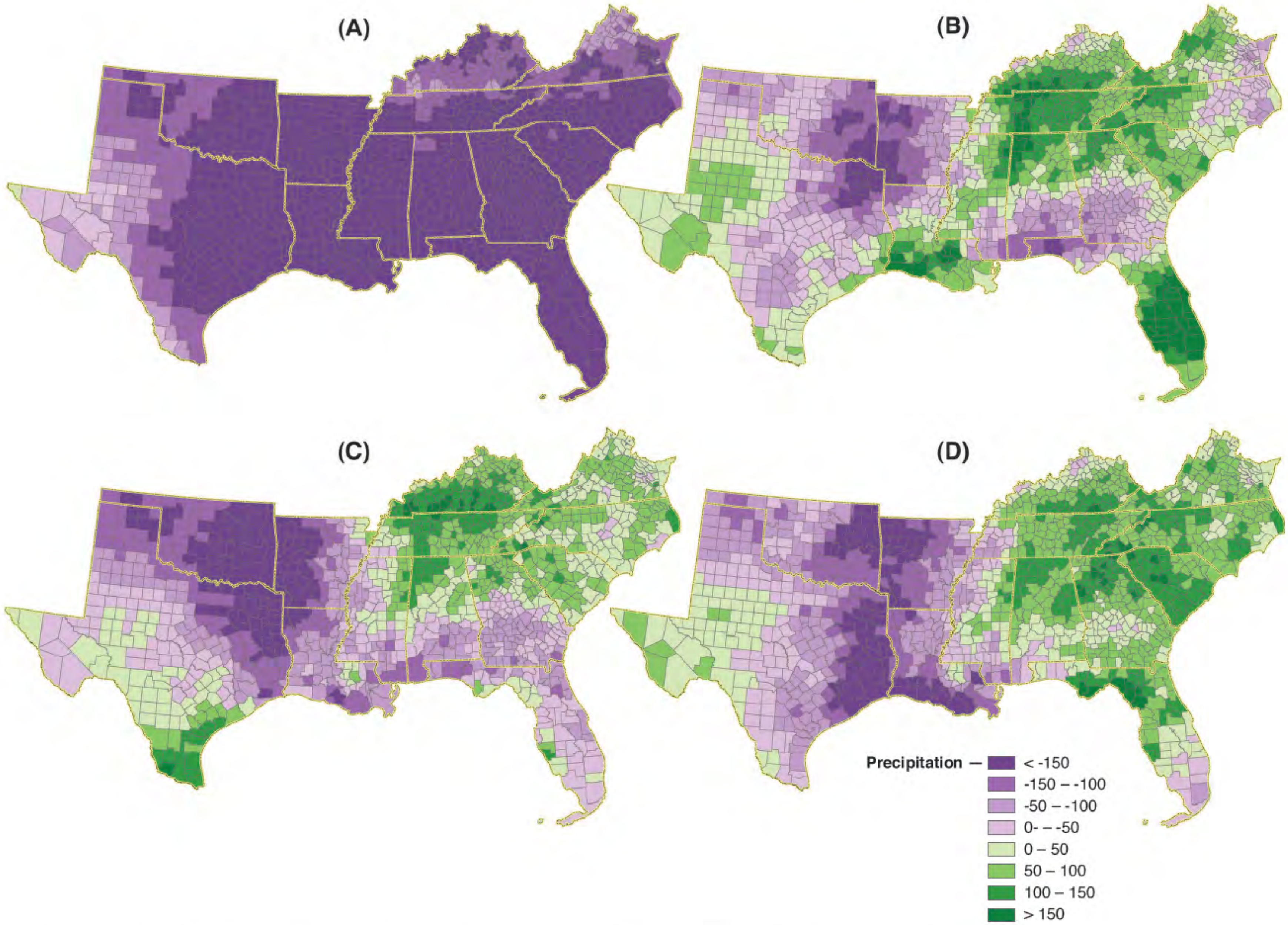


Figure 2.11—Change in 10-year average annual precipitation for 10-year periods ending in 2010 and 2060 under Cornerstone Futures A, B, C, and D.

Table 2.1—Definition of Cornerstone Futures used in the Southern Forest Futures Project, based on two storylines from the 2010 Resources Planning Act (RPA) Assessment and three general circulation models (GCMs)

Cornerstone Futures		RPA Storylines					
Tag	Label	Label	Economic growth	Population Growth	Climate (GCM) model	Timber prices	Planting rates
A	High growth/high prices	A1B	High	Moderate	MIROC	Increasing	Base
B	High growth/low prices	A1B	High	Moderate	CSIRO	Decreasing	Base
C	Low growth/high prices	B2	Low	Low	CSIRO	Increasing	Base
D	Low growth/low prices	B2	Low	Low	Hadley	Decreasing	Base
E	High growth/high prices/high planting	A1B	High	Moderate	MIROC	Increasing	High
F	Low growth/low prices/low planting	B2	Low	Low	Hadley	Decreasing	Low

decreasing timber prices and baseline tree planting rates.

- **Cornerstone C**: Low population/income growth along with increasing timber prices and baseline tree planting rates.
- **Cornerstone D**: Low population/income growth along with decreasing timber prices and baseline tree planting rates.

These four Cornerstones use what we label baseline rates of tree planting following a harvest based on data from the Forest Inventory and Analysis Program of the Forest Service to forecast future planting. Cornerstones E and F depart from these four either by augmenting planting rates by 50 percent for Cornerstone A (E), where economic growth is strong and timber markets are expanding, or by decreasing planting rates by 50 percent for Cornerstone D (F), where economic growth is reduced and timber markets are declining.

- **Cornerstone E**: High population/income growth along with increasing timber prices and high tree planting rates.
- **Cornerstone F:** Low population/income growth along with decreasing timber prices and low tree planting rates.

The six Cornerstone Futures define a broad range of potential future conditions within which forests might develop. They address the set of four change factors identified by the expert panel using public input: wood products markets, bioenergy, land uses, and climate changes. They address bioenergy and wood products markets in a qualitative fashion—through exogenously defined trajectories of timber prices—that capture a broad range of market conditions. And they address land use and climate change in a detailed and spatially explicit way through projections of population, income, temperatures, and precipitation downscaled to the county level.

ACKNOWLEDGMENTS

Thanks to those who served on the expert panel for developing alternative futures in June 2008.

LITERATURE CITED

Coulson, D.P.; Joyce L.A.; Price, D.T. [and others]. 2010. Climate scenarios for the conterminous United States at the county spatial scale using SRES scenarios A1B and A2 and PRISM climatology. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/data_archive/dataaccess/US_ClimateScenarios_county_A1B_A2_PRISM.shtml. [Date accessed: January 10, 2011].

Ince, P.J.; Kramp, A.D.; Skog, K.E. [and others]. 2011. U.S. Forest Products Module for RPA forest assessment. Res. Pap. FPL-RP-662. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 61 p.

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007: synthesis report. Geneva, Switzerland. http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html. [Date accessed: January 24, 2012].

Joyce, L.A.; Price, D.T.; McKenney, D.W. [and others]. 2011. High resolution interpolation of climate scenarios for the conterminous United States and Alaska derived from general circulation model simulations. Gen. Tech. Rep. RMRS-GTR-263. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 87 p.

Nakicenovic, N.; Alcamo, J.; Davis, G. [and others]. 2000. Special report on emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. 599 p. http://www.grida.no/climate/ipcc/emission/index.htm. [Date accessed: March 25, 2011].

Poylakov, M.; Wear, D.N.; Huggett, R. 2010. Harvest choice and timber supply models for forest forecasting. Forest Science. 56(4): 344-355.

Prestemon, J.; Abt, R.C. 2002. Timber products supply and demand. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen.

Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 299-325.

Price, D.T.; McKenney, D.W.; Joyce, L.A. [and others]. 2011. High-resolution interpolation of climate scenarios for Canada derived from general circulation model simulations. Information Report NOR-X-421. Edmonton, AB: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre. 104 p.

Raunikar, R.; Buongiorno, J.; Turner, J.A.; Zhu, S. 2010. Global outlook for wood and forests with the bioenergy demand implied by scenarios of the Intergovernmental Panel on Climate Change. Forest Policy and Economics. 12: 48-56.

Sun, G.; McNulty, S.G.; Moore Myers, J.; Cohen, E.C. 2008. Impacts of multiple stresses on water demand and supply across the Southeastern United States. Journal of American Water Resources Association. 44(6): 1441–1457.

U.S. Department of Agriculture (USDA) Forest Service. 2012. Future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. RMRS-GTR-272. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 34 p.

Ward, J.D.; Mistretta, P.A. 2002. Impacts of pests on forest health. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 403-428.

Wear, D.N.; Greis, J.G.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS–115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Wear, D.N.; Huggett, R.; Li, R. [and others]. 2013. Forecasts of forest conditions in U.S. regions under future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-170. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 101 p.

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

CHAPTER 3.
Climate Change Summary

Steve McNulty, Jennifer Moore Myers,
Peter Caldwell, and Ge Sun[1]

KEY FINDINGS

- Since 1960, all but two southern capital cities (Montgomery, AL, and Oklahoma City, OK) have experienced a statistically significant increase in average annual temperature (approximately 0.016° C), but none has experienced significant trends in precipitation.
- The South is forecasted to experience warmer temperatures for the duration of the 21st century; forecasts are mixed for precipitation changes during the same period.
- Climate predictions range from wet and warm (1167 mm/19.06° C) to moderate and warm (1083 mm/19.45° C and 1106 mm/19.27° C) to dry and hot (912 mm/20.22° C).

INTRODUCTION

This chapter summarizes the climate predictions that have been used throughout the Southern Forest Futures Project (IPCC 2007b). Four distinct combinations of general circulation models (GCMs) and special report emissions scenarios were selected as Cornerstone Futures. GCMs are complex models that provide geographically and physically consistent estimates of regional climate change (IPCC 2009). The emissions scenarios are global storylines representing alternative demographic, socioeconomic, and environmental futures (Nakicenovic 2000).

The GCMs selected for the Futures Project were the MK2 and MK3.5 from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), the HadCM3 from the United Kingdom Meteorological Center, and the MIROC 3.2 from the Japanese National Institute for Environmental Studies.

Two emissions scenarios were selected for the Futures Project. The A1B scenario is characterized by low population growth, high energy use, and high economic growth. The B2 scenario is characterized by medium population growth, medium energy use, and medium economic growth (IPCC 2007b). These scenarios represent two levels of global carbon dioxide (CO_2) emissions by 2100: 60 gigatons of CO_2-equivalents (eq) (IPCC 2007a) in the A1B scenario (resulting in an atmospheric concentration of approximately 700 ppm) (Solomon and others 2007) and 65 gigatons of CO_2-eq (IPCC 2007a) in the B2 scenario (resulting in an atmospheric concentration of approximately 600 ppm) (Solomon and others 2007). The relationship between CO_2 equivalent emissions and atmospheric CO_2 concentration is not linear, and the estimates for 2100 are influenced by emission rates throughout the 21st century. The A1B scenario peaks higher around 2050 and tapers off, while the B2 scenario increases more slowly and steadily. For comparison, carbon dioxide emissions for 2009 were estimated at 40 gigatons of CO_2-eq (resulting in an atmospheric concentration of 387 parts per million) (IPCC 2007a, Tans 2011).

The Futures Project combines GCMs and emissions scenarios into four Cornerstone Futures—CSIROMK3.5+A1B, MIROC3.2+A1B, CSIROMK2+B2, and HadCM3+B2—which are described in this chapter. Although this chapter does not discuss subregional variations in detail, the GCM summary data have been provided in both tabular and graphic formats to allow the reader to examine climate change impacts for subregions of interest.

DATA SOURCES AND METHODS

Because the original scale of the GCMs was too coarse for regional analysis, the Cornerstone Futures were downscaled from their original resolution of approximately 2 degrees by the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3) (Maurer and others 2007). Each GCM was spatially downscaled to one-twelfth degree (5 arc minute) using ANUSPLIN, a interpolation model that incorporates four dimensions (climatic variable, latitude, longitude, and elevation) to produce gridded surfaces for both monthly precipitation and surface air temperature (Hutchinson 2009).

The CMIP3 data were obtained and processed by Coulson and others (2010) for use in the 2010 Resources Planning Act (RPA) Assessment. Monthly precipitation and

[1]Steve McNulty is Supervisory Ecologist, Jennifer Moore Myers is a Resource Information Specialist, and Peter Caldwell and Ge Sun are Research Hydrologists, Eastern Forest Environmental Threat Assessment Center, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27606.

temperature data from 2000 to 2100 were scaled to the county level for the conterminous United States. All chapters in this assessment use the county level precipitation and temperature data. All regional and subregional averages were area-weighted to remove bias that would result from averaging counties of different areas.

For this chapter, annual and decadal averages were generated for the South and for its five subregions using the JMP 8.0 software application (SAS Institute Inc. 2010). For a historical perspective, trends in air temperature and precipitation for the 13 southern capital cities from 1960 to 2007 were obtained from the PRISM Climate Group (Gibson and others 2002). Maps were generated using the ArcMap version 9.3.1 software application (ESRI 2010). The decades selected for this chapter were 2010, 2020, 2040, 2060, and 2090. To calculate the decadal averages, the ten years surrounding each period were summed, in the case of precipitation, and then averaged. The decadal average for 2010 included data from the years 2005–14, 2020 included data from 2015–24, 2040 included data from 2035–44, etc. The results section describes averages and anomalies for each of the four Cornerstones.

RESULTS

Regional Forecasts

Table 3.1 summarizes precipitation and temperature averages forecasted for the South through 2100, with historical data for comparison. Figures 3.1 through 3.4 present graphic and map displays of precipitation data, and figures 3.5 through 3.8 present graphic and map displays of temperature data.

Characterized by low population growth and high energy-use/economic-growth (MIROC3.2+A1B), Cornerstone A is forecasted to be dry and hot, with average annual precipitation of 912 mm and average annual temperature of 20.22° C. Annual precipitation expected for any southern county ranges from 103 to 4999 mm, and temperature ranges from -12.01 to 50.24° C. Average maximum monthly temperatures would exceed the single-day southern maximum of 48.89° C, which was set in Oklahoma in 1994 (Burt 2007).

Also characterized by low population growth and high energy-use/economic-growth (CSIROMK3.5+A1B), Cornerstone B is forecasted to be wet and warm, with average annual precipitation of 1167 mm and average temperature of 19.06° C. Annual precipitation expected for southern counties ranges from 93 to 3912 mm, and temperature ranges from -11.21 to 44.24° C.

Characterized by moderate population/income growth and energy use (CSIROMK2+B2), Cornerstone C is forecasted to be moderate and warm, with average annual precipitation of 1083 mm and average annual temperature of 19.45° C. Annual precipitation expected for any southern county ranges from 35 to 2641 mm. That precipitation minimum would break the 1956 regional low of 42 mm in Texas (Burt 2007). Temperature is expected to range from -19.73 to 45.39° C.

Also characterized by moderate population/income growth and energy use (HadCM3+B2), Cornerstone D is also forecasted to be moderate and warm, with average annual precipitation of 1106 mm (higher than Cornerstone C) and average annual temperature of 19.27° C (lower than Cornerstone C). Annual precipitation expected for

Table 3.1—Summary statistics for predicted (2010–2100) and historical (2001–09) annual precipitation and temperature forecasts for the Southern United States by four Cornerstone Futures A through D

	Precipitation (mm)				Temperature (°C)			
Cornerstone[a]	Minimum	Maximum	Average	Standard deviation	Minimum	Maximum	Average	Standard deviation
A	733	1675	912	198	17.29	21.35	20.22	1.05
B	627	1517	1167	138	17.98	23.93	19.06	1.33
C	803	1369	1083	126	17.07	21.74	19.45	1.08
D	724	1383	1106	121	16.76	22.36	19.27	1.10
Average all Cornerstones	NA	NA	1066	NA	NA	NA	19.57	NA
Historical (2001 to 2009)	864	1552	1136	NA	16.97	19.45	17.87	NA

NA = not applicable.
[a]Each Cornerstone represents a general circulation model paired with one of two emission scenarios (A1B represents low-population/high-economic growth, high energy use; B2 represents moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.
Source: Intergovernmental Panel on Climate Change 2007b.

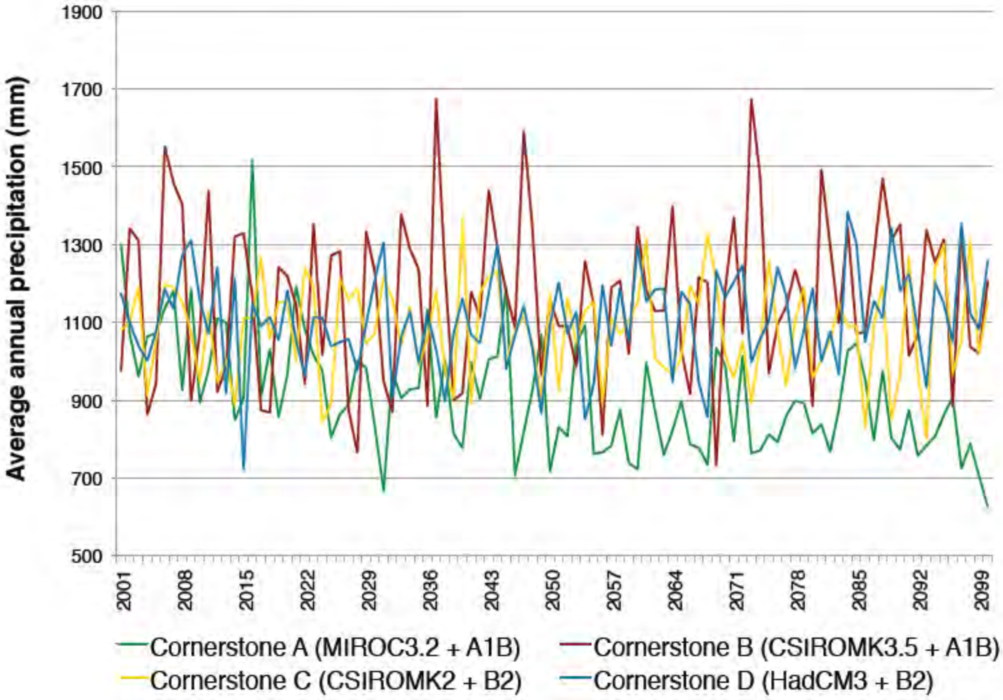


Figure 3.1—Historical and predicted annual precipitation for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

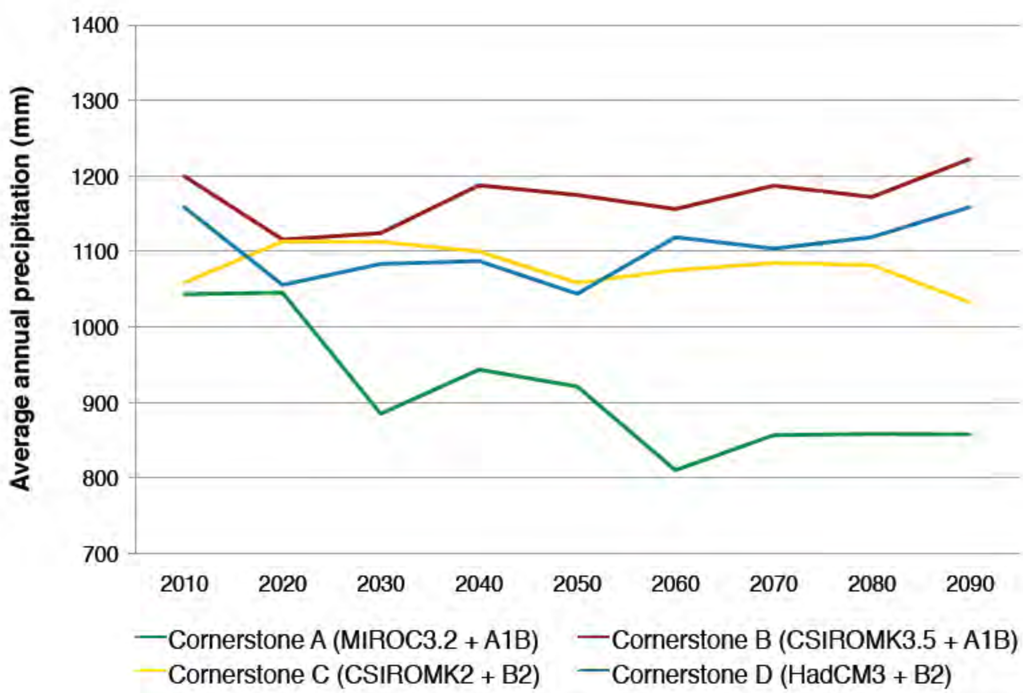


Figure 3.2—Predicted annual precipitation (2010, 2020, 2040, 2060, and 2090) for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

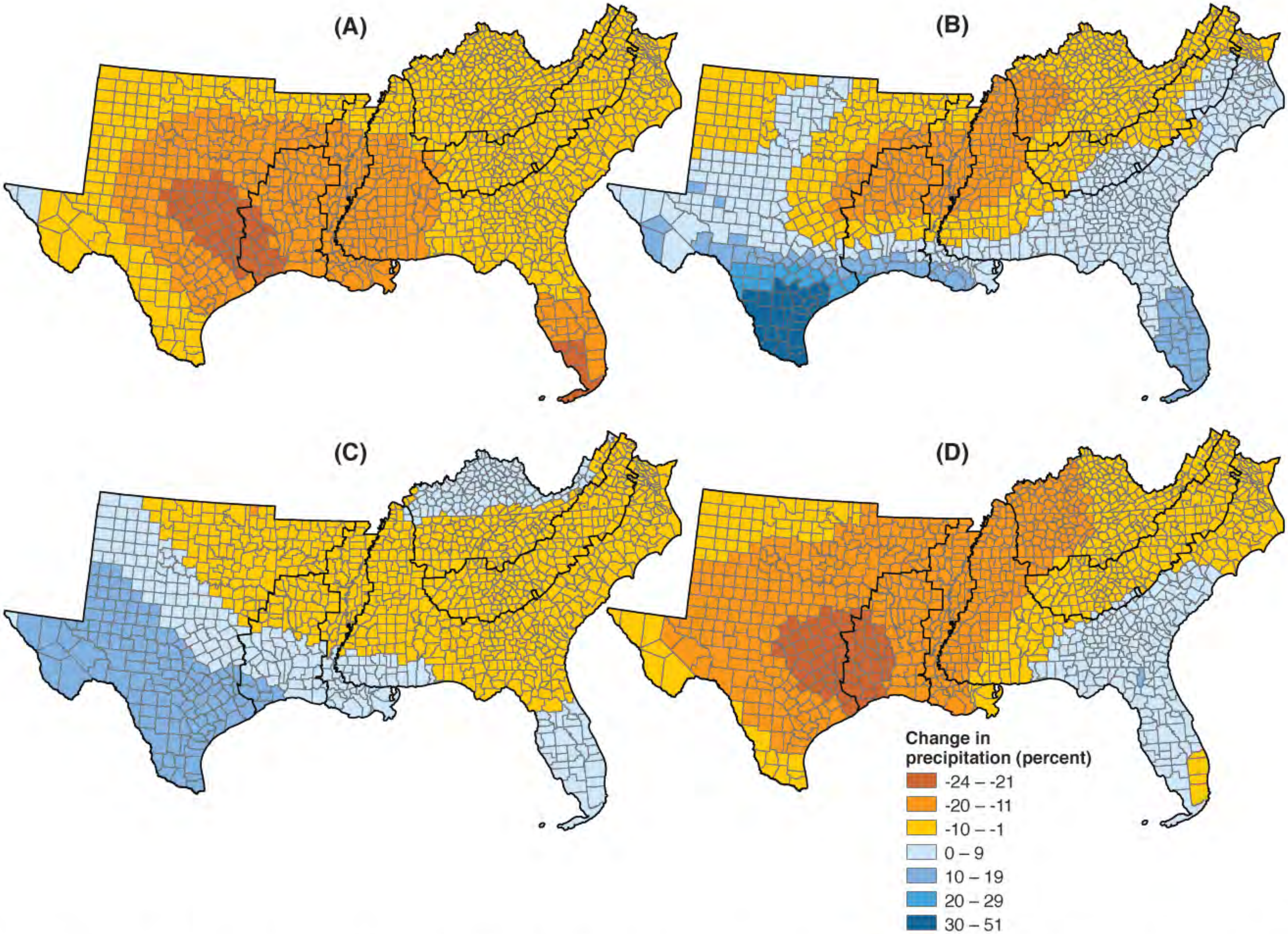


Figure 3.3—Predicted change in precipitation from 2010 to 2050 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b).

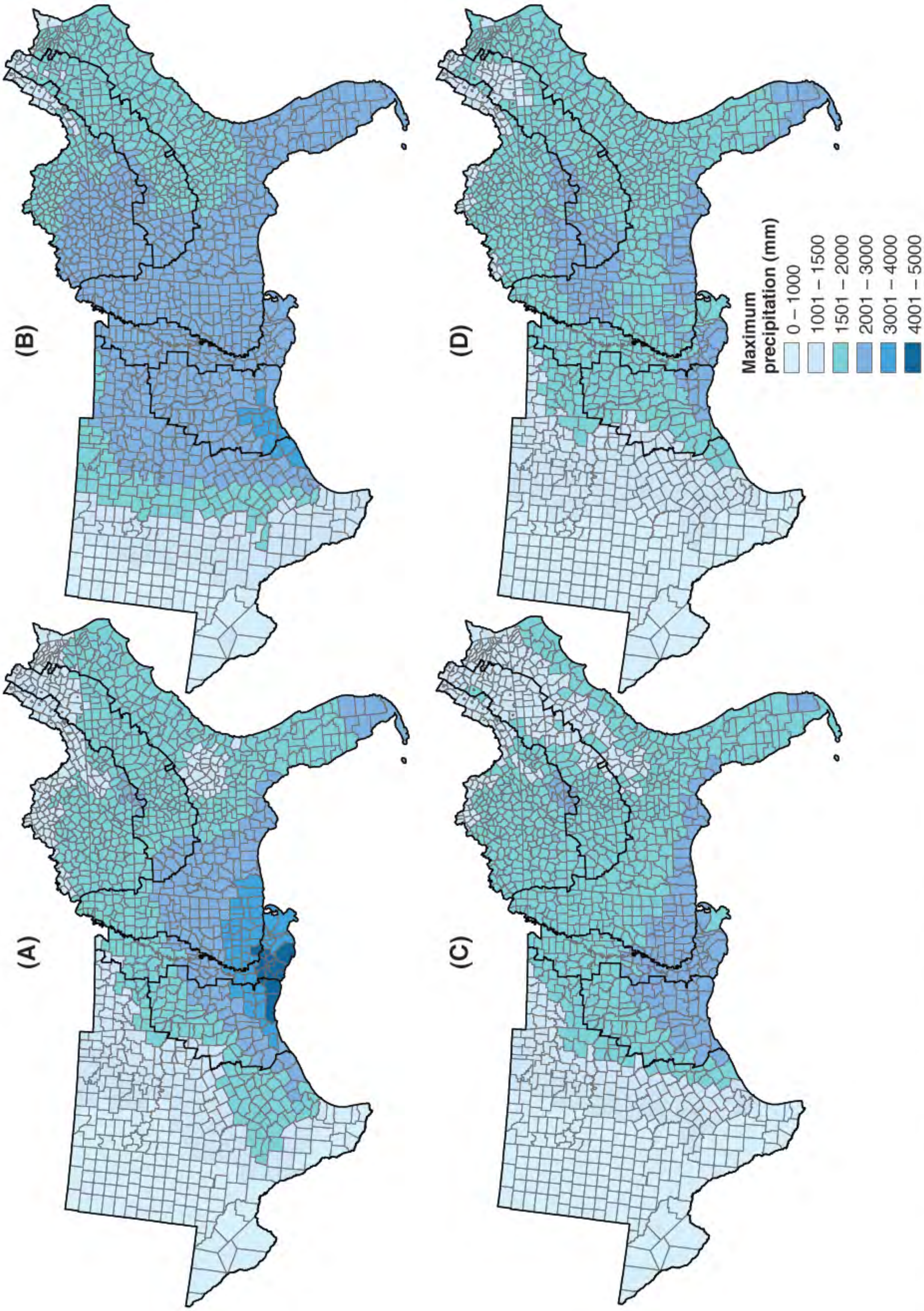


Figure 3.4—Maximum precipitation from 2010 to 2060 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b)

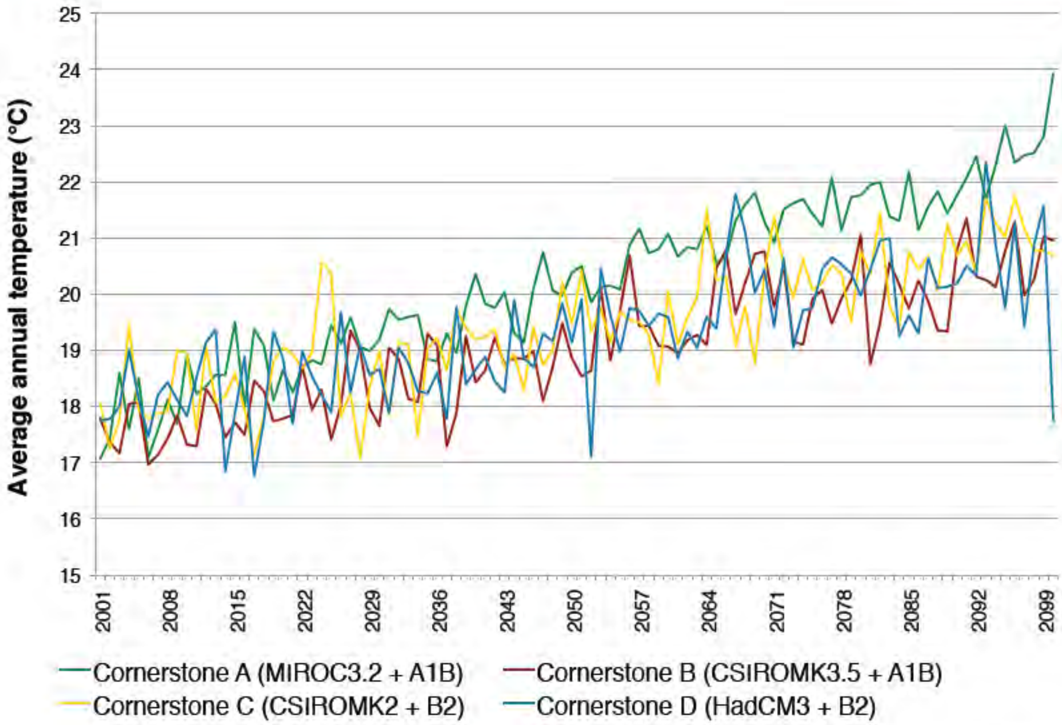


Figure 3.5—Historical and predicted annual air temperature for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

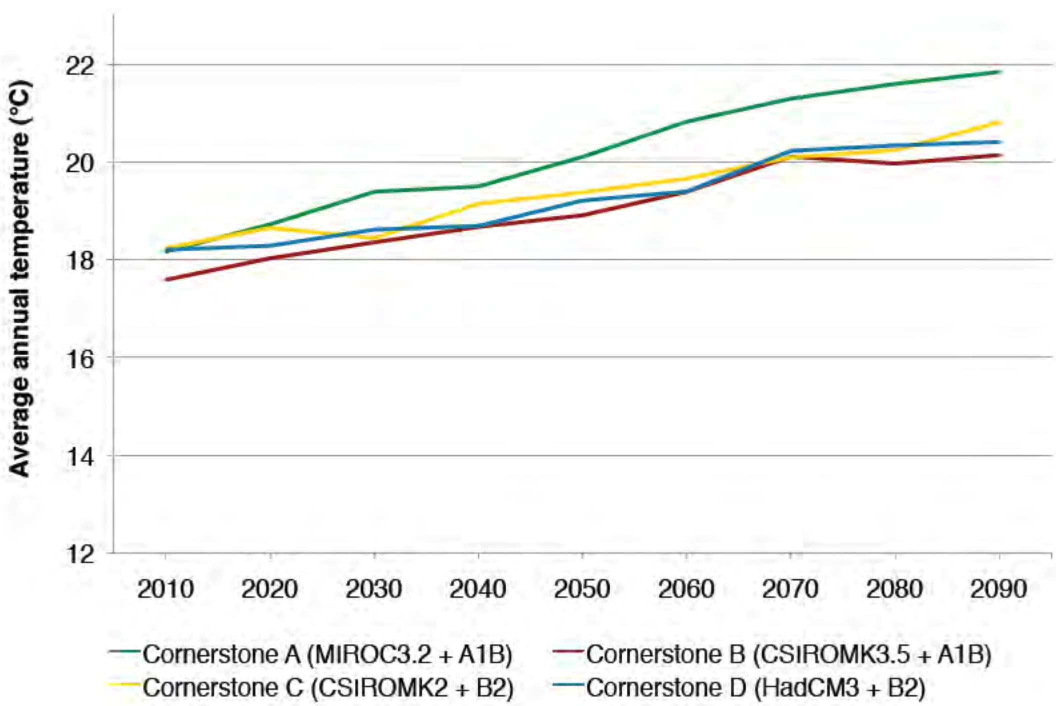


Figure 3.6—Predicted annual air temperature (2010, 2020, 2040, 2060, and 2090) for the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

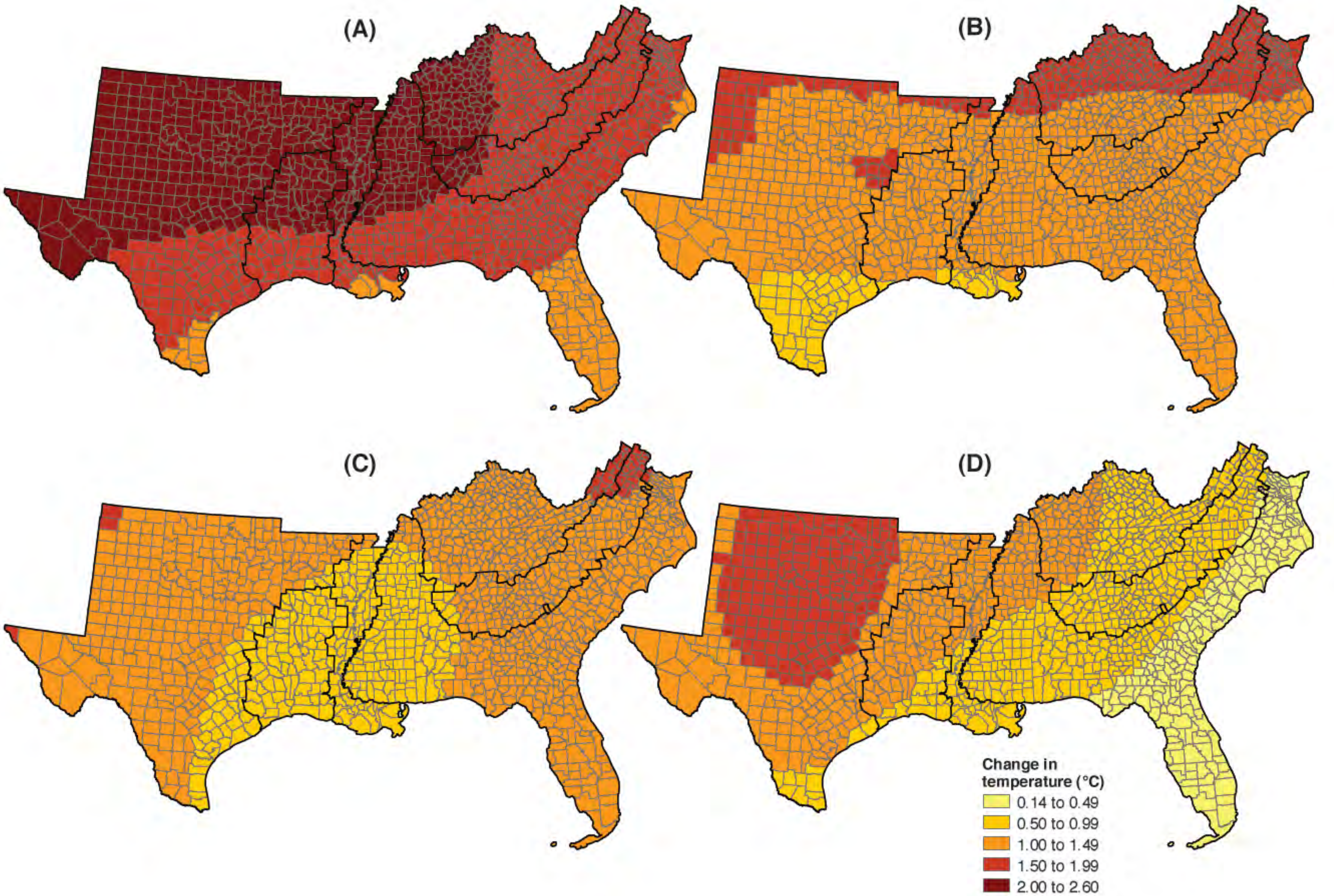


Figure 3.7—Predicted change in air temperature from 2010 to 2050 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b)

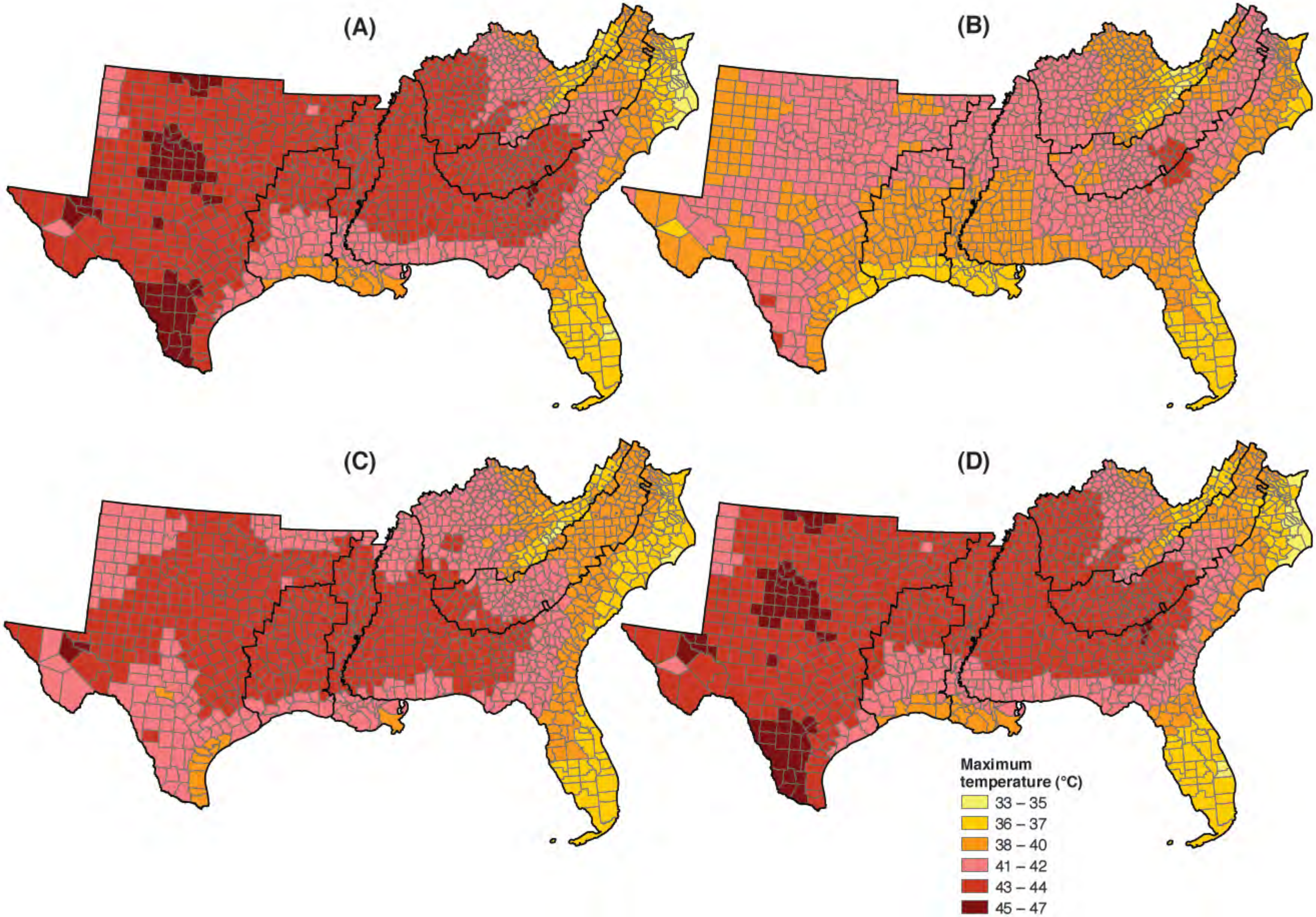


Figure 3.8—Maximum air temperature from 2010 to 2060 for the Southern United States as forecasted by four Cornerstones Futures, each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use—(A) MIROC3.2+A1B, (B) CSIROMK3.5+A1B, (C) CSIROMK2+B2, and (D) is HadCM3+B2. (Source: Intergovernmental Panel on Climate Change 2007b).

any southern county ranges from 102 to 2708 mm, and temperature ranges from -18.68 to 48.01° C.

Subregional Forecasts

In the Southern United States, forecasted precipitation (table 3.2) and temperature averages (table 3.3) are not expected to be uniform, with significant variations across the five subregions and between seasons (table 3.4). Figures 3.9 and 3.10 present graphic and map displays of precipitation and temperature data.

Cornerstone A's high energy-use/economic-growth (MIROC3.2+A1B) is predicted to result in the least decadal precipitation by 2060, with an overall average of 810 mm for all five southern subregions and a low of 525 mm in the Mid-South. This trend is expected to abate only slightly by 2090 to an average of 858 mm for all subregions and 535 mm for the Mid-South—still much drier than the historical overall average of 1136 mm.

Although also based on high energy-use/economic-growth, Cornerstone B (CSIROMK3.5+A1B) predicts more decadal precipitation than the other Cornerstones by 2060, with an overall average of 1156 mm. This trend continues into 2090, with an overall average predicted to be 1223 mm. Cornerstone B also predicts cooler decadal temperatures than the other Cornerstones by 2060—with an overall average of 19.39° C—for every subregion except the Mid-South. This trend continues into 2090, with Cornerstone B's overall average of 20.14° C, lower than all the others for all subregions.

Cornerstone A predicts warmer decadal temperatures than the other Cornerstones by 2060, with an overall average of 20.83° C for all five southern subregions. This trend continues into 2090, with Cornerstone A's overall average of 21.84° C leading all the others for all subregions.

Comparing these predictions with historical trends in air temperature and precipitation for the 13 southern capital cities from 1960 to 2007 shows a statistically significant increase (total of 0.705° C, average of 0.016° C) in air temperature but no significant change in precipitation (fig. 3.11). These findings are consistent with a trend of significant increases in temperature from 1970 to 2008 reported by Karl and others (2009) (table 3.4), but not after their data from 1901 to 1969 were included.

DISCUSSION AND CONCLUSIONS

GCMs provide some indication of how climate will change across the South in coming decades. Each has been independently developed, often for a specific region, and frequently calibrated to recreate historical climate on the assumption that successful modeling of the past increases the likelihood of accurately forecasting the future. However, the same calibration that allows an accurate recreation of historical climate for one region can result in over- or under-predicting climate change for others.

An example of possible over-predicting is Cornerstone A (MIROC3.2+A1B), which assumes high energy-use and economic-growth and predicts the warmest conditions, with monthly averages sometimes exceeding single-day historical highs (fig. 3.12). Similarly, Cornerstone A's average precipitation is about 20 percent lower (fig. 3.13). For these reasons, it is considered the most severe of the Cornerstones in terms of extreme events as well as annual averages. The other GCMs used in this analysis also predict maximum monthly air temperatures in excess of historically observed conditions, but by a smaller margin. In particular, Cornerstone B (CSIROMK3.5+A1B) predicts increases in average annual precipitation compared to historical averages.

Another caveat is that averaged or summed monthly values are less able to express climate variability (especially extremes) than daily values. Monthly average air temperatures are expected to be much lower than some of the individual daily highs, and higher than some of the individual daily lows. For example, if a maximum monthly air temperature is predicted to be 40° C, then individual daily air temperatures are likely to exceed 45 or even 50° C.

Likewise, monthly average precipitation does not fully represent the number or magnitude of individual events. Although Cornerstone A predicts a reduction in average precipitation, many of its monthly maximums exceed historical highs. Similarly, variations among months may not be captured by monthly averages or annual summaries. For example, 1000 mm of precipitation during a 5-month period in winter and spring would produce a very different impact than if evenly distributed throughout the year or concentrated during growing-season months. And for monthly level predictions, a 100-mm average would mask the water quality and flooding impacts that would result if precipitation were concentrated in one or two major events.

The GCMs also have limited spatial resolution. Their one-twelfth degree by one-twelfth degree resolution is a significant improvement on older model forecasts, but still coarse for predicting precipitation, which can be highly variable with adjacent areas receiving drastically different precipitation amounts from a single event. This variation is also important for localized flood forecasting and in estimating water quality.

Table 3.2—Predicted average precipitation for subregions of the Southern United States as forecasted by four Cornerstone Futures A through D

		Cornerstone[a] prediction of average precipitation (mm)			
Date	Subregion	A	B	C	D
2010	Appalachian-Cumberland	1223	1419	1303	1390
	Coastal Plain	1216	1375	1268	1328
	Mid-South	721	812	663	784
	Mississippi Alluvial Valley	1351	1550	1358	1472
	Piedmont	1263	1484	1285	1379
2020	Appalachian-Cumberland	1257	1376	1371	1307
	Coastal Plain	1210	1313	1289	1257
	Mid-South	677	735	710	659
	Mississippi Alluvial Valley	1427	1397	1462	1348
	Piedmont	1285	1259	1326	1272
2040	Appalachian-Cumberland	1139	1448	1336	1298
	Coastal Plain	1174	1295	1307	1309
	Mid-South	579	837	713	725
	Mississippi Alluvial Valley	1261	1524	1392	1321
	Piedmont	1202	1273	1328	1331
2060	Appalachian-Cumberland	940	1444	1338	1362
	Coastal Plain	1037	1370	1309	1370
	Mid-South	525	729	650	717
	Mississippi Alluvial Valley	1024	1455	1371	1346
	Piedmont	1065	1345	1324	1371
2090	Appalachian-Cumberland	999	1434	1271	1417
	Coastal Plain	1109	1358	1195	1396
	Mid-South	536	884	666	743
	Mississippi Alluvial Valley	1110	1582	1303	1456
	Piedmont	1164	1395	1231	1388

[a]Each Cornerstone represents a general circulation model paired with one of two emission scenarios (A1B represents low-population/high-economic growth, high energy use; B2 represents moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.
Source: Intergovernmental Panel on Climate Change 2007b.

Table 3.3—Predicted average temperature (°C) for subregions of the Southern United States as forecasted by four Cornerstone Futures A through D

		Cornerstone[a] prediction of average temperature (°C)			
Date	Subregion	A	B	C	D
2010	Appalachian-Cumberland	14.02	13.18	14.31	14.01
	Coastal Plain	19.36	18.89	19.49	19.45
	Mid-South	18.60	18.02	18.48	18.59
	Mississippi Alluvial Valley	19.01	18.54	19.36	19.15
	Piedmont	16.16	15.41	16.34	16.24
2020	Appalachian-Cumberland	14.57	13.99	14.67	13.91
	Coastal Plain	19.91	19.24	19.84	19.30
	Mid-South	19.15	18.40	19.01	19.01
	Mississippi Alluvial Valley	19.67	18.95	19.63	19.16
	Piedmont	16.73	16.02	16.72	16.05
2040	Appalachian-Cumberland	15.55	14.68	15.46	14.17
	Coastal Plain	20.61	19.98	20.27	19.80
	Mid-South	19.93	18.91	19.44	19.36
	Mississippi Alluvial Valley	20.38	19.63	20.04	19.75
	Piedmont	17.59	16.77	17.39	16.41
2060	Appalachian-Cumberland	16.87	15.03	15.91	15.16
	Coastal Plain	21.85	20.44	20.80	20.49
	Mid-South	21.34	20.11	19.97	19.97
	Mississippi Alluvial Valley	21.92	20.27	20.68	20.39
	Piedmont	18.79	17.05	17.84	17.26
2090	Appalachian-Cumberland	17.73	15.78	17.29	16.32
	Coastal Plain	22.78	21.30	21.96	21.50
	Mid-South	22.53	20.74	21.01	20.90
	Mississippi Alluvial Valley	22.73	20.94	21.87	21.34
	Piedmont	19.74	17.89	19.12	18.46

[a]Each Cornerstone represents a general circulation model paired with one of two emission scenarios (A1B represents low-population/high-economic growth, high energy use; B2 represents moderate growth and use): A is MIROC3.2+A1B, B is CSIROMK3.5+A1B, C is CSIROMK2+B2, and D is HadCM3+B2.
Source: Intergovernmental Panel on Climate Change 2007b.

Table 3.4—Average change in temperature and precipitation in the Southeastern United States, as recreated from Karl and others (2009)

	Temperature change (°F)			Precipitation change (percent)	
	1901-2008	1970-2008		1901-2008	1970-2008
Annual	0.3	1.6	Annual	6.0	-7.7
Winter	0.2	2.7	Winter	1.2	-9.6
Spring	0.4	1.2	Spring	1.7	-29.2
Summer	0.4	1.6	Summer	-4.0	3.6
Autumn	0.2	1.1	Autumn	27.4	0.1

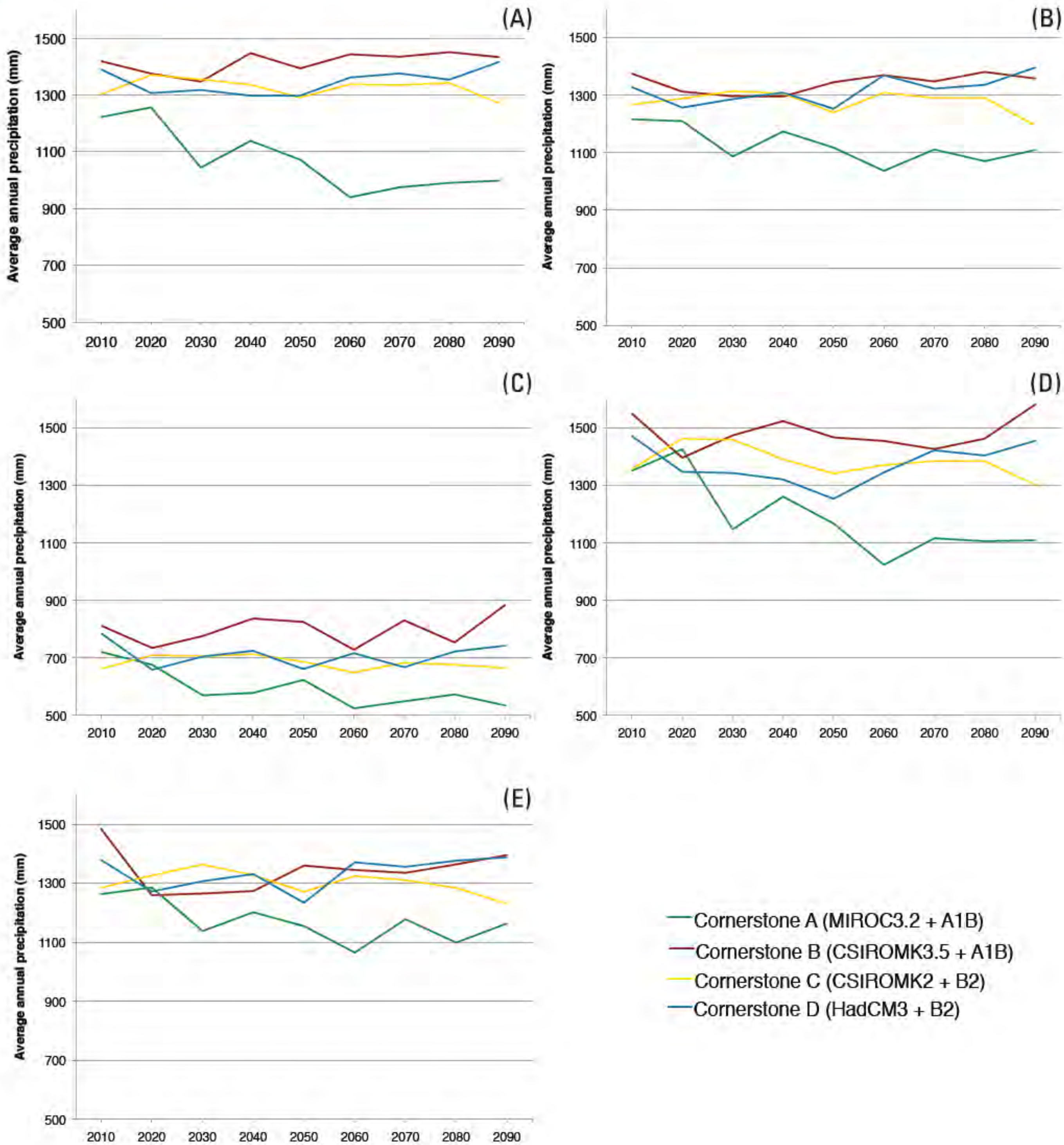


Figure 3.9—Predicted annual precipitation (2010, 2020, 2040, 2060, and 2090) for the (A) Appalachian-Cumberland, (B) Coastal Plain, (C) Mid-South, (D) Mississippi Alluvial Valley, and (E) Piedmont subregions of the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b).

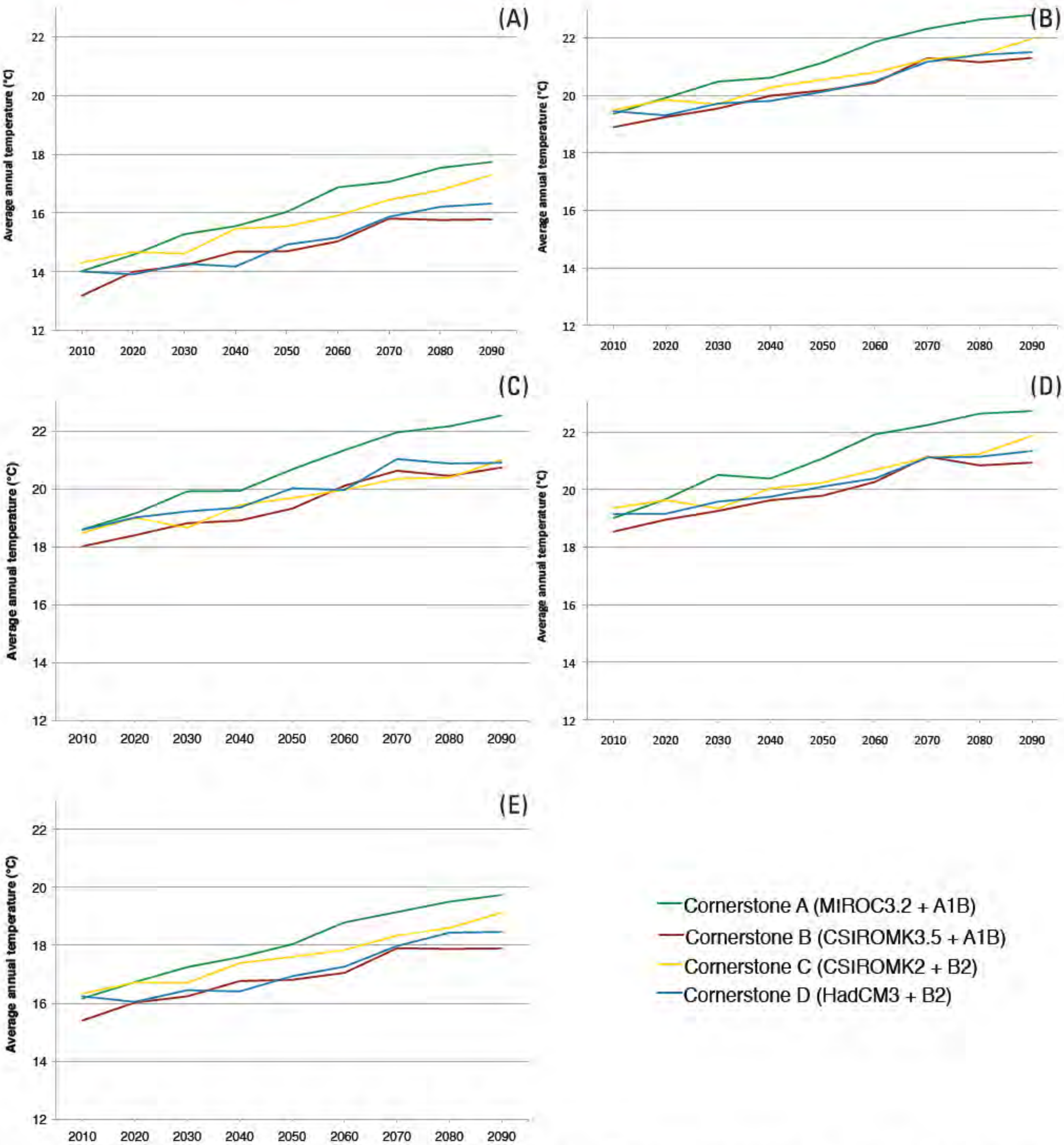


Figure 3.10—Predicted annual air temperature (2010, 2020, 2040, 2060, and 2090) for the (A) Appalachian-Cumberland, (B) Coastal Plain, (C) Mid-South, (D) Mississippi Alluvial Valley, and (E) Piedmont subregions of the Southern United States as forecasted by four Cornerstones Futures (A through D), each of which represents a general circulation model paired with one of two emission scenarios—A1B representing low-population/high-economic growth, high energy use, and B2 representing moderate growth and use. (Source: Intergovernmental Panel on Climate Change 2007b)

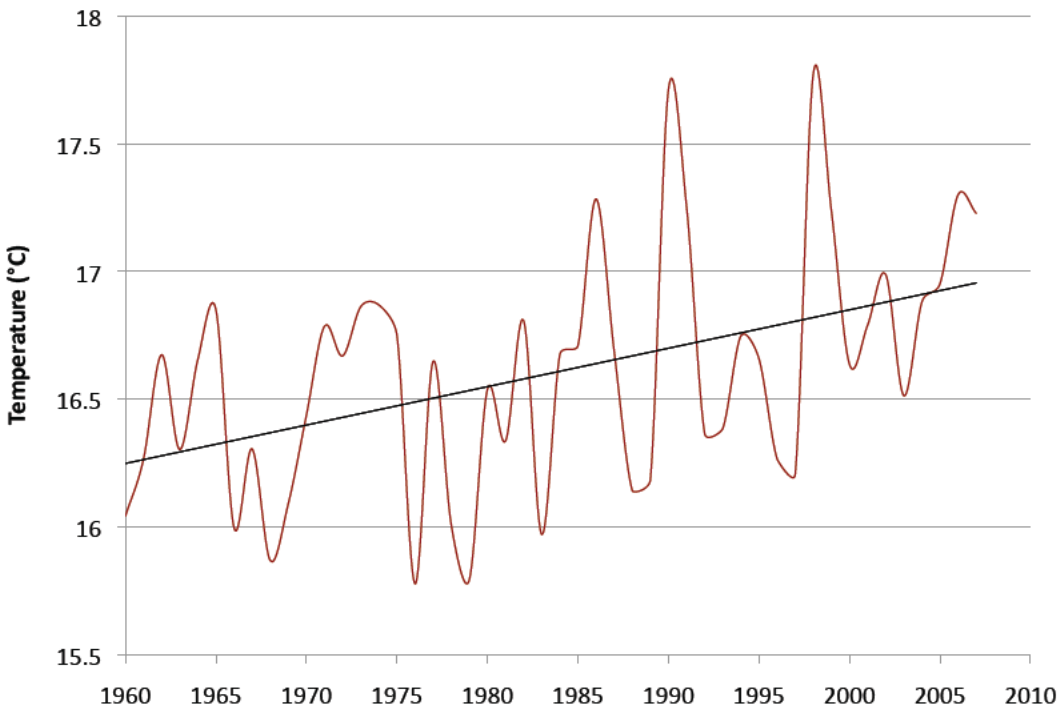


Figure 3.11—Average annual air temperature for the 13 southern capital cities from 1960 to 2007. (Source: Gibson and others 2002)

These factors complicate efforts to develop detailed assessments of climate change for every subregion. For example, even though Cornerstone A predicts a hotter and drier climate for the South, some areas within the region could become wetter (although not likely cooler). Finally, the GCMs were designed to produce decadal, long-term averages for air temperature and precipitation. As with historical climate, any given year could be cooler, hotter, drier, or wetter than the long-term average.

Even with these caveats, several strong trends emerge from the analysis of the climate change predictions. First and foremost, air temperature across the South is forecasted to increase significantly from historical and current levels. None of the models used in this analysis, or any others published by other climate scientists, suggest that air temperatures will remain stable or will cool. The precipitation predictions of these GCMs are in much better agreement than those of previous climate model assessments (NAST 2001). All but Cornerstone A predict relatively little change in precipitation across the region, but as previously discussed, variation could be significant from one subregion to the next.

Changes in precipitation need to be examined in the context of air temperature changes. As temperature increases in an ecosystem, water use also increases. Therefore, temperature increases will likely offset small increases in precipitation, resulting in more frequent water shortages and streamflow reductions. If precipitation remains at historical levels (or less), then water shortage issues will increase.

Although the magnitude and temporal and spatial distribution of climate change is uncertain, all indications suggest that some change is certain. Even the most conservative estimates would produce dramatic changes in ecosystem water use (chapter 13), carbon sequestration (chapter 5), species composition (chapter 5), and human societies (chapter 12).

KNOWLEDGE AND INFORMATION GAPS

The GCMs on which the climate change predictions are based are improving both spatially and temporally as computational power increases and our understanding of atmospheric physics and chemistry interactions improves. Early models had few interactions among terrestrial, ocean, and atmospheric drivers of climate change. Since the passage of the U.S. Global Climate Change Research Act of 1991, billions of dollars have been dedicated to understanding these relationships. Additionally, international contributions to this effort have been significant, producing improvements in understanding and forecasting.

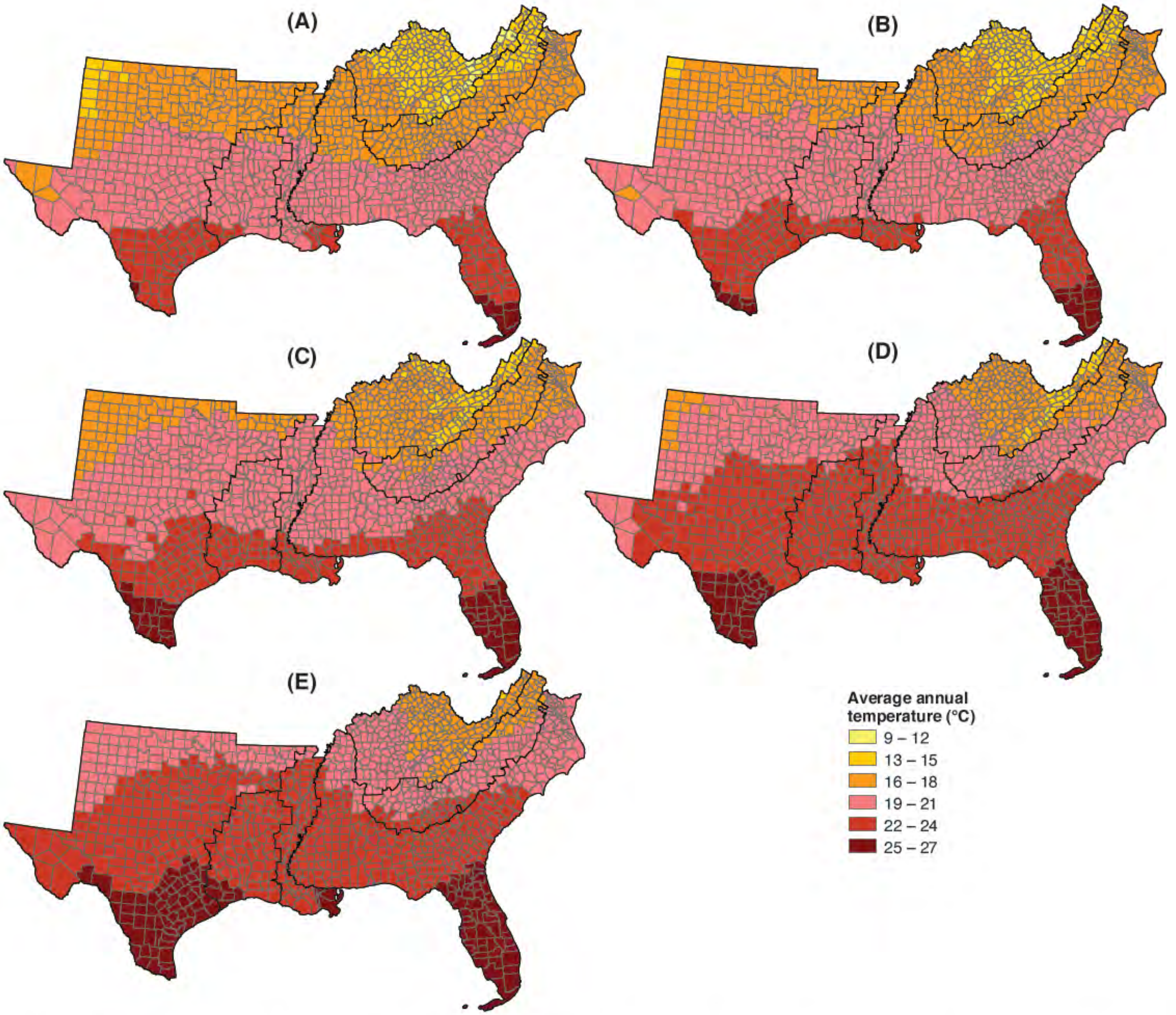


Figure 3.12—Predicted annual average air temperature for selected decades —(A) 2010, (B) 2020, (C) 2040, (D) 2060, (E) 2090—for the Southern United States as forecasted by Cornerstone A, a future representing the MIROC3.2 general circulation model and an emission scenario (A1B) of low-population/high-economic growth and high energy use. (Source: Intergovernmental Panel on Climate Change 2007b)

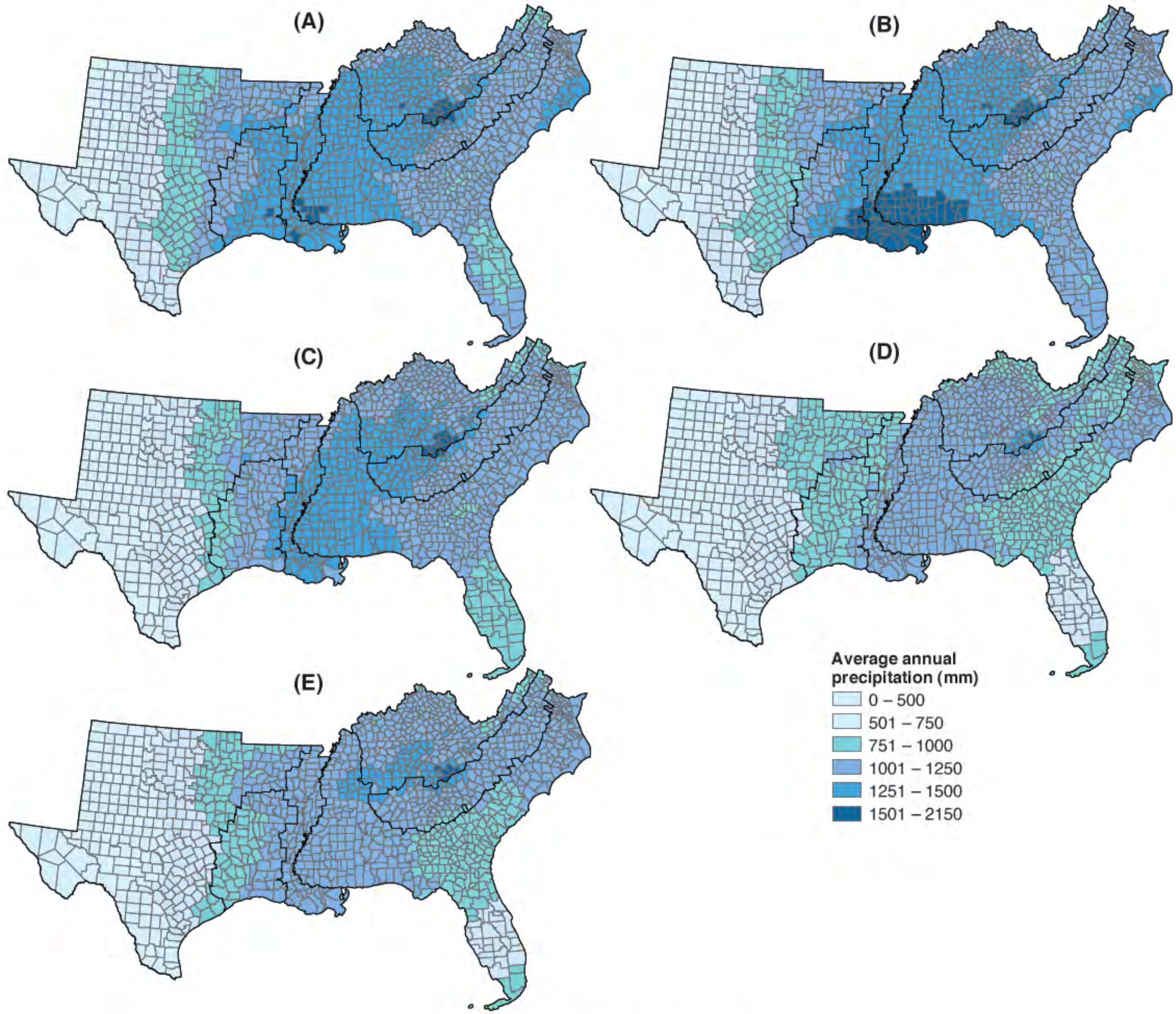


Figure 3.13—Predicted annual average precipitation for selected decades—(A) 2010, (B) 2020, (C) 2040, (D) 2060, (E) 2090—for the Southern United States as forecasted by Cornerstone A, a future representing the MIROC3.2 general circulation model and an emission scenario (A1B) of low-population/high-economic growth and high energy use. (Source: Intergovernmental Panel on Climate Change 2007b)

However, gaps still exist, both in knowledge and its implementation. For example, the GCMs from the most recent assessment incorporate changes in albedo from polar ice cap melting (IPCC 2007b), an improvement over previous assessments (Winton 2008) that can offer more accurate simulations but only if this important feedback is incorporated into new model runs. Additionally, the positive feedback between permafrost melting and subsequent release of carbon dioxide and methane adds important greenhouse gases to the atmosphere that must be included in the global warming predictions (Walter and others 2006).

Just as weather forecasts commonly predict from 7 to 10 days into the future with decreasing accuracy over time, climate forecasts based on existing and developing global ocean and atmospheric circulation patterns currently predict 6 to 12 months into the future. Although additional improvement in the accuracy and forecast length of these seasonal predictions are likely, accurately predicting specific weather events or patterns that may occur years or decades in the future is unlikely anytime soon. The science needed to predict the impacts of doubling atmospheric carbon dioxide on global air temperature and precipitation is very different from the science needed to predict monthly air temperature for a specific city on a specific date. Given these limitations, land managers will need to rely on the climate envelopes (ranges of climatic conditions for specific places and times) as they develop climate change impact assessments and coping strategies.

ACKNOWLEDGMENTS

We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison and the World Climate Research Programme (WCRP) Working Group on Coupled Modeling for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy. We also acknowledge John Buckley and Erika Cohen, Southern Research Station, U.S. Department of Agriculture, Forest Service, for their assistance with reviewing climate summaries.

LITERATURE CITED

Burt, C.C. 2007. Extreme weather: a guide and record book. New York: W.W. Norton and Co. 303 p.

Coulson, D.P.; Joyce, L.A.; Price, D.T. [and others]. 2010. Climate scenarios for the conterminous United States at the county spatial scale using SRES scenarios A1B and A2 and PRISM climatology. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/data_archive/dataaccess/US_ClimateScenarios_county_A1B_A2_PRISM.shtml. [Date accessed: January 10, 2011].

Environmental Systems Research Institute (ESRI). 2010. ArcGIS. Version 9.3.1. Redlands, CA: Environmental Systems Research Institute.

Gibson, W.; Daly, C.; Kittel, T. [and others]. 2002. Development of a 103-year high-resolution climate dataset for the conterminous United States. In: Proceedings of 13th American Meteorological Society Conference on Applied Climatology. Portland, OR: American Meteorological Society: 181–183.

Hutchinson, M.F. 2009. ANUSPLIN Version 4.3. http://fennerschool.anu.edu.au/publications/software/anusplin.php. [Date accessed: March 17, 2011].

Intergovernmental Panel on Climate Change (IPCC). 2007a. Contribution of working groups I, II, and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change. 104 p. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. [Date accessed: March 16, 2011].

Intergovernmental Panel on Climate Change (IPCC). 2007b. IPCC fourth assessment report: climate change 2007 (AR4). http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm. [Date accessed: July 7, 2010].

Intergovernmental Panel on Climate Change (IPCC). 2009. What is a GCM? http://www.ipcc-data.org/ddc_gcm_guide.html. [Date accessed: August 18, 2010].

Karl, T.R.; Melillo, J.M.; Peterson, T.C. 2009. Global change impacts in the United States. Cambridge, UK: Cambridge University Press. 188 p. http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report. [Date accessed: August 24, 2010].

Maurer, E.P.; Brekke, L.; Pruitt, T.; Duffy, P.B. 2007. Fine-resolution climate projections enhance regional climate change impact studies. Eos, Transactions American Geophysical Union. 88(47): 504.

National Assessment Synthesis Team (NAST). 2001. Climate change impacts on the United States: the potential consequences of climate variability and change. Foundation Report. Report for the U.S. global change research program. Cambridge, UK: Cambridge University Press. 154 p.

Nakicenovic, N.; Swart, R., eds. 2000. Special report on emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. 599 p. http://www.grida.no/climate/ipcc/emission/index.htm. [Date accessed: August 26, 2010].

SAS Institute Inc. © 2010. JMP. SAS/STAT user’s guide. Version 8. Cary, NC: SAS Institute Inc. [pages unknown].

Solomon, S.; Qin, D.; Manning, M.; Chen, Z. [and others], eds. 2007. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. 996 p. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html. [Date accessed: March 15, 2011].

Tans, P. 2011. Trends in atmospheric carbon dioxide. NOAA/ESRL. http://www.esrl.noaa.gov/gmd/ccgg/trends. [Date accessed: March 15, 2011].

Walter, K.M.; Zimov, S.A.; Chanton, J.P. [and others]. 2006. Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. Nature. 443(7): 71–75.

Winton, M. 2008. Sea ice albedo feedback and nonlinear Arctic climate change. In: DeWeaver, E.; Bitz, C.M.; Tremblay, B., eds. Arctic Sea Ice Decline: Observations, Projections, Mechanisms, and Implications. Geophysical Monograph Service. Washington, DC: 111–131. Vol. 180.

CHAPTER 4.
Forecasts of Land Uses

David N. Wear[1]

KEY FINDINGS

- Between 30 million and 43 million acres of land in the South are forecasted to be developed for urban uses by 2060 from a base of 30 million acres in 1997. These forecasts are based on a continuation of historical development intensities.
- From 1997 to 2060, the South is forecasted to lose between 11 million acres (7 percent) and 23 million acres (13 percent) of forests, nearly all to urban uses. All of the South's five subregions are expected to lose at least some forest acreage under all evaluated futures.
- Strong timber markets can ameliorate losses of southern forest somewhat, but this comes at the expense of cropland uses.
- Among the South's five subregions, the Piedmont is forecasted to lose the greatest proportion of its forest area—21 percent under the highest-loss forecast—by 2060. The Mid-South and Mississippi Alluvial Valley are forecasted to lose the smallest proportion (between 8 and 9 percent).
- At 34 percent, Peninsular Florida is forecast to lose the most forest land of the 21 sections nested within the South's five subregions. All sections within the Piedmont subregion are forecasted to lose at least 19 percent of their forest land.
- The area of cropland in the South is forecasted to decline by as much as 17 million acres from 1997 to 2060 from a base of about 84 million acres in 1997. Cropland futures assume constant real returns to agricultural products.
- Cropland losses would be highest in North Carolina, southern Florida, and central Texas.

INTRODUCTION

Land use patterns define both the extent of human presence on a landscape and the ability of land to provide a full range of ecosystem services. The future sustainability of forests in the South has been and will continue to be largely influenced by the dynamics of land use. And as the region's population grows so too will the area of developed uses. The pattern of these developments, returns from the various products of rural land, and the land's inherent productivity will determine the distribution of forest, crop, and other rural land uses, and therein the structure and function of terrestrial ecosystems (Chen and others 2006, Wear 2002).

The purpose of this chapter is to examine how land use could respond to the economic and population forecasts associated with the Cornerstone Futures for the Southern Forest Futures Project. Our forecasts use empirical models to address the Cornerstone Futures and to examine some specific questions about alternative land use futures. Land use forecasts play a central role in the U.S. Forest Assessment System (Wear and others 2013), with the information developed in this chapter providing one of the inputs to the Forest Assessment System's forest dynamics model, which in turn generates forecasts of southern forest conditions (chapter 5). In addition, land use and forest forecasts feed additional analyses in the Futures Project, including analyses of timber markets (chapter 9), water (chapter 13), wildlife and biodiversity (chapter 14), and fire (chapter 17).

[1]David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695.

THE CORNERSTONE FUTURES

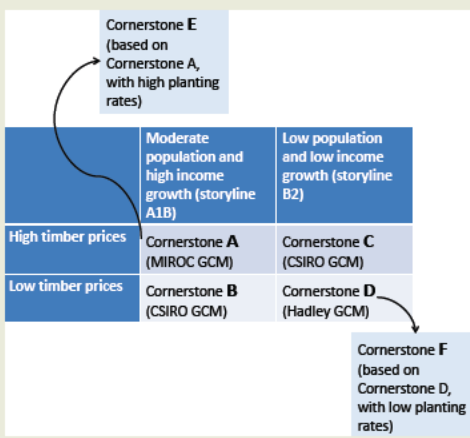
The Southern Forest Futures Project uses six Cornerstone Futures (labeled with letters A to F) to provide alternative scenarios about the future of several exogenous variables. These are based on projections of county-level population, income, and emissions-driven climate changes that were developed for the national assessment conducted by the Forest Service, U.S. Department of Agriculture, in accordance with the Resources Planning Act (RPA) and findings by the Intergovernmental Panel on Climate Change, with assumptions added about future timber scarcity and tree planting rates (chapter 2).

Two RPA storylines, labeled A1B and B2, are used for the Cornerstone Futures. B2 provides a lower rate of population growth (a 40 percent increase from 2010 to 2060) and A1B provides a somewhat higher rate of growth (60 percent). Income growth is also higher with A1B. Both of these storylines are connected to detailed global economic/demographic scenarios (USDA Forest Service 2012).

Timber price futures address increasing or decreasing scarcity, with real prices progressing at an orderly rate of 1 percent per year from the 2005 base through 2060. We also hold the real returns to agricultural crops constant throughout the forecasts.

Another element of the storylines embedded in these Cornerstone Futures is the climate forecasting derived from the application of general circulation models to the assumptions of the storylines. However, these climate forecasts do not influence land use changes as modeled here.

The six Cornerstone Futures are displayed below in a diagram that emphasizes their key variables. Cornerstones A through D are defined by the matrix formed by intersecting storylines A1B and B2 with increasing and decreasing timber price futures. Although some new forests may be established through the land use model (afforestation), more substantial forest-type changes are likely to accrue in response to management choices (reforestation). These four Cornerstones use historical tree planting rates following harvests (by State and forest type) to forecast future planting. Two additional alternatives depart from these four either by increasing planting rates for Cornerstone A to produce Cornerstone E, or by decreasing planting rates for Cornerstone D to produce Cornerstone F (chapters 2 and 5).



Cornerstone Scenarios		RPA Storylines					
Tag	Label	Label	Economic Growth	Population Growth	Climate Model	Timber Prices	Planting Rates
A	High growth/high prices	A1B	High	+60%	MIROC	Increasing	Base
B	High growth/low prices	A1B	High	+60%	CSIRO	Decreasing	Base
C	Low growth/high prices	B2	Low	+40%	CSIRO	Increasing	Base
D	Low growth/low prices	B2	Low	+40%	Hadley	Decreasing	Base
E	High growth/high prices/high planting	A1B	High	+60%	MIROC	Increasing	High
F	Low growth/low prices/low planting	B2	Low	+40%	Hadley	Decreasing	Low

METHODS

To forecast land use, we adopt the RPA econometric models developed by Wear (2011) to reflect variations in land use patterns and biophysical capability among the U.S. regions. The land use model for the South addresses all of the 13 States in the Futures Project's analysis area except for central and western Texas and Oklahoma, where results derive from the land use model developed for the Rocky Mountain/Great Plains region.

Each land use model has two major components: changes in county-level population and personal income, which are used to simulate future urbanization; and allocations of rural land among competing uses that are likely to result from predicted urbanization and rural land rents. Output from both components is based on land use data from 1987 and 1997 to ensure that forecasted land use changes are generally consistent with observed urbanization intensities and rural land use changes (Wear 2011).

The land use model for the South is driven by county-level changes in population density, personal income, and timber and crop prices. In comparison, land use change in the Rockies/Great Plains model is sensitive only to changes in population and income, and with changes in rural land uses forecasted to be proportional to their 1997 levels. Because tree planting following harvest does not alter total land use projections, the projections developed in this chapter are limited to Cornerstone Futures A through D (with Cornerstone E having forecasts equivalent to Cornerstone A, and Cornerstone F having forecasts equivalent to Cornerstone D).

DATA SOURCES

Observations of historical land uses were derived from the 1987 and 1997 surveys conducted by National Resources Inventory, which provides the only consistent, repeated, and exhaustive measures of all non-Federal land uses. Uses include pasture, crops, forest, range, or urban uses (which includes both urban and lower density developed areas); they cumulatively define the total "mutable" land for modeling change in the South (table 4.1). Other land use categories—including Federal land, water area, enrolled Conservation Reserve Program lands, and utility corridors—were held constant within the forecasts.

We applied the population and personal income projections for the two RPA storylines (A1B for Cornerstones A and B; B2 for Cornerstones C and D) to drive forecasts of urbanization. The A1B population forecasts are based on 2004 Census projections for the entire country; B2 population forecasts are lower than the Census projections. Zarnoch and others (2010) developed county-level projections for each scenario; their projections are tied to spatial econometric/demographic forecasts (Woods and Poole Economics 2007) that are generally consistent with the A1B projection for 2000 to 2030. County-level projections for A1B were disaggregated by extending 2000–30 patterns of growth from the Woods and Poole projections (Zarnoch and others 2010). Projections for B2 applied the same spatial pattern of population change, but were adjusted to yield county-level projections that added up to the storyline's total (chapter 2).

A1B corresponds to mid-range population growth and the highest per capita disposable personal income level of the RPA storylines (chapter 2). Under this storyline, the South can expect to see about 160 million people and a per capita personal income of around $80,000 (2006 dollars) by 2060. B2 projects a lower population growth and lower personal income, predicting a population of 143 million people with per capita personal income around $60,000 in 2060. A third storyline, A2 was used in the RPA analysis, but was not selected for use in the Forest Futures analysis (chapter 2). A fourth storyline, B1, was not included in either the RPA or the Forest Futures analysis because of data compatibility issues.

Population is not forecasted to grow evenly across the South. Rather, projected growth is concentrated on a number of existing urban centers. In addition, population declines are forecasted for many counties (chapter 2). Population loss is expected to be especially high in the Great Plains portions of Texas and Oklahoma, the Mississippi Alluvial Valley, and southern Alabama and Mississippi.

Timber price projections also vary across the Cornerstone Futures. Cornerstones A and C assume increasing prices while B and D assume decreasing prices. The land use model for the South is sensitive to these changes in prices. Increasing timber prices (relative to crop prices) encourages higher retention of forest land than price decreases. For all the Cornerstone Futures, the price of crops was held constant at current (2006) values.

RESULTS

Percent coverage of the five land uses for non-Federal land (table 4.1) in 1997 are individually shown at the county level in figure 4.1 and are compared for the region as a whole in figure 4.2. Patterns of rural uses reflect biome boundaries and differences in productivity that are in turn affected by biophysical conditions. Figure 4.1 shows that forest uses are predominant across much of the South, cropland is concentrated in the Mississippi Valley and in northwest Texas (with areas of moderate concentration in the upper Atlantic Coastal Plain and along the Gulf of Mexico in Texas and Louisiana), range is concentrated in the High Plains area

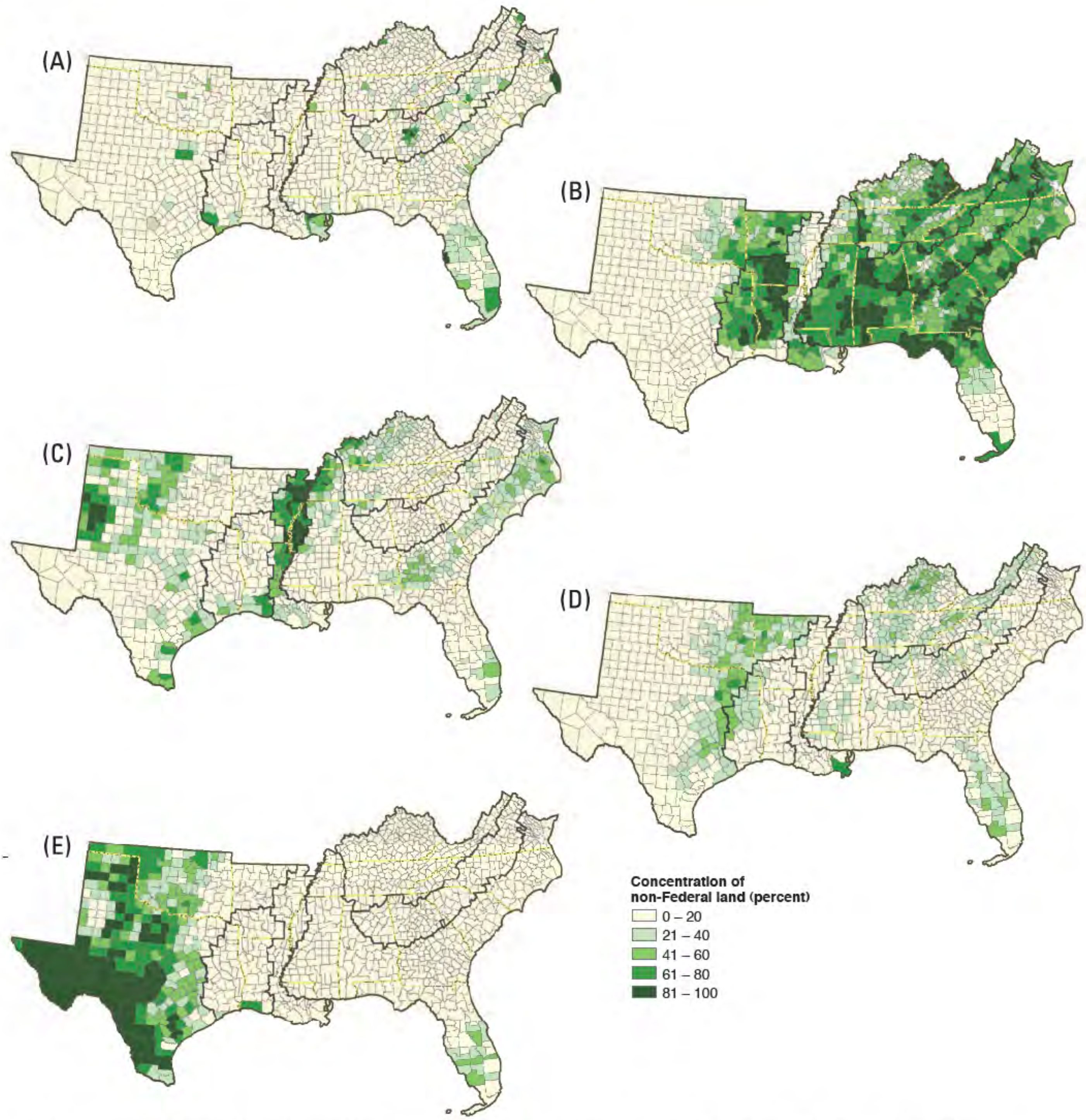


Figure 4.1—Concentration of non-Federal land in (A) urban, (B) forest, (C) crop, (D) pasture, and (E) rangeland uses, 1997. (Source: National Resource Inventory)

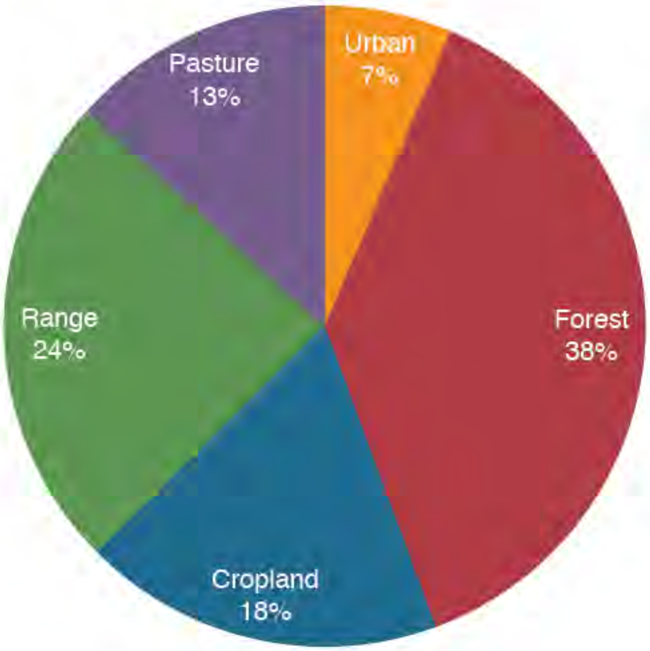


Figure 4.2—Distributions of non-Federal land uses in the South, 1997 (reflecting the National Resource Inventory definition of mutable land base for total land in the South).

of West Texas, and pasture is sparse across the South (with the exception of the Cross Timbers area of eastern Texas and Oklahoma, the Cumberland Plateau, and the Blue Ridge Mountains).

Figure 4.1 also shows that Dallas, Houston, Miami, and Atlanta are the most densely developed urban areas in the South; and that the Southern Appalachian Piedmont and Peninsular Florida are experiencing broad areas of moderate urban density. The county-level scaling of these maps masks the distribution of small urban areas in large counties and suburban and exurban sprawl into some counties adjacent to metropolitan areas.

Land use forecasts indicate a range of results for the various Cornerstone Futures (fig. 4.3). Urbanization adds between 29 million and 42 million acres of developed uses by 2060, with losses of varying degrees accruing for all other land uses. The Cornerstone Futures are in general agreement about predicted changes for range and pasture use but not for cropland and forest area. Predicted losses range from about 11 million acres (-6.5 percent) to about 22 million acres (-13.1 percent) for forest uses, and from about 5 million acres (-6 percent) to about 16 million acres (-19 percent) for cropland uses (fig. 4.4). In the following sections, we examine these changes in detail, organized by land use category.

Urban Land Uses

By model construction, urban forecasts are driven exclusively by population and income forecasts and are not influenced by the future trajectory of timber or agricultural prices. Cornerstones A and B (with the A1B storyline) have the same higher rates of income growth and population growth. The result is an expansion in urban uses of about 43 million acres (about 143 percent) by 2060 from the 1997 base of about 30 million acres (table 4.2 and fig. 4.5). Cornerstones C and D (with the B2 storyline) have lower rates of income growth and population growth, with a resulting gain in urban uses of about 30 million acres (98 percent) over this same time period (table 4.3).

Urbanization is highest in areas experiencing the highest population growth (chapter 2); for the South, this growth is at the periphery of urban centers (fig. 4.6). For Cornerstones C and D, gains in urban uses are widespread with the exception of the few areas expected to experience population declines (such as the Mississippi Alluvial Valley and southwestern Alabama). For Cornerstones A and B (fig. 4.7), urbanization spreads out across an even broader area, highlighting its dependence on increases in income.

The amount of urban growth varies across the South's five subregions (fig. 4.8 and table 4.2 for Cornerstones A and B; table 4.3 for Cornerstones C and D). Under Cornerstones A and B, almost 18 million of the 43 million acres of additional urban area is on the Coastal Plain. The Piedmont and Mid-South add about 9 million acres each, the Appalachian-Cumberland adds about 7 million acres, and the Mississippi Alluvial Valley is last with a comparatively small increase. The Appalachian-Cumberland has the highest growth rate, adding about 175 percent to its relatively small 1997 urban base; fastest growing sections are in central-northern Kentucky (an area bordered by Lexington, Louisville, and Cincinnati, OH) and in areas around Nashville and Knoxville in Tennessee. Growth rates for the other four subregions range from 125 to 140 percent.

Forest Land Uses

Unlike urban land uses, forest-land use forecasts for the South depend on timber prices as well as the more dominant population- and income-growth drivers of urbanization. All Cornerstone Futures predict losses, but the degree of loss is variable. The greatest loss is projected to be 23 million acres (13 percent) by 2060 for Cornerstone B, which is based on high economic growth (storyline A1B) and declining timber prices (fig. 4.9). At the other end of the spectrum is a projected loss of about 11 million acres (7 percent) for Cornerstone C, which is based on low economic growth

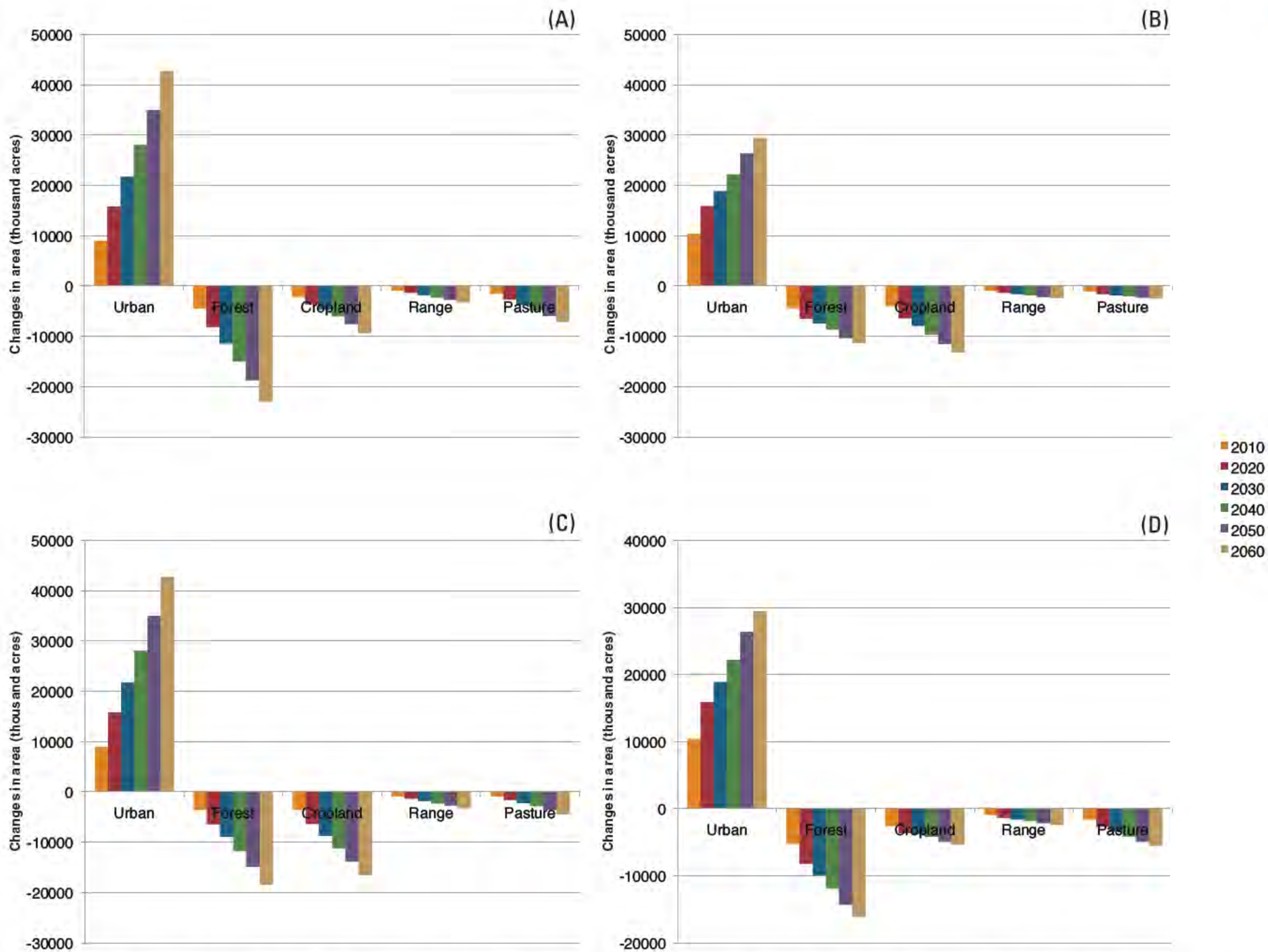


Figure 4.3—Changes in urban, forest, cropland, range, and pasture land uses for each of four Cornerstone Futures: (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

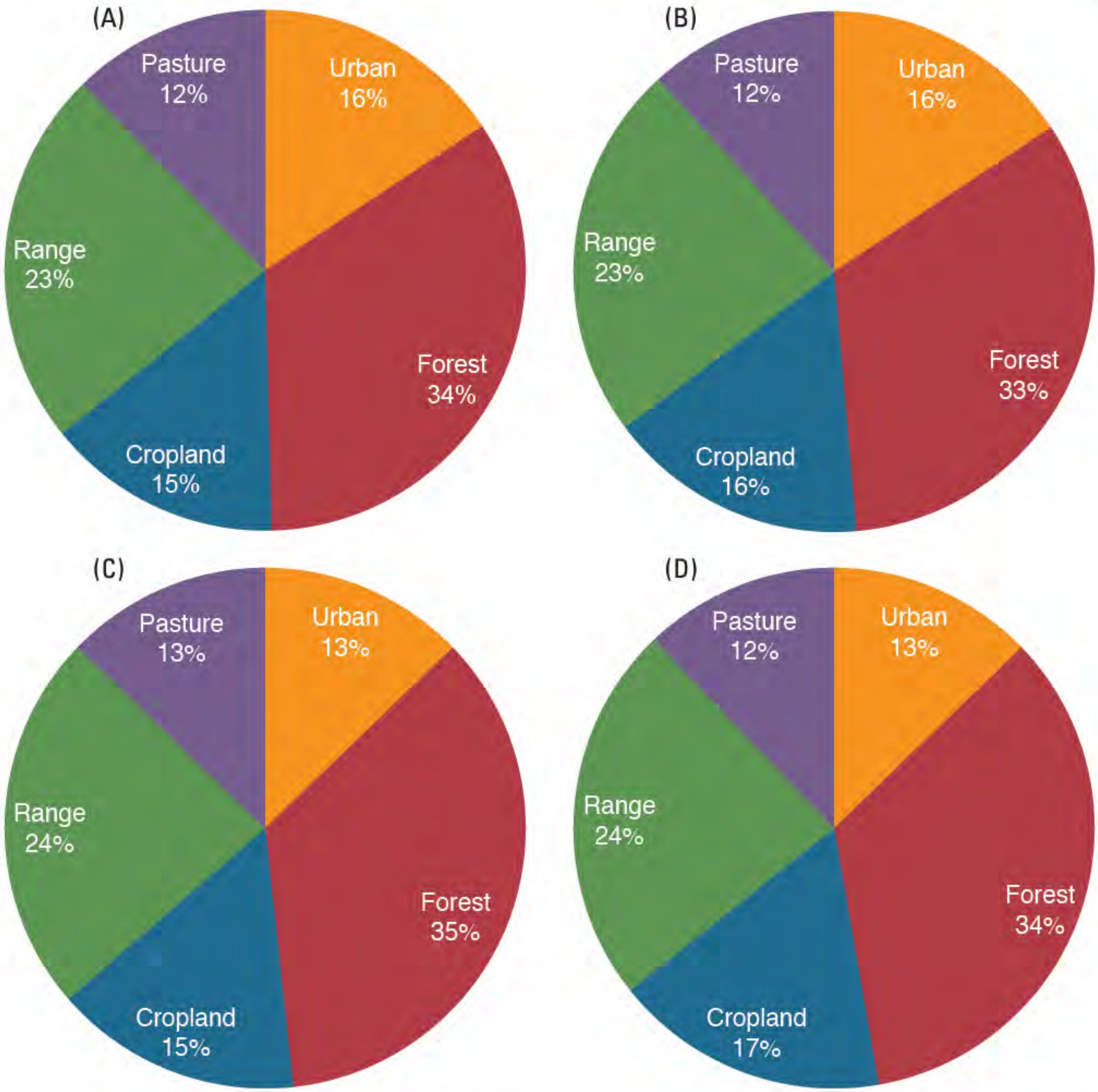


Figure 4.4—Forecasted distributions of non-Federal land use, 2060, for four Cornerstone Futures: (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

Table 4.1—Land use definitions from the National Resources Inventory survey

Forest land A land cover/use that is at least 10 percent stocked by single stemmed forest trees of any size that will be at least 4 m (13 feet) tall at maturity. When viewed vertically, canopy cover is 25 percent or greater. Also included are areas bearing evidence of natural regeneration of tree cover (cutover forest or abandoned farmland) and not currently developed for nonforest use. For classification as forest land, an area must be at least 1 acre and 100 feet wide.
Cropland A land cover/use category that includes areas used for the production of adapted crops for harvest. Two subcategories of cropland are recognized: cultivated and noncultivated. Cultivated cropland comprises land in row crops or close-grown crops and also other cultivated cropland, for example, hayland or pastureland that is in a rotation with row or close-grown crops. Noncultivated cropland includes permanent hayland and horticultural cropland.
Rangeland A land cover/use category on which the climax or potential plant cover is composed principally of native grasses, grasslike plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and such practices as deferred grazing, burning, chaining, and rotational grazing are used, with little or no chemicals or fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper are also included as rangeland.
Urban and built-up areas A land cover/use category consisting of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (< 10 acres) within urban and built-up areas; and highways, railroads, and other transportation facilities if they are surrounded by urban areas. Also included are tracts of < 10 acres that do not meet the above definition but are completely surrounded by urban and built-up land. Two size categories are recognized in the NRI: (1) areas a quarter of an acre to 10 acres, and (2) areas > 10 acres.
Pastureland and native pasture A land cover/use category of land managed primarily for the production of introduced or native forage plants for livestock grazing. Pastureland may consist of a single species in a pure stand, a grass mixture, or a grass-legume mixture. Management usually consists of cultural treatments-fertilization, weed control, reseeding, or renovation and control of grazing. (Includes land that has a vegetative cover of grasses, legumes, and/or forbs, regardless of whether or not it is being grazed by livestock.)

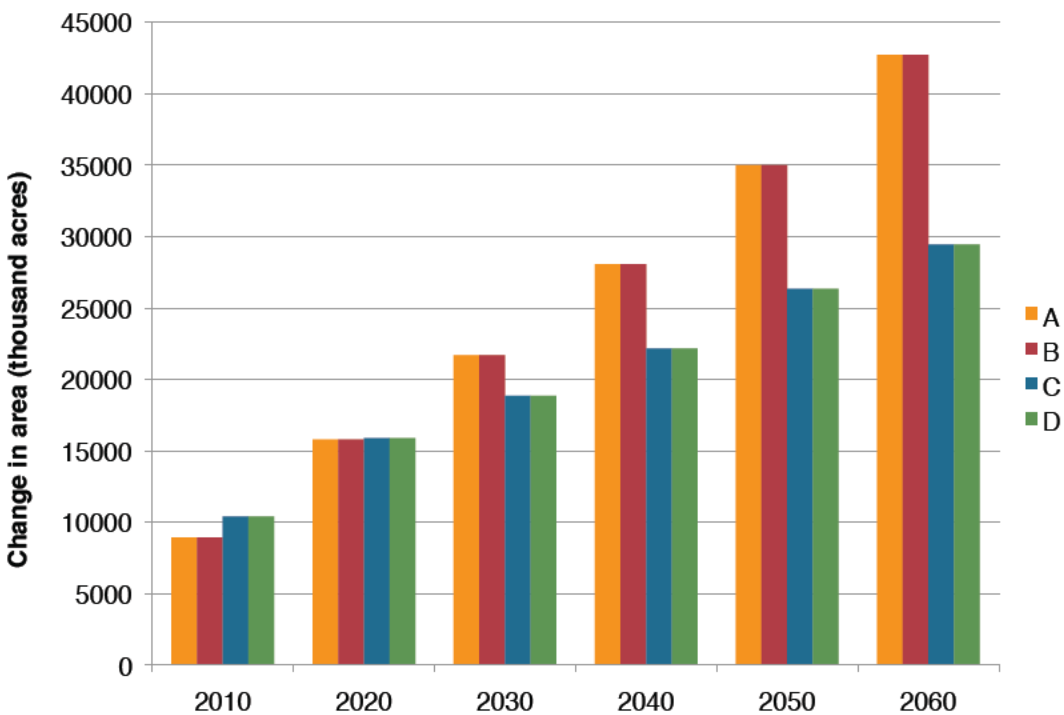


Figure 4.5—Change in urban land uses for the South, 1997 to 2060, under four Cornerstone Futures: (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

Table 4.2—Forecasted area of non-Federal urban land in the South, 1997–2060, based on an expectation of large urbanization gains, either with increasing timber prices (Cornerstone A) or with decreasing timber prices (Cornerstone B)

Subregion	Section	Area in urban use					Change from 1997 to 2060	
		1997	2010	2030	2040	2060	Area	Percent
		thousand acres						
Appalachian-Cumberland	Blue Ridge	682.21	854.25	1,174.81	1,354.33	1,807.49	1,125.28	164.9
	Cumberland Plateau and Mountain	469.55	597.30	846.34	984.75	1,342.71	873.16	186.0
	Interior Low Plateau	1,822.28	2,448.63	3,505.26	4,081.21	5,442.43	3,620.15	198.7
	Northern Ridge and Valley	471.81	542.72	663.96	731.25	908.64	436.83	92.6
	Southern Ridge and Valley	456.63	571.03	774.03	883.02	1,129.77	673.14	147.4
Total		**3,902.48**	**5,013.92**	**6,964.41**	**8,034.56**	**10,631.03**	**6,728.55**	**172.4**
Coastal Plain	Eastern Atlantic	2,713.76	3,395.82	4,615.85	5,261.60	6,807.01	4,093.25	150.8
	Florida Peninsular	3,348.83	4,471.36	5,571.94	5,945.23	6,652.38	3,303.55	98.6
	Middle Gulf-eastern	1,496.16	1,957.23	2,861.68	3,359.27	4,627.79	3,131.63	209.3
	Middle Gulf-western	726.64	928.79	1,321.43	1,539.08	2,110.12	1,383.48	190.4
	Northern Atlantic	904.00	1,174.00	1,653.72	1,899.70	2,459.74	1,555.74	172.1
	Southern Gulf	1,663.88	2,085.55	2,907.67	3,349.93	4,426.32	2,762.44	166.0
	Western Gulf	1,624.49	2,000.27	2,471.46	2,672.09	3,135.43	1,510.94	93.0
Total		**12,477.77**	**16,013.02**	**21,403.75**	**24,026.90**	**30,218.79**	**17,741.02**	**142.2**
Mid-South	Cross Timbers	3,571.32	4,755.67	5,918.31	6,496.88	7,587.58	4,016.26	112.5
	High Plains	2118.25	2772.43	3572.02	3982.05	4889.5	2,771.25	130.8
	Ozark-Ouachita Highlands	715.10	973.87	1,436.92	1,696.06	2,334.79	1,619.69	226.5
	West Texas Basin and Range	214.99	241.45	279.75	299.04	338.51	123.52	57.5
Total		**6,619.66**	**8,743.41**	**11,206.99**	**12,474.03**	**15,150.38**	**8,530.72**	**128.9**
Mississippi Alluvial Valley	Deltaic Plain	199.17	251.6	341.32	382.6	486.75	287.58	144.4
	Holocene Deposits	508.81	602.30	809.24	928.76	1,252.68	743.87	146.2
Total		**707.98**	**853.90**	**1,150.56**	**1,311.37**	**1,739.44**	**1,031.46**	**145.7**
Piedmont	Central Appalachian Piedmont	2,832.92	3,727.25	4,983.75	5,534.74	6,747.92	3,915.00	138.2
	Piedmont Ridge, Valley and Plateau	850.14	1,049.91	1,407.31	1,601.26	2,073.66	1,223.52	143.9
	Southern Appalachian Piedmont	2,488.36	3,420.82	4,455.83	4,958.51	6,030.92	3,542.56	142.4
Total		**6,171.41**	**8,197.98**	**10,846.90**	**12,094.50**	**14,852.49**	**8,681.08**	**140.7**
Grand total		**29,879.31**	**38,822.24**	**51,572.62**	**57,941.36**	**72,592.12**	**42,712.81**	**143.0**

Table 4.3—Forecasted area of non-Federal urban land in the South, 1997–2060, based on an expectation of moderate urbanization gains, either with increasing timber prices (Cornerstone C) or with decreasing timber prices (Cornerstone D)

		Area in urban use					Change from 1997 to 2060	
Subregion	**Section**	**1997**	**2010**	**2030**	**2040**	**2060**	**Area**	**Percent**
		thousand acres						
Appalachian-Cumberland	Blue Ridge	682.21	898.84	1,025.97	1,194.22	1,416.45	734.24	107.6
	Cumberland Plateau and Mountain	469.55	638.36	732.81	841.36	1,001.51	531.96	113.3
	Interior Low Plateau	1,822.28	2,562.29	2,997.70	3,544.79	4,215.44	2,393.16	131.3
	Northern Ridge and Valley	471.81	567.09	610.38	655.86	726.44	254.63	54.0
	Southern Ridge and Valley	456.63	586.29	673.38	782.91	907.15	450.52	98.7
Total		**3,902.48**	**5,252.87**	**6,040.25**	**7,019.13**	**8,266.99**	**4,364.51**	**111.8**
Coastal Plain	Eastern Atlantic	2,713.76	3,566.44	4,055.23	4,646.96	5,388.98	2,675.22	98.6
	Florida Peninsular	3,348.83	4,516.60	5,188.72	5,683.24	6,137.52	2,788.69	83.3
	Middle Gulf-eastern	1,496.16	2,110.54	2,452.39	2,845.60	3,401.49	1,905.33	127.3
	Middle Gulf-western	726.64	1,008.53	1,148.20	1,293.60	1,519.92	793.28	109.2
	Northern Atlantic	904.00	1,249.91	1,444.74	1,659.98	1,932.15	1,028.15	113.7
	Southern Gulf	1,663.88	2,199.30	2,529.40	2,935.69	3,449.93	1,786.05	107.3
	Western Gulf	1,624.49	2,049.65	2,248.00	2,471.10	2,704.67	1,080.18	66.5
Total		**12,477.77**	**16,700.97**	**19,066.68**	**21,536.17**	**24,534.67**	**12,056.90**	**96.6**
Mid-South	Cross Timbers	3,571.32	4,802.41	5,358.32	6,043.35	6,742.91	3,171.59	88.8
	High Plains	2118.25	2836.53	3183.58	3628	4092.01	1,973.76	93.2
	Ozark-Ouachita Highlands	715.10	1,026.17	1,216.15	1,467.04	1,792.84	1,077.74	150.7
	West Texas Basin and Range	214.99	244.78	261.44	283.21	302.64	87.65	40.8
Total		**6,619.66**	**8,909.89**	**10,019.49**	**11,421.60**	**12,930.40**	**6,310.74**	**95.3**
Mississippi Alluvial Valley	Deltaic Plain	199.17	264.48	306.72	338.02	382.89	183.72	92.2
	Holocene Deposits	508.81	643.92	713.95	780.48	897.83	389.02	76.5
Total		**707.98**	**908.40**	**1,020.67**	**1,118.50**	**1,280.72**	**572.74**	**80.9**
Piedmont	Central Appalachian Piedmont	2,832.92	3,862.19	4,402.23	5,029.05	5,642.96	2,810.04	99.2
	Piedmont Ridge, Valley, and Plateau	850.14	1,095.03	1,239.98	1,417.97	1,647.41	797.27	93.8
	Southern Appalachian Piedmont	2,488.36	3,558.85	3,978.52	4,500.33	5,015.03	2,526.67	101.5
Total		**6,171.41**	**8,516.07**	**9,620.74**	**10,947.35**	**12,305.40**	**6,133.99**	**99.4**
Grand total		**29,879.31**	**40,288.20**	**45,767.82**	**52,042.75**	**59,318.19**	**29,438.88**	**98.5**

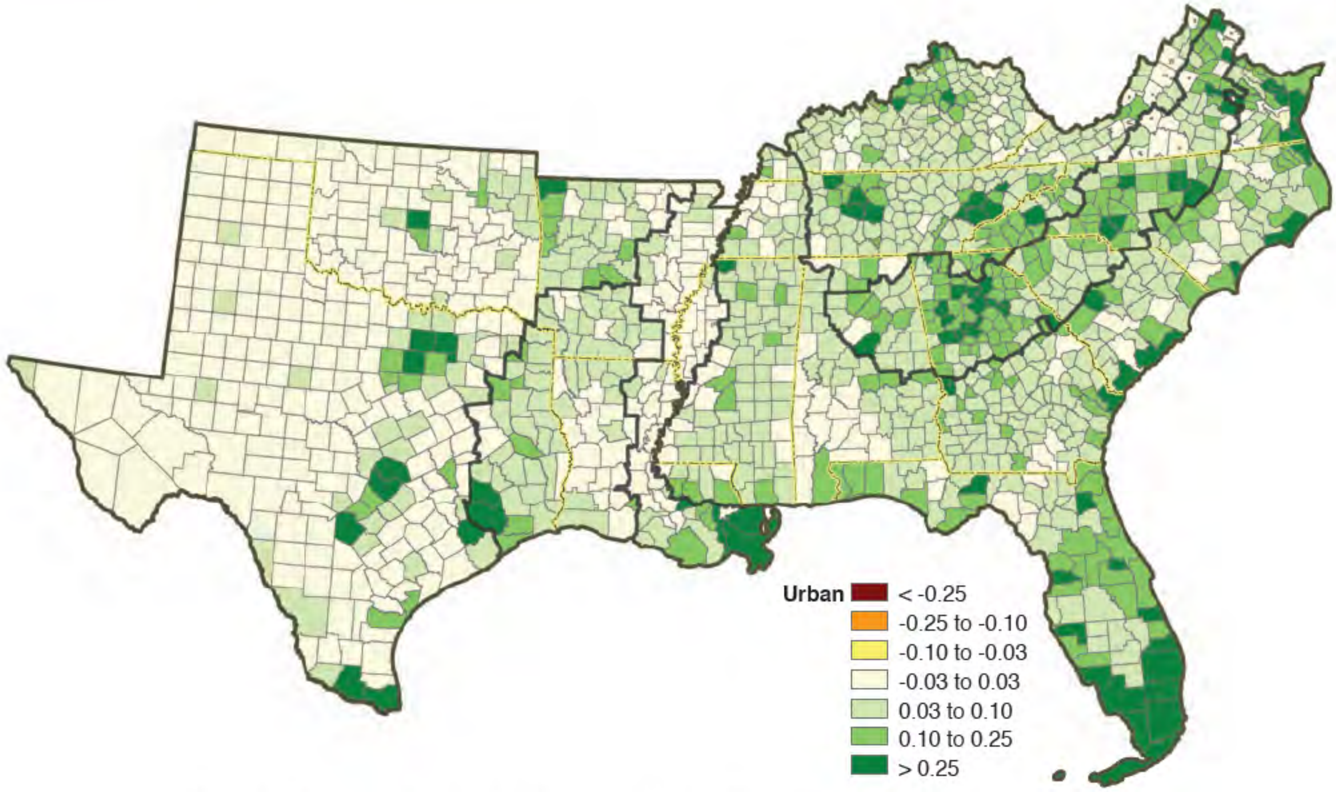


Figure 4.6—Percentage change in urban land uses, 1997 to 2060, based on an expectation of moderate urbanization gains with increasing timber prices (Cornerstone C).

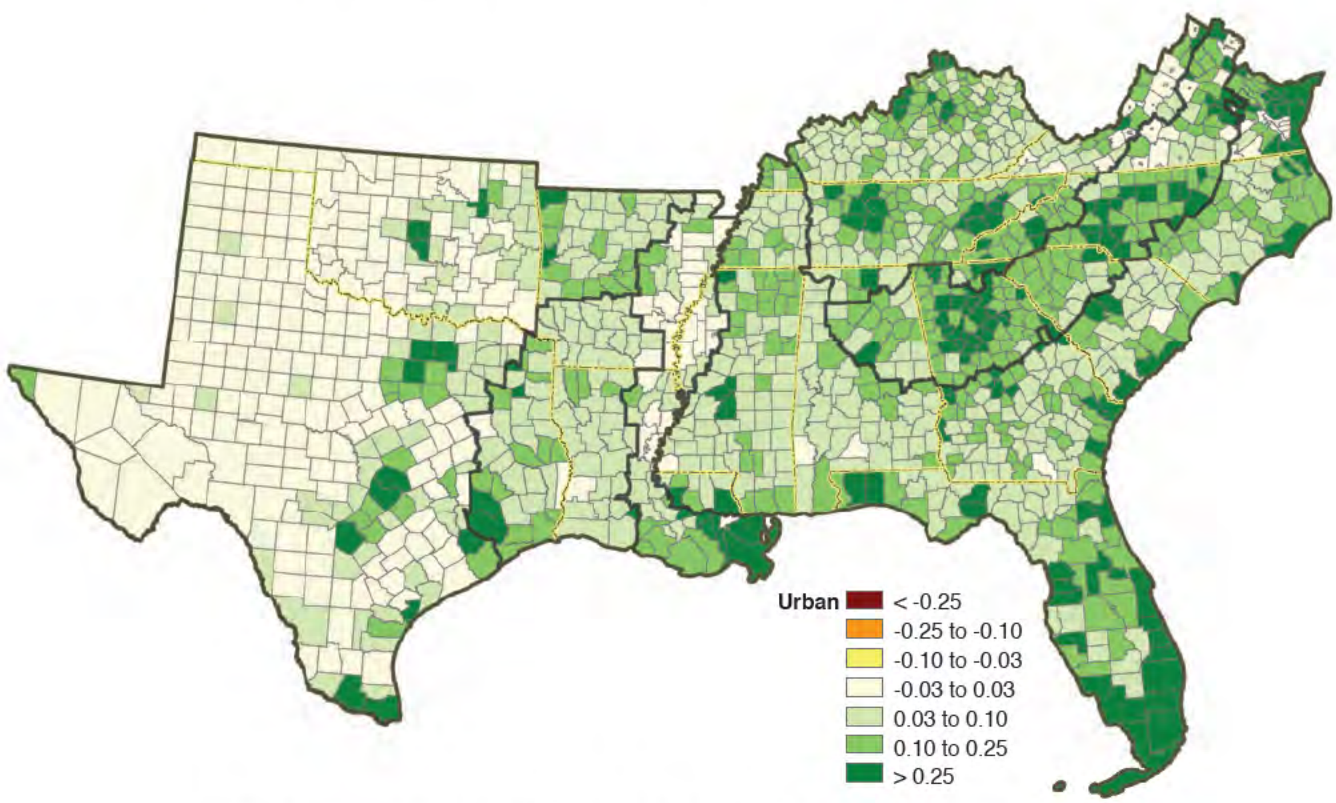


Figure 4.7—Percentage change in urban land uses, 1997 to 2060, based on an expectation of large urbanization gains with increasing timber prices (Cornerstone A).

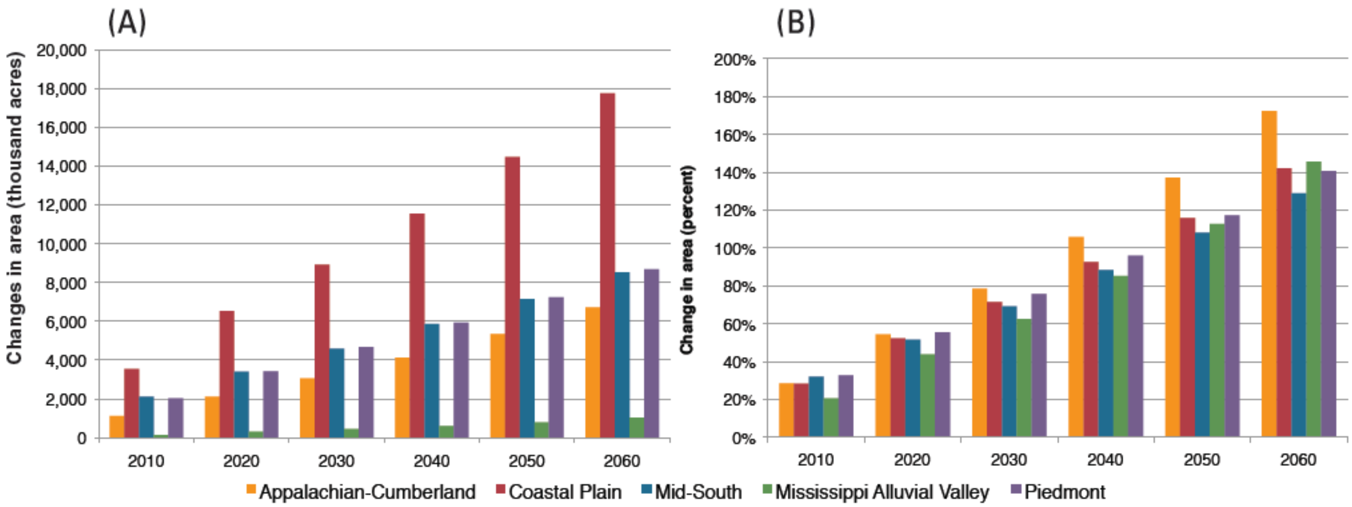


Figure 4.8—Cumulative change in urban area by southern subregion from 1997 to 2060 by decade, expressed in (A) acres and (B) percent; based on an expectation of large urbanization gains, either with increasing timber prices (Cornerstone A) or with decreasing timber prices (Cornerstone B).

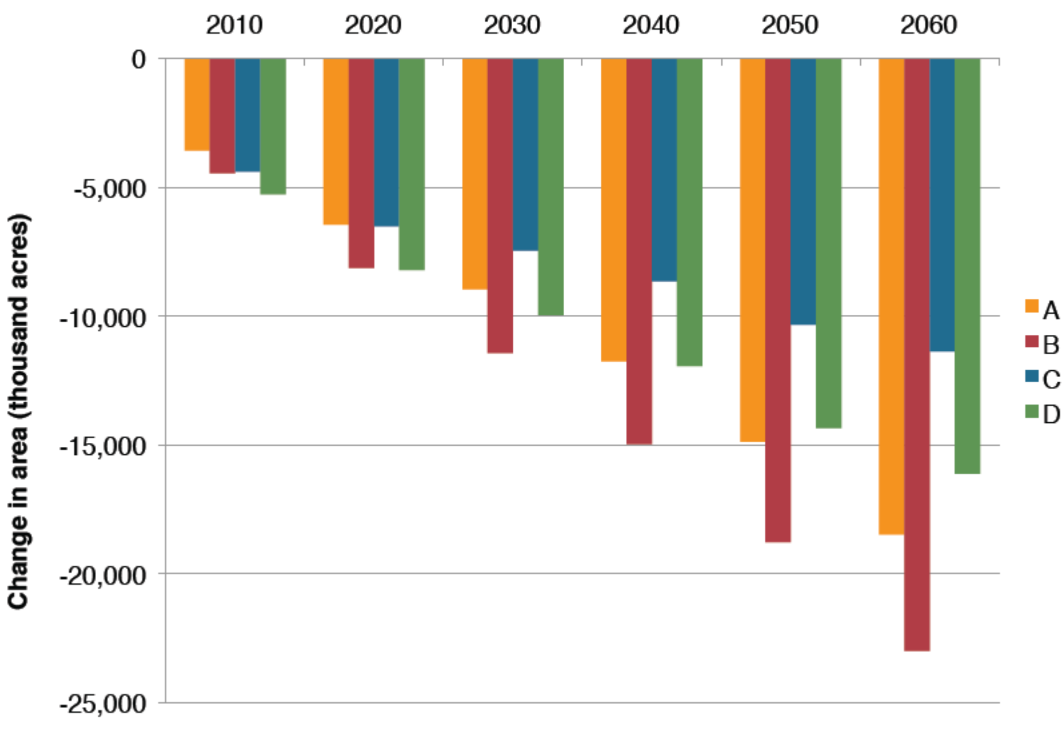


Figure 4.9—Cumulative change in forest land uses by southern subregion from 1997 to 2060 by decade, expressed in (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

(storyline B2) and increasing timber prices. Comparing forecasts for Cornerstones A and B with those for Cornerstones C and D shows a 5-million acre difference between a future of increasing timber prices and a future of decreasing prices, confirming that the effects of the economic/population storyline dominate the effects of timber prices.

Forest losses are especially high in a few areas of the South (tables 4.4 and 4.5). For all Cornerstone Futures, losses are concentrated in the Piedmont from northern Georgia through North Carolina and into parts of Virginia, as figure 4.10 shows for Cornerstone C (selected because it is bracketed by the other Cornerstones). Other areas of concentrated forest losses are on the Atlantic Coast, along the Gulf of Mexico, and in parts of eastern Texas outside of Houston. The income-fueled development in Cornerstones A and B spreads low-intensity forest losses across a broader area (fig. 4.11).

Under Cornerstone B, forest losses are highest in the Coastal Plain, at about 12 million acres by 2060, and lowest in the Mississippi Alluvial Valley and the Mid-South (fig. 4.12). Percentage losses are greatest in the Piedmont, where 21 percent of existing forests would be lost, followed by an Appalachian-Cumberland loss of 13 percent and a Coastal Plain loss of about 11 percent.

Figures 4.10 and 4.11 show changes in the percentage of each county that is in forest cover to enable ready comparisons across counties of variable size. If instead we examine the percentage change in forest, then different information is conveyed. Figure 4.13 shows the percentage change in forest uses for Cornerstone C, where economic growth is low (storyline B2) but timber prices are increasing, to highlight areas where slight gains in forest are forecast in response to increasing timber prices (and stable crop prices)—most notably in central-western Kentucky and the Lower Mississippi Alluvial Valley. It also shows where the percentage loss of forests would be highest, with highest acreage losses generally at the periphery of urban areas such as the ring around Atlanta (fig. 4.10), and highest percentage losses at the core of these urban areas (fig. 4.13). This means that the percentage forest loss is highest where current populations is highest and where we might expect the aesthetic, recreational, and microclimate (cooling) services of forests to be most needed.

Figure 4.14 displays the loss of forest land by 2060 under Cornerstone B for each of the sections that comprise the South's five subregions. All sections are forecasted to lose forests, with the highest loss (about 34 percent) expected for Peninsular Florida. The Deltaic Plain at the mouth of the Mississippi River is forecasted to lose about 25 percent, but this is from a very small 1997 base. All three sections in the Piedmont—Central Appalachian Piedmont, Piedmont Ridge Valley and Plateau, and Southern Appalachian Piedmont—would lose between 19 and 24 percent of their forest area.

Cropland Uses

As with forest area, the change in cropland area depends on the economic conditions defined by each alternative future. However unlike forest area, which is dominated by urbanization patterns (driven by the A1B storyline), cropland change is more heavily influenced by the timber price futures. Losses range from about 16 million under Cornerstone A's high economic growth (A1B) with increasing timber prices, to only about 5 million acres under Cornerstone D's lower economic growth (B2) with decreasing timber prices (fig. 4.15). The difference in crop loss between storylines A1B and B2 (holding price futures constant) is about 3 million acres. The difference between increasing and decreasing price futures (holding storylines constant) is about 8 million acres.

Cornerstone D, which predicts the lowest levels of cropland loss, shows especially high levels in North Carolina, southern Florida, central Kentucky and Tennessee, and the area in Texas bordered by Dallas, Houston, and Austin (fig. 4.16). Cornerstone A, where crop losses are highest (fig. 4.17), shows losses that are spread across broader areas of North Carolina, Tennessee, and Kentucky; and additional losses in southeastern Georgia and the coastal areas of Texas and Louisiana. Among the five southern subregions, the highest percentage loss of cropland is in the Piedmont (28 percent under Cornerstone B and 51 percent under Cornerstone A), followed by large Coastal Plain and Appalachian-Cumberland areas (figs. 4.18 and 4.19).

Other Land Uses

Pasture—The pattern of pasture losses across the Cornerstone Futures is similar to the pattern of forest losses. The highest loss is forecasted with Cornerstone B (about 7 million acres), and the lowest is forecast with Cornerstone C (fig. 4.20). Similar to the pattern of cropland forecasts, pasture area change is more heavily affected by timber price projections than by the economic growth forecasts. Pasture losses for all the Cornerstone Futures are concentrated in three broad zones: the first stretching from northern Georgia to northern Kentucky and including a large area of Tennessee, the second in Peninsular Florida, and the third including the Ozark-Ouachita Highlands and the Cross Timbers area of eastern Texas and Oklahoma. There is substantial variation across the five southern subregions. As is the case for forests and crops, the Piedmont has the largest percentage loss, about 25 percent for Cornerstone B (fig. 4.21), followed by Appalachian-Cumberland losses of 15 percent, Coastal Plain losses of 11 percent, and for the Mid-South losses of 9 percent (fig. 4.22).

Table 4.4—Forecasted area of non-Federal forest land in the South, 1997–2060, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B)

Subregion	Section	Area in forest use					Change from 1997 to 2060	
		1997	2010	2020	2040	2060	Area	Percent
		thousand acres						
Appalachian-Cumberland	Blue Ridge	4,312.16	4,192.92	4,077.08	3,847.05	3,536.92	-775.24	-18.0
	Cumberland Plateau and Mountain	8,637.99	8,529.94	8,420.09	8,210.54	7,936.19	-701.80	-8.1
	Interior Low Plateau	10,309.89	10,013.07	9,752.17	9,249.47	8,660.85	-1,649.04	-16.0
	Northern Ridge and Valley	2,823.01	2,784.61	2,748.56	2,680.78	2,588.49	-234.52	-8.3
	Southern Ridge and Valley	1,836.39	1,783.46	1,734.52	1,633.66	1,508.63	-327.76	-17.8
Total		**27,919.43**	**27,304.00**	**26,732.42**	**25,621.50**	**24,231.08**	**-3,688.35**	**-13.2**
Coastal Plain	Eastern Atlantic	23,265.04	22,705.80	22,184.98	21,209.56	20,033.81	-3,231.23	-13.9
	Florida Peninsular	3,604.77	3,229.70	3,004.05	2,674.57	2,379.75	-1,225.02	-34.0
	Middle Gulf-eastern	20,744.52	20,429.34	20,100.35	19,477.49	18,666.28	-2,078.24	-10.0
	Middle Gulf-western	13,700.96	13,555.13	13,404.23	13,118.79	12,727.14	-973.82	-7.1
	Northern Atlantic	6,443.70	6,287.92	6,134.30	5,857.61	5,538.17	-905.53	-14.1
	Southern Gulf	21,693.85	21,342.15	20,987.29	20,314.23	19,479.36	-2,214.49	-10.2
	Western Gulf	9,275.35	9,066.80	8,919.50	8,652.13	8,363.80	-911.55	-9.8
Total		**98,728.19**	**96,616.83**	**94,734.71**	**91,304.38**	**87,188.33**	**-11,539.86**	**-11.7**
Mid-South	Cross Timbers	4,582.04	4,500.57	4,447.78	4,338.32	4,250.32	-331.72	-7.2
	High Plains	116.34	116.19	115.91	115.32	114.48	-1.86	-1.6
	Ozark-Ouachita Highlands	10,355.32	10,216.25	10,086.52	9,826.35	9,486.59	-868.73	-8.4
	West Texas Basin and Range	0	0	0	0	0	0.00	
Total		**15,053.70**	**14,833.01**	**14,650.22**	**14,279.99**	**13,851.39**	**-1,202.31**	**-8.0**
Mississippi Alluvial Valley	Deltaic Plain	707.83	670.05	635.56	587.87	526.93	-180.90	-25.6
	Holocene Deposits	4,869.42	4,821.75	4,773.78	4,684.08	4,573.39	-296.03	-6.1
Total		**5,577.25**	**5,491.80**	**5,409.34**	**5,271.95**	**5,100.32**	**-476.93**	**-8.6**
Piedmont	Central Appalachian Piedmont	12,089.77	11,569.80	11,176.14	10,468.66	9,728.00	-2,361.77	-19.5
	Piedmont Ridge, Valley and Plateau	4,773.56	4,622.42	4,480.43	4,206.27	3,861.46	-912.10	-19.1
	Southern Appalachian Piedmont	11,670.56	10,936.10	10,501.44	9,695.65	8,862.91	-2,807.65	-24.1
Total		**28,533.89**	**27,128.31**	**26,158.00**	**24,370.58**	**22,452.37**	**-6,081.52**	**-21.3**
Grand total		**175,812.46**	**171,373.95**	**167,684.68**	**160,848.40**	**152,823.49**	**-22,988.97**	**-13.1**

Table 4.5—Forecasted area of non-Federal forest land in the South, 1997 to 2060, based on an expectation of moderate urbanization gains and increasing timber prices (Cornerstone C)

		Area in forest use					Change from 1997 to 2060	
Subregion	Section	1997	2010	2020	2040	2060	Area	Percent
		thousand acres						
Appalachian-Cumberland	Blue Ridge	4,312.16	4,182.00	4,109.46	4,016.85	3,883.87	-428.29	-9.9
	Cumberland Plateau and Mountain	8,637.99	8,541.08	8,493.43	8,448.57	8,352.67	-285.32	-3.3
	Interior Low Plateau	10,309.89	10,092.69	9,996.56	9,947.65	9,871.77	-438.12	-4.2
	Northern Ridge and Valley	2,823.01	2,784.17	2,769.88	2,760.96	2,742.38	-80.63	-2.9
	Southern Ridge and Valley	1,836.39	1,782.09	1,745.98	1,703.43	1,653.26	-183.13	-10.0
Total		**27,919.43**	**27,382.03**	**27,115.30**	**26,877.46**	**26,503.95**	**-1,415.48**	**-5.1**
Coastal Plain	Eastern Atlantic	23,265.04	22,712.73	22,422.69	22,129.75	21,740.09	-1,524.95	-6.6
	Florida Peninsular	3,604.77	3,249.81	3,080.31	2,920.72	2,773.70	-831.07	-23.1
	Middle Gulf-eastern	20,744.52	20,448.50	20,310.78	20,221.68	20,054.00	-690.52	-3.3
	Middle Gulf-western	13,700.96	13,531.61	13,452.46	13,380.06	13,250.55	-450.41	-3.3
	Northern Atlantic	6,443.70	6,274.25	6,182.97	6,095.06	5,977.76	-465.94	-7.2
	Southern Gulf	21,693.85	21,349.76	21,155.13	20,956.38	20,688.80	-1,005.05	-4.6
	Western Gulf	9,275.35	9,062.91	8,966.13	8,857.77	8,733.82	-541.53	-5.8
Total		**98,728.19**	**96,629.56**	**95,570.48**	**94,561.42**	**93,218.72**	**-5,509.47**	**-5.6**
Mid-South	Cross Timbers	4,582.04	4,510.84	4,478.97	4,449.96	4,410.01	-172.03	-3.8
	High Plains	116.34	116.14	115.95	115.84	115.57	-0.77	-0.7
	Ozark-Ouachita Highlands	10,355.32	10,215.68	10,135.17	10,037.04	9,900.33	-454.99	-4.4
	West Texas Basin and Range	0	0	0	0	0	0.00	
Total		**15,053.70**	**14,842.66**	**14,730.08**	**14,602.85**	**14,425.92**	**-627.78**	**-4.2**
Mississippi Alluvial Valley	Deltaic Plain	707.83	671.81	650.97	642.87	627.54	-80.29	-11.3
	Holocene Deposits	4,869.42	4,853.69	4,859.30	4,899.07	4,937.64	68.22	1.4
Total		**5,577.25**	**5,525.49**	**5,510.27**	**5,541.93**	**5,565.18**	**-12.07**	**-0.2**
Piedmont	Central Appalachian Piedmont	12,089.77	11,528.27	11,240.68	10,911.87	10,584.00	-1,505.77	-12.5
	Piedmont Ridge, Valley and Plateau	4,773.56	4,617.11	4,528.85	4,432.82	4,296.76	-476.80	-10.0
	Southern Appalachian Piedmont	11,670.56	10,902.33	10,613.07	10,239.61	9,862.29	-1,808.27	-15.5
Total		**28,533.89**	**27,047.72**	**26,382.60**	**25,584.30**	**24,743.05**	**-3,790.84**	**-13.3**
Grand total		**175,812.46**	**171,427.46**	**169,308.73**	**167,167.96**	**164,456.82**	**-11,355.64**	**-6.5**

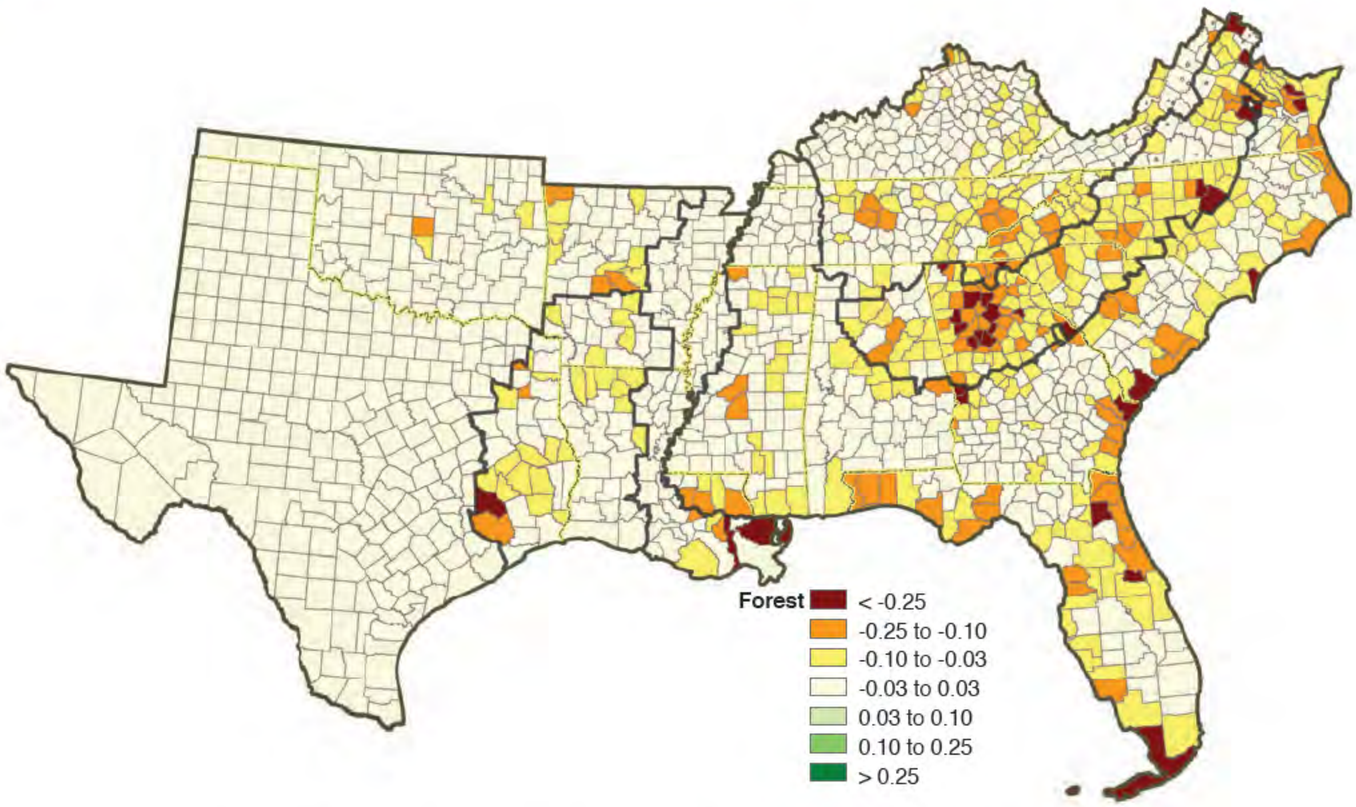


Figure 4.10—Percentage change in forest land uses, 1997 to 2060, based on an expectation of moderate urbanization gains and increasing timber prices (Cornerstone C).

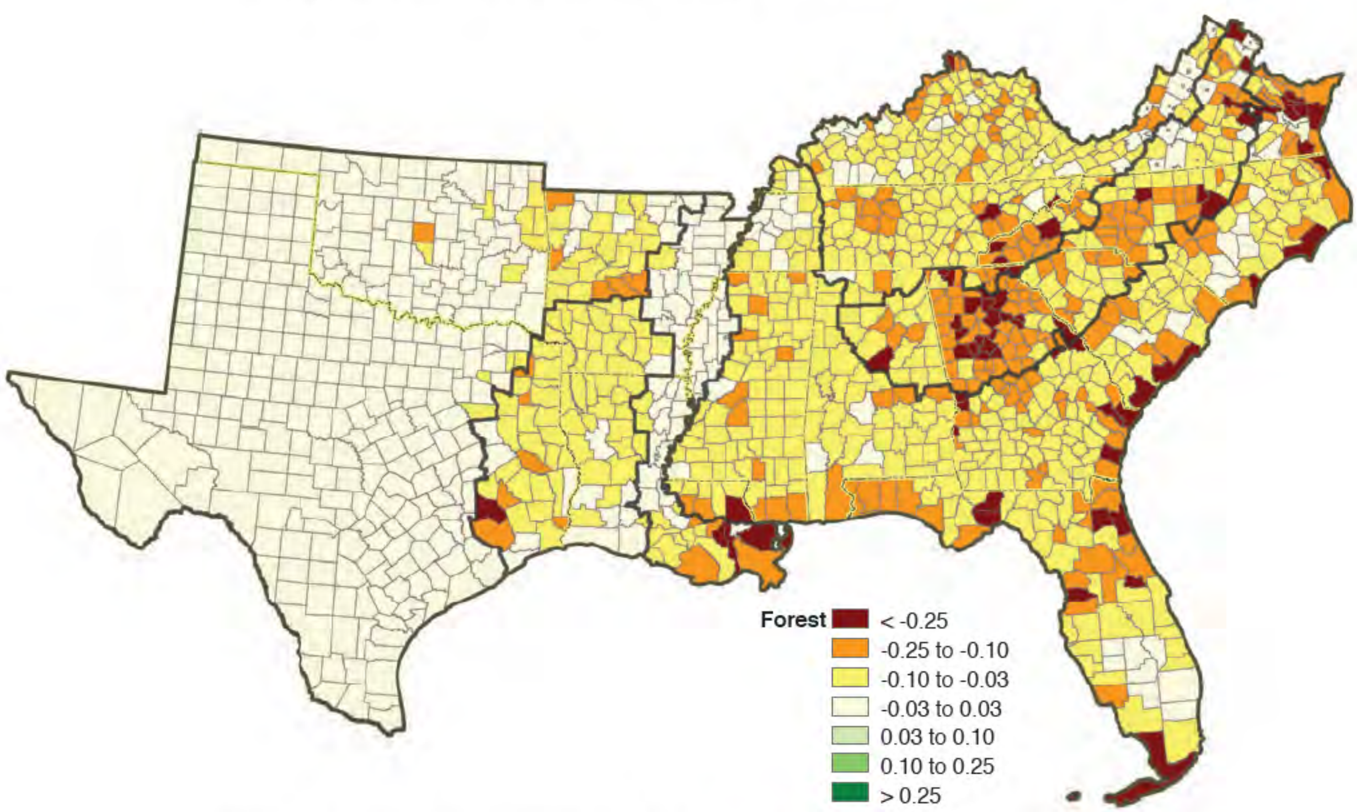


Figure 4.11—Percentage change in forest land uses, 1997 to 2060, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B).

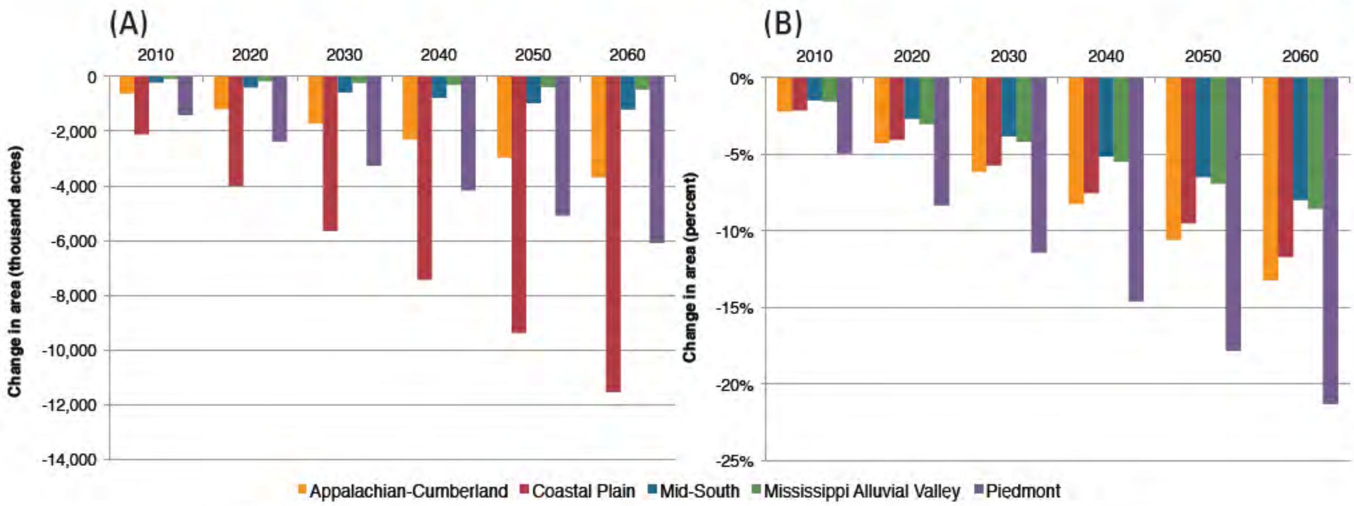


Figure 4.12—Cumulative change in forest area by southern subregion from 1997 to 2060 by decade, expressed in (A) acres and (B) percent; based on an expectation of large urbanization gains with decreasing timber prices (Cornerstone B).

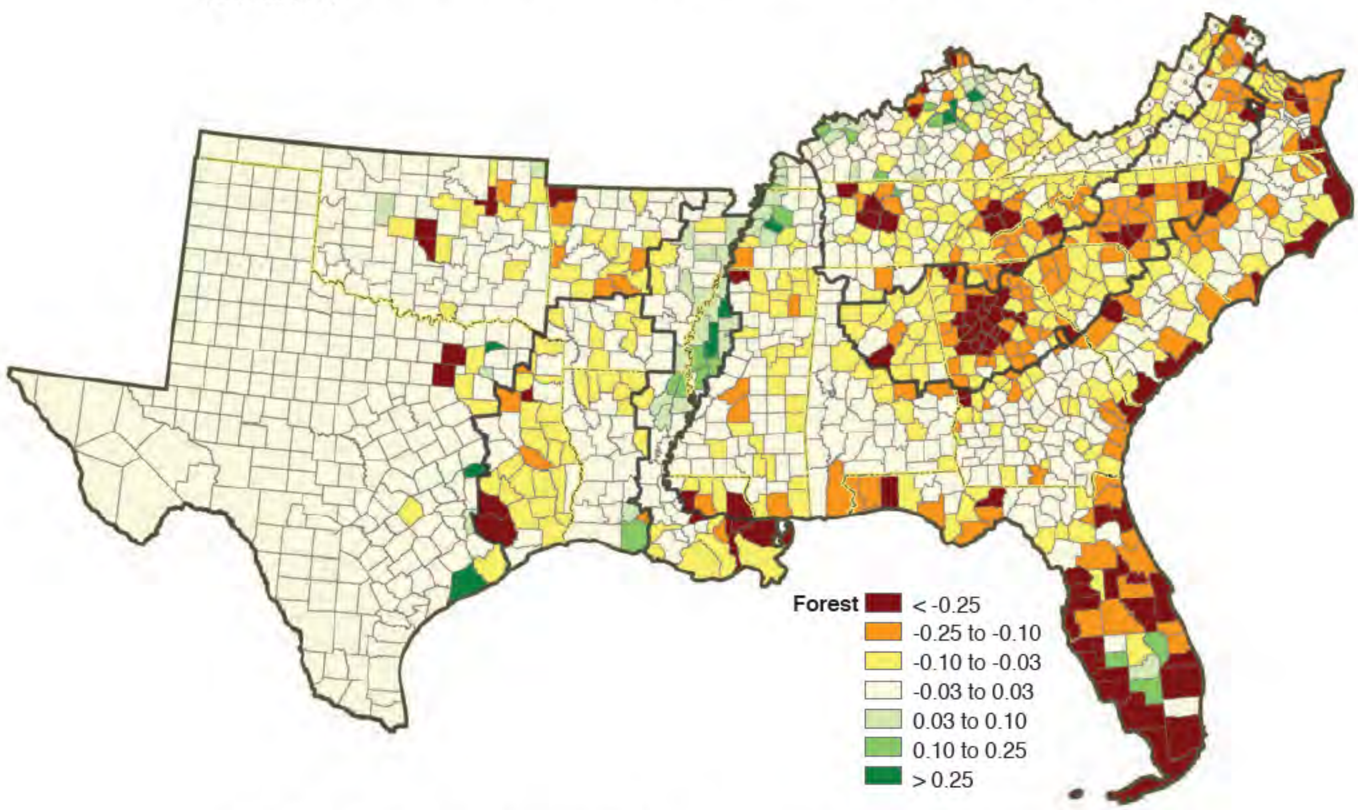


Figure 4.13—Percentage change in forest land uses, 1997 to 2060, based on an expectation of moderate urbanization gains with increasing timber prices (Cornerstone C).

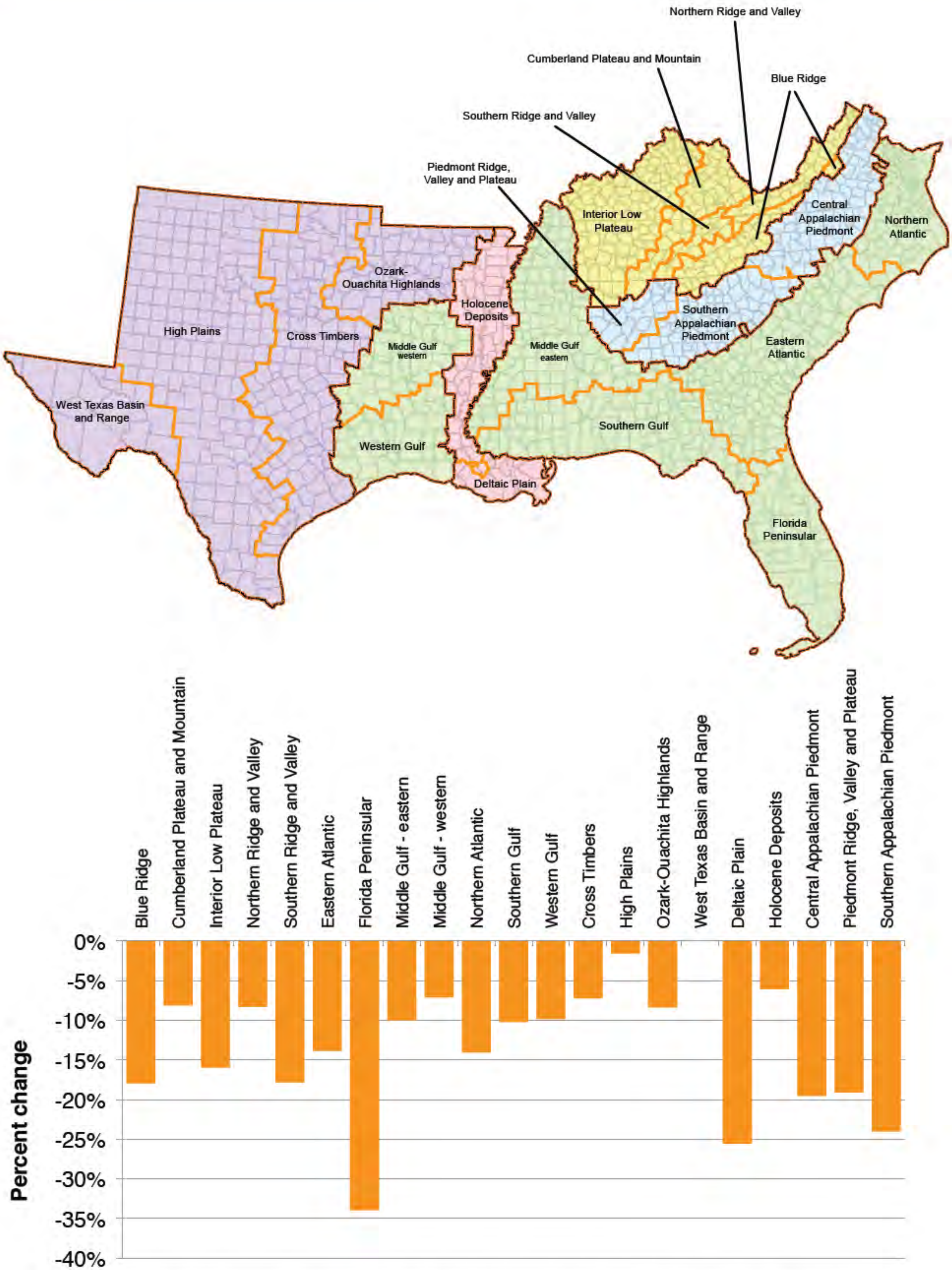


Figure 4.14—Percentage change in forest land uses by southern subregion and section, 1997 to 2060, based on an expectation of large urbanization gains with decreasing timber prices (Cornerstone B).

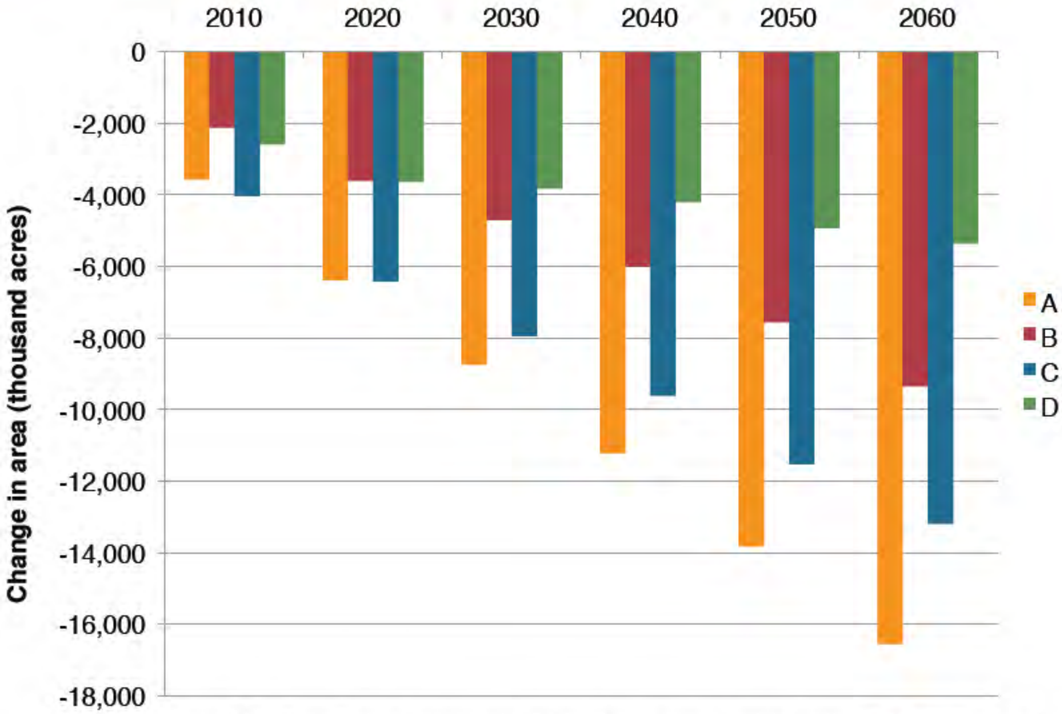


Figure 4.15—Cumulative change in cropland uses by southern subregion from 1997 to 2060 by decade, expressed in (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

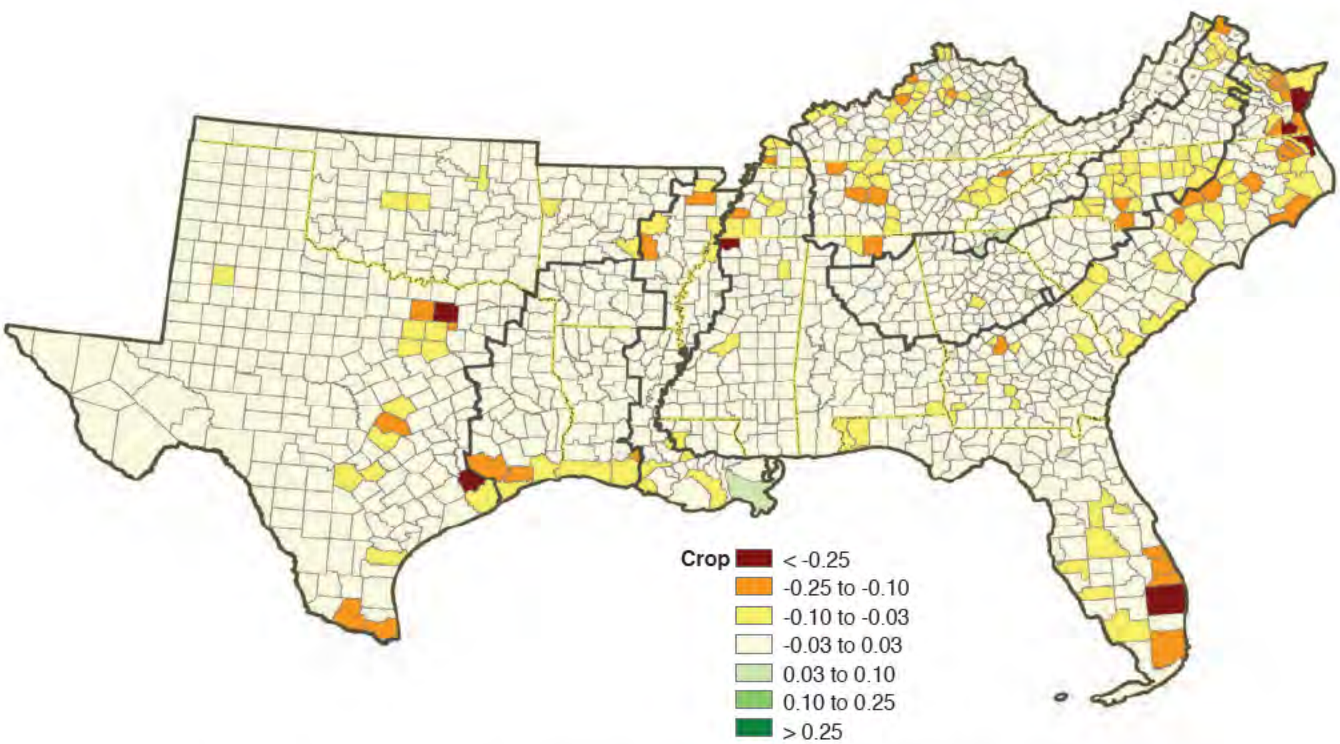


Figure 4.16—Percentage change in cropland uses, 1997 to 2060, based on an expectation of moderate urbanization gains with decreasing timber prices (Cornerstone D).

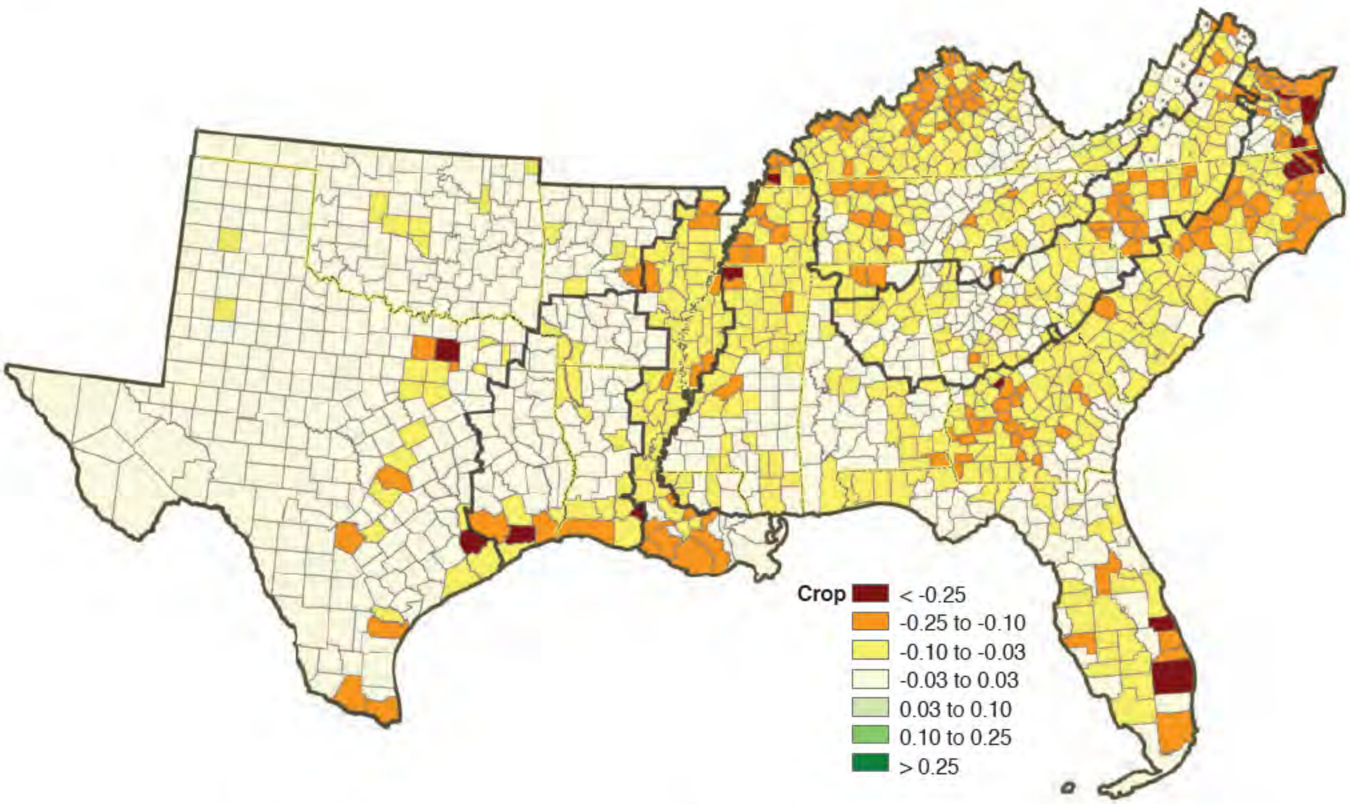


Figure 4.17—Percentage change in cropland uses, 1997 to 2060, based on an expectation of large urbanization gains with increasing timber prices (Cornerstone A).

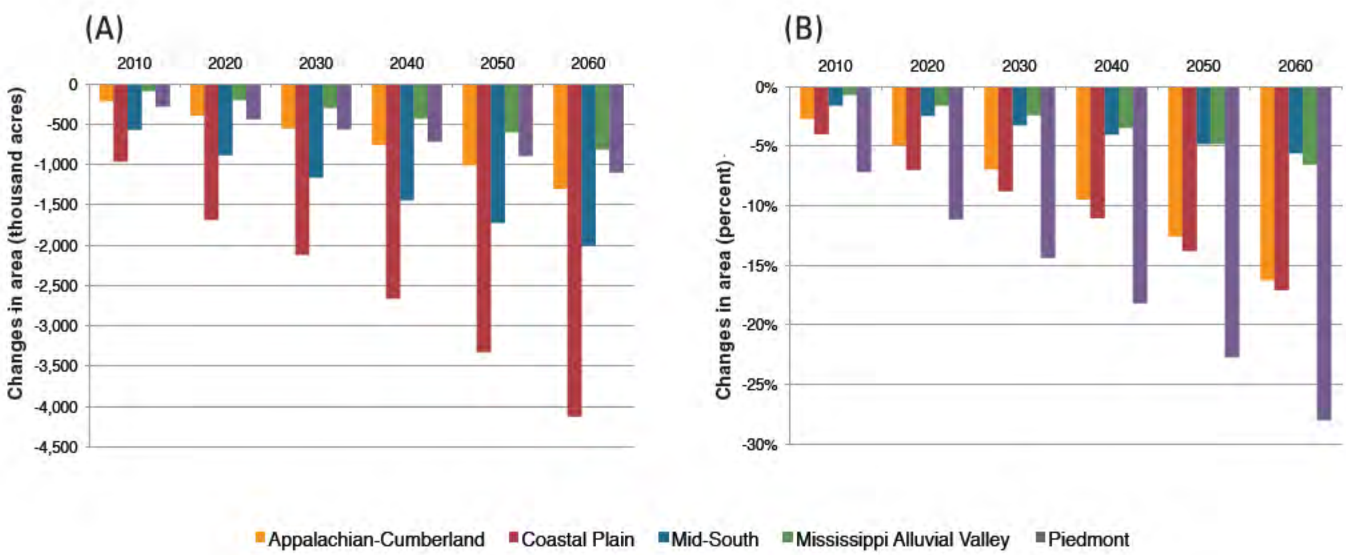


Figure 4.18—Cumulative change in cropland area by southern subregion from 1997 to 2060 by decade, expressed in (A) acres and (B) percent; based on an expectation of large urbanization gains with decreasing timber prices (Cornerstone B).

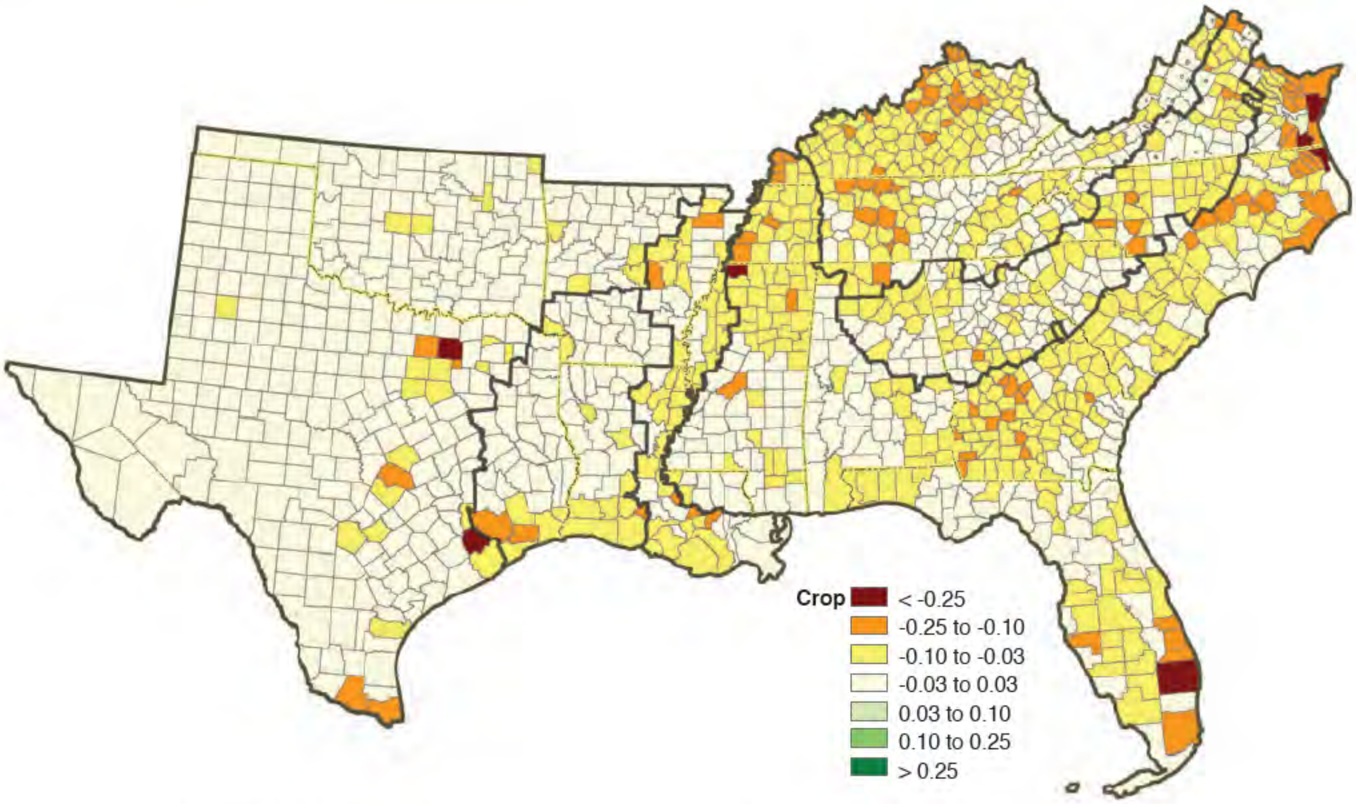


Figure 4.19—Percentage change in cropland uses, 1997 to 2060, based on an expectation of moderate urbanization gains with increasing timber prices (Cornerstone C).

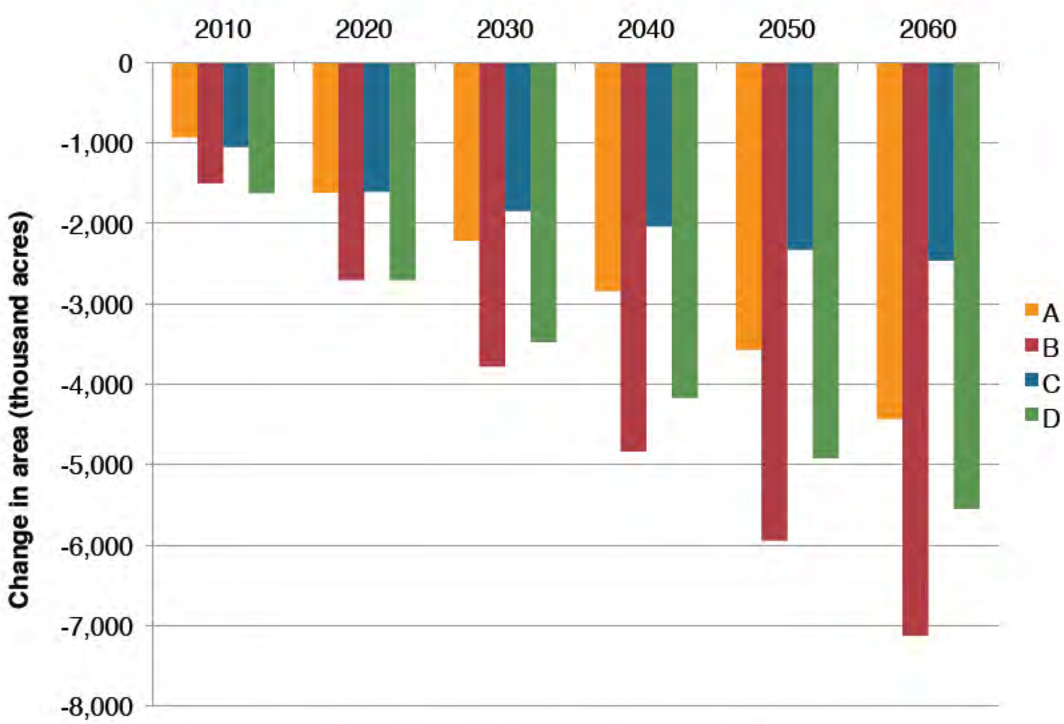


Figure 4.20—Cumulative change in pasture land uses by southern subregion from 1997 to 2060 by decade, expressed in (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

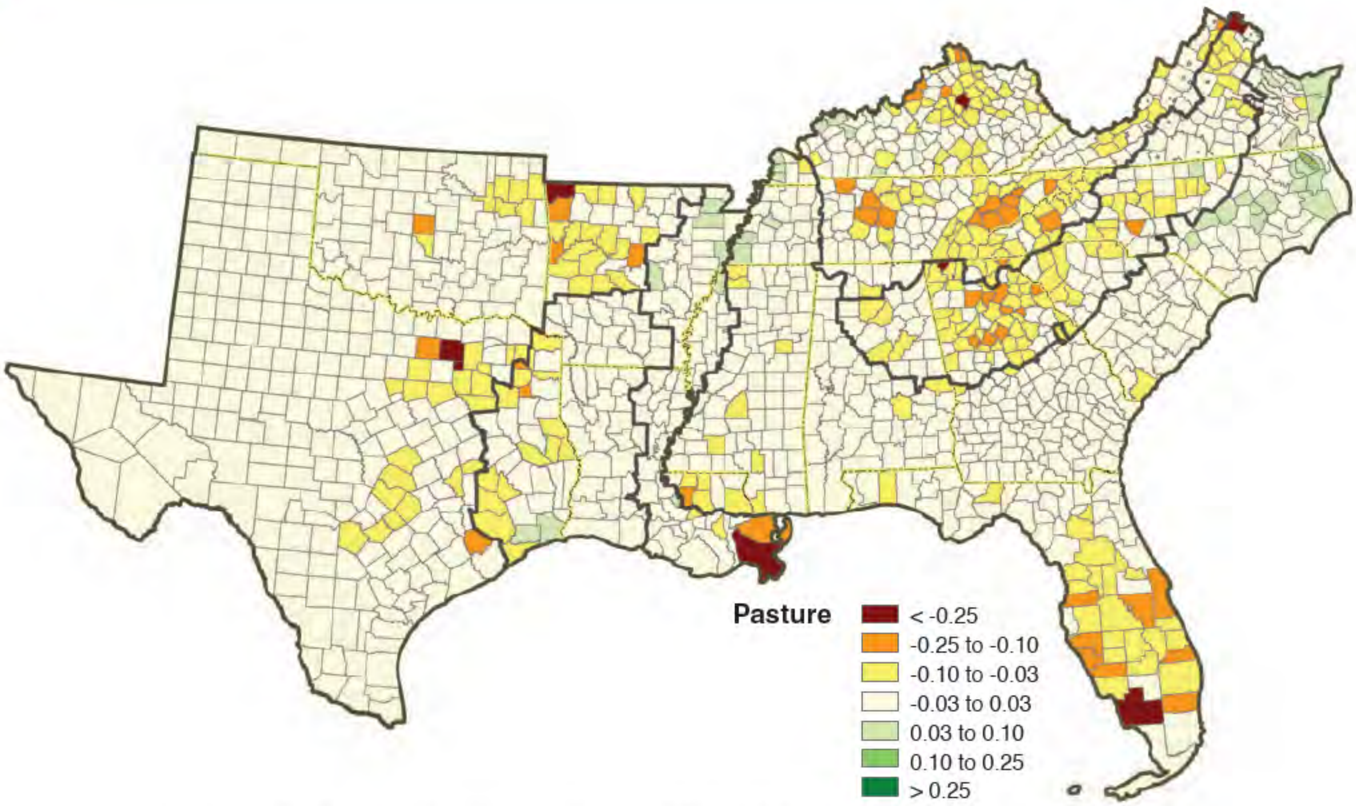


Figure 4.21—Percentage change in pasture land uses, 1997 to 2060, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B).

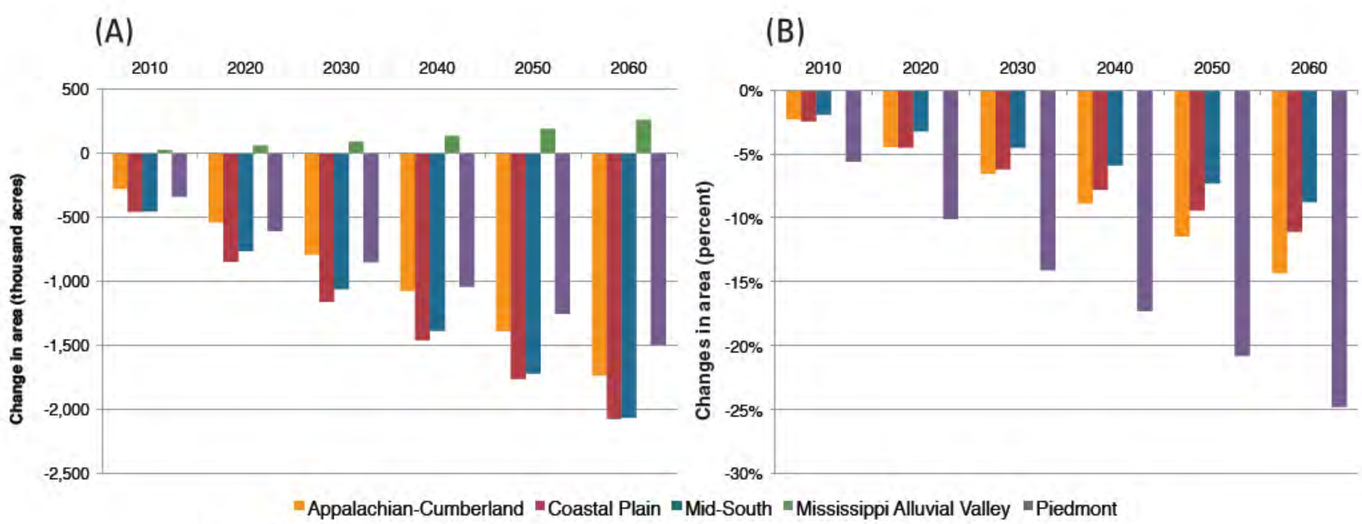


Figure 4.22—Cumulative change in pasture area by southern subregion from 1997 to 2060 by decade, expressed in (A) acres and (B) percent; based on an expectation of large urbanization gains with decreasing timber prices (Cornerstone B).

Rangeland—By construction, forecasts of change in range area are limited to Texas and Oklahoma and only reflect the effects of urbanization (not being sensitive to alternative futures for timber prices). Rangeland declines by about 2.5 million acres from 1997 to 2060 for Cornerstone Futures C and D and about 3.2 million acres for Cornerstones A and B (fig. 4.23). Rangeland losses are concentrated in the urbanizing Cross Timbers area of eastern Texas and Oklahoma, especially around Dallas and Austin, and along the border with Mexico (fig. 4.24).

DISCUSSION AND CONCLUSIONS

Forecasts of population and income growth point toward an expanding area of developed uses in the South. All Cornerstone Futures considered here lead to at least a doubling of urban area by 2060 and predict strong growth in urban uses from 1997 to 2010. We chose 1997 as the base year for applying county-level models because the 1997 survey of land uses was the most recent source of comprehensive data at the time of our analysis. Subsequently, State-level land use data (USDA 2009) have become available, and they provide some confirmations of our forecasts. They show a 24 percent increase in developed land uses from 1997 to 2007 in the 13 Southern States, slightly less than the 29 percent forecasted for 1997 to 2010 by our models. This confirms that the modeled relationship between population/income growth and the demand for urban land has held up over the past decade and supports the use of our models for forecasting future growth.

Between 30 and 43 million acres of land in the South are forecasted to be developed for urban uses by 2060 from a base of 30 million acres in 1997. This doubling of urban land uses defines a general challenge to the sustainability of southern forests, especially in areas where population growth is likely to be concentrated. Urban growth is forecasted to be especially high in much of the Piedmont (continuing into portions of the Southern Appalachians that form the western borders of the Carolinas), the urban areas of Texas, and Peninsular Florida.

Urbanization is forecasted to produce declines in all rural uses of land over the next 50 years. Forest area, which is

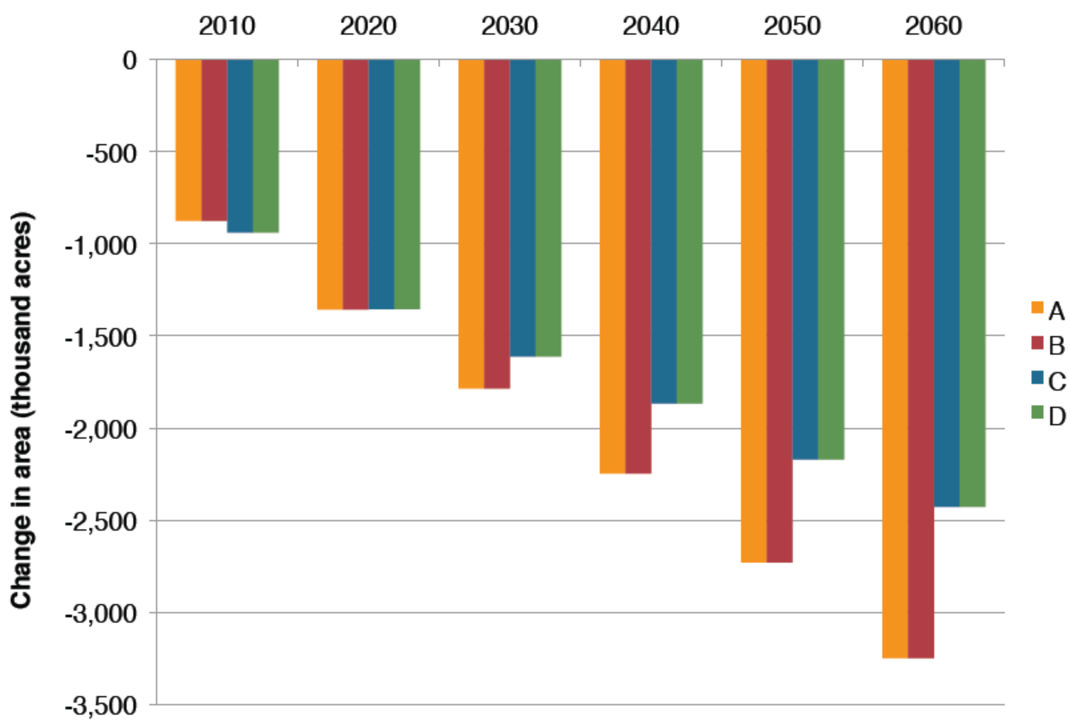


Figure 4.23—Cumulative change in rangeland uses by southern subregion from 1997 to 2060 by decade, expressed in (A) large urbanization gains with increasing timber prices, (B) large urbanization gains with decreasing timber prices, (C) moderate urbanization gains with increasing timber prices, and (D) moderate urbanization gains with decreasing timber prices.

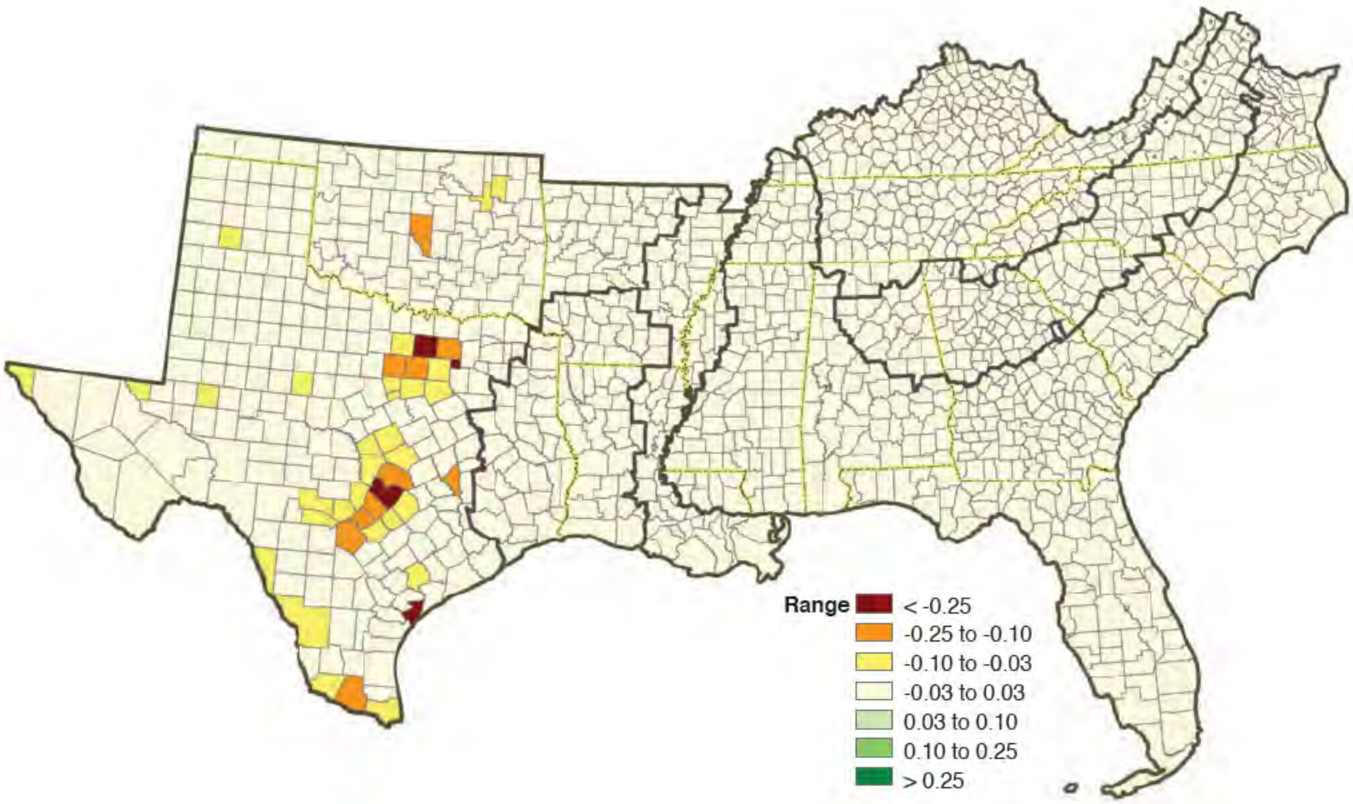


Figure 4.24—Percentage change in rangeland land uses, 1997 to 2060, based on an expectation of large urbanization gains and decreasing timber prices (Cornerstone B).

currently the largest land use in the South, is forecasted to decline by the largest amount—between 11 million acres (7 percent) and 23 million acres (13 percent)—for all Cornerstone Futures, with forecasted losses varying to reflect the effects of economic growth (storylines) and market futures for timber products. All subregions are expected to lose at least some forest acreage under all Cornerstone Futures, and nearly all of this area is expected to be converted to urban uses. The forecasts indicate that strong future timber markets could ameliorate forest losses somewhat, but this comes at the expense of cropland uses.

Urbanization as well as forest losses are not spread evenly across the region. Rather there are subregions and sections with disproportionately high forecasted losses. Among the subregions, the Piedmont is forecasted to lose the greatest proportion of its forest area: 21 percent under the highest-loss Cornerstone. The Mid-South and Mississippi Alluvial Valley are forecasted to lose the least percent of forest area (between 8 and 9 percent).

Urbanization is forecasted to reduce the area of cropland in the South at a rate that is proportionally greater than for forests. This is due to spatial distribution of anticipated population and income changes—i.e., focused in areas with existing agricultural production—but also is affected by the relative returns to agricultural and timber products. Range and pasture losses also decline, but not as much as cropland and forest land. Overall, the area of cropland in the South is forecasted to decline by as much as 17 million acres by 2060 from a 1997 base of about 84 million acres. Cropland losses would be highest in North Carolina, southern Florida, and central Texas.

KNOWLEDGE AND INFORMATION GAPS

The land use forecasts developed for this chapter are consistent with a modeling framework applied to the National Resources Inventory land use data set and forecasts of several exogenous variables. The model's strength derives from its explicit connection to the broader framework of the U.S. Forest Assessment System—it is designed to be driven by the key RPA variables. As with any forecasting model, its limitations have to do with the range of data upon which it is based—that is, the time period addressed by the land use inventory data—and also by the accuracy of the forecasts of exogenous variables. The model used for our analysis is especially dependent on the spatially explicit RPA forecasts of population and income. Future models may be enhanced with more frequent data on observed land uses, and also by the development of new methods for the combined forecasting of population change, economic development, and land use choices.

LITERATURE CITED

Chen, H.; Tian, H.Q.; Liu, M.L. [and others]. 2006. Effect of land-cover change on terrestrial carbon dynamics in the Southern United States. Journal of Environmental Quality. 35: 1533-1547.

Hardie, I.; Parks, P.; Gottleib, P.; Wear, D.N. 2000. Responsiveness of rural and urban land uses to land rent determinants in the U.S. South. Land Economics. 76: 659-673.

Lubowski, R.N.; Plantinga, A.J.; Stavins, R.N. 2006. Land-use change and carbon sinks: econometric estimation of the carbon sequestration supply function. Journal of Environmental Economics and Management. 51: 135-152.

Lubowski, R.N.; Plantinga, A.J.; Stavins, R.N. 2008. What drives land-use change in the United States? A national analysis of landowner decisions. Land Economics. 84: 529-550.

U.S. Department of Agriculture (USDA) Forest Service. 2012. Future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. RMRS-GTR-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 34 p.

U.S. Department of Agriculture (USDA). 2009. Summary report: 2007 national resources inventory. Washington, DC: Natural Resources Conservation Service and Center for Survey Statistics and Methodology. Ames, IA: Iowa State University. 123 p. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS//stelprdb1041379.pdf. [Date accessed: January 24, 2012].

Wear, D.N. 2002. Land use. In: Wear, D.N.; Greis, J.G., eds. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 153-173.

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

Wear, D.N.; Huggett, R.; Li, R. [and others]. 2013. Forecasts of forest conditions in U.S. regions under future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-170. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 101 p.

Woods and Poole Economics. 2007. Complete economic and demographic data source (CEDDS) technical documentation. Washington, DC: Woods and Poole Economics Inc. 101 p.

Zarnoch, S.J.; Cordell, H.K.; Betz, C.J.; Langner, L. 2010. Projecting county-level populations under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. e-Gen. Tech. Rep. SRS-128. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 8 p.

APPENDIX A.
Synopsis of Models

Land Use Models

This appendix provides documentation of the land use models used to generate forecasts for this report. Wear (2011) provides details on this modeling approach. We model changes in land use as a function of independent variables defined by the RPA scenarios. Population and income projections, downscaled to counties for each scenario, drive our forecasts of land development activities. A theoretically complete analysis of urbanization would jointly address the mechanics of land supply and demand to determine both development values and land in developed uses (e.g., Lubowski and others 2008). By taking RPA population and income forecasts as givens, we are adopting an implicit spatial economic growth solution. As such, the modeling task is to define the response of land use allocations to the population and income forecasts from the scenario framework.

We model changes in the area of land within a county for a small complement of land use classes in response to these and other variables. Variation in historical land allocations reflects differences in the demand for various goods and services derived from land as well as a number of supply factors, such as soil characteristics and climate that define comparative advantage for producing these goods and services. In a qualitative sense we follow the approach of Hardie and others (2000) by adopting a model that is a synthesis of the von Thunen concept of developed land use organized by steep rent gradients around central business districts and Ricardo's model of rural land use allocation based on rents accruing to competing rural uses (Lubowski and others 2006). More to the point, we assume that demand for urban uses follows some pattern of spatial contagion (defined relative to a single or multiple growth poles) and that rents associated with new urban uses supersede rents for all rural land uses—a near vertical rent gradient for the urban use in von Thunen's model.

Our modeling approach differs from previous efforts (e.g., Lubowski and others 2008, Hardie and others 2000) in some important ways. These previous models focus on testing hypotheses regarding land use distributions (e.g., interacting Ricardian and von Thunen specifications, Hardie and others 2000) and conducting counterfactual simulations regarding policy effects on land use distributions (e.g., for carbon policies, Lubowski and others 2006). Explaining the existing distribution of land uses requires extensive data that account for differences in productivity, including climate, soil, and topographic variables. We focus here on forecasting change in land use conditioned on the current distribution of land uses and based on forecasts of a much smaller set of exogenous variables.

For each county in the forested area of the South (excluding central and western Texas and Oklahoma), we model the urbanization process and changes in four rural uses: forest, crops, range, and pasture. The data set used for model estimations is a panel of observed land uses in two years (1987 and 1997), the most recent comprehensive data set available for our use derived from the NRI land use inventory. Models were applied to what we define as the variable or mutable land base: non-Federal land classified as developed, crops, pasture, range, or forests. All other land in the county was held fixed in its current use. We adopted a two-stage modeling approach which first defines urban-rural allocations and then allocation for four rural land uses.

We assume that the demand for urban uses dominates all other land uses. That is, we expect that the amount of urban land use is determined by demand factors that influence urban land rents and is unaffected by competition with any other land use. Consider the following reduced form model:

$$U = f(\overline{Y}, \overline{Z}, \overline{X}) \qquad (1)$$

Where U is the area in urban use, $\overline{Y}$ is a vector of time-varying variables from the RPA scenarios, including the population contained in the county (pop), and the real per capita disposable income for the county (inc). These variables change within each RPA scenario. The vectors $\overline{Z}$ and $\overline{X}$ are vectors of observed and unobserved time-invariant variables respectively, and describe the land quality attributes of the county—for example soil productivity, access to markets, etc.... A linear specification of equation 1 is:

$$U_{it} = \beta_0 + \beta_1 pop_{it} + \beta_2 pop_{it}^2 + \beta_3 inc_{it} + \delta\overline{Z}_i + \alpha\overline{X}_i + \varepsilon_{it} \qquad (2)$$

Population and income are expected to be positively associated with the area of urban uses. To model changes in the area of urban land use, we difference equation 2:

$$U_{it} = U_{i-1} + \underset{(+)}{\beta_1} (pop_{it} - pop_{it-1}) + \quad (3)$$

$$\underset{(-)}{\beta_2} (pop_{it}{}^2 - pop^2_{it-1}) + \underset{(+)}{\beta_3} (inc_{it} - inc_{it-1})\ \varepsilon^*_{it}$$

Differencing causes observed and unobserved fixed attributes of the county to fall out of the change equation (see Wooldridge 2002). Change therefore relies strictly on time-varying variables that are forecast to change between periods. Other time-varying variables such as rents accruing to crop or timber uses are excluded from this model by assumption—i.e., that urban rents completely dominate all other rural rents in the area of the county affected by the shift in demand. We posit that this urban growth difference equation may differ across subregions of the United States, due in part to the effects of topography and climate on the spatial agglomeration of uses (e.g., mountainous areas and flat areas may reveal different development patterns determined in part by topographic features). We therefore estimated separate models for broad regions and within each regional model we allowed for differences in coefficients by ecological provinces (Rudis 1999) by interacting dummy variables for the ecological provinces with each independent variable.

To complete our model, we address changes in rural land uses in response to changes in rural land rent determinants in addition to urbanization. Changes to relative rents could lead to rural land use switching irrespective of population/income changes. Consider the equations for current amounts of forest and crop uses similar to equation (2):

$$F_t = \varphi_0 + \varphi_{ff} p_{f,t} + \varphi_{fc} p_{c,t} + \varphi_{fu} U_t + \delta_f \overline{Z} + \alpha_f \overline{X} + \varepsilon_u \quad (4.1)$$

$$C_t = \gamma_0 + \gamma_{cf} p_{f,t} + \gamma_{cc} p_{c,t} + \gamma_{cu} U_t + \delta_c \overline{Z} + \alpha_c \overline{X} + \varepsilon_u \quad (4.2)$$

Here we assume that the areas of land in forest and crops are determined by the time-varying rents accruing to forests and crops (p's) and vectors of observed and unobserved fixed attributes that influence the suitability of land for various uses ($\overline{Z}$ and γ respectively). Pasture area (P) is defined as a residual land use. Rental values for forest and crop uses and the area of urban use are considered time-varying. To account for the urbanization dynamic in the Rent-Biased Model, we substitute equations (5.1) and (5.2) for urban change terms in equations (7.1) and (7.2) as follows:

$$C_t = C_{t-1} + [\ \alpha_c + \beta_{cc} P_{ct} + \beta_{cf} P_{ft}]\ \delta_{cu} + \quad (5.1)$$

$$\varphi_{cf} [\ P_{f,t} - P_{f,t-1}] + \varphi_{cc} [\ P_{c,t} - P_{c,t-1}] + \varepsilon^*_F$$

$$F_t = F_{t-1} + [\ \alpha_f + \beta_{fc} P_{ct} + \beta_{ff} P_{ft}]\ \delta_{fu} + \quad (5.2)$$

$$\gamma_{cf} [P_{c,t} - P_{c,t-1}] + \gamma_{ff} [\ P_{f,t} - P_{f,t-1}] + \varepsilon^*_c$$

$$P_t = P_{t-1} - ([\ U_t - U_{t-1}] + [\ F_t - F_{t-1}] + [\ C_t - C_{t-1}]) \quad (5.3)$$

We estimated equations 3, 5.1 and 5.2 using a weighted Seemingly Unrelated Estimation approach to account for cross equation correlations. Coefficient estimates are described in Wear (2011).

For areas in central and western Texas and Oklahoma, we use a model developed for the Rocky Mountain region. This model requires that we address changes in rangeland and uses the same structure for predicting urbanization. However, a simpler model is applied to rural land use changes where forest, crop, range and pasture uses are forecasted to change in response to urbanization with proportional change determined by the existing proportion of each rural land use (see Wear 2011).

Forecasting Algorithm—Our models are designed to forecast change in the areas of urban, forest, and crop uses with pasture use as a residual. Because areas in any land use are not constrained to be positive by the structure of these equations, nonnegativity constraints and "adding-up" rules need to be applied to ensure logical forecasts. We forecast change in land use in response to the driving variables of each scenario, including population, personal income, and relative timber prices (indexed by the price of softwood pulpwood).

CHAPTER 5.
Forecasts of Forest Conditions

Robert Huggett, David N. Wear, Ruhong Li, John Coulston, and Shan Liu[1]

KEY FINDINGS

- Among the five forest management types, only planted pine is expected to increase in area. In 2010 planted pine comprised 19 percent of southern forests. By 2060, planted pine is forecasted to comprise somewhere between 24 and 36 percent of forest area.
- Although predicted rates of change vary, all forecasts reveal that land use changes and conversion to pine plantations will result in a continuing downward trend in naturally regenerated pine types.
- Changes in forest types are influenced by urbanization and timber markets: hardwood types are most strongly influenced by urbanization; softwood types are most sensitive to future timber market conditions.
- Reversing a 50-year trend of accumulating about 2.5 billion cubic feet per year, forest biomass is forecasted to increase slightly over the next 10 to 20 years and then decline gradually.
- After accounting for harvests, forest growth, land use, and climate change, the total carbon pool represented by the South's forests is forecasted to increase slightly from 2010 to 2020/2030 and then decline.
- Urbanization patterns are the dominant determinates of the size of the future forest carbon pool, although stronger forest product markets can ameliorate carbon losses.
- Because of increases in timber supply from 1990 to 2010, removals of forest biomass (growing stock) are forecasted to increase for all Cornerstones, including those that project decreasing prices. This reflects an outward shift in timber supply associated with forest inventories between 1990 and 2010.
- Removals of softwood pulpwood are responsive to futures for forest planting and product prices. Under a high price future, softwood pulpwood output would increase by 56 percent, roughly equal to the expansion observed between 1950 and 2000.
- Although the overall loss of upland hardwood acreage is forecasted to be in the range of 8 to 14 percent, the oak-hickory forest type remains essentially constant while the areas of other forest types decline at higher rates. The yellow-poplar forest type is forecasted to decline the most, with the highest losses forecasted for the Piedmont.
- The age and species structure of softwood forest types are most strongly influenced by forest harvesting and management tied to timber markets. This is not the case for hardwood forests.
- The future structure of hardwood forests is most strongly affected by urbanization-driven land use changes (increased population growth and income).
- Reductions of naturally regenerated pine forests are not equally distributed among age classes. Mid-age and early-age forests decline, but old-age forests remain relatively constant.
- The distribution of upland and lowland hardwoods shifts, with less of these forest management types classified as early age and more classified as older age.

INTRODUCTION

The South's forests have been shaped by a long history of harvesting, forest management, and land use conversions. European settlers began a wave of farming and land clearing that continued to expand until around 1920 (USDA Forest Service 1988). Starting in the 1920s, extensive farm abandonment resulted in widespread forest establishment and old-field succession. With this period of forest recovery, forest area and forest biomass grew steadily through much of the 20th century and forest area peaked in the 1960s. In the 1970s and 1980s, industrial scale agriculture led to some losses in forest acreage especially in the Mississippi Alluvial Valley, and in the 1990s, urbanization became the dominant dynamic affecting forest area (Wear and Greis 2002). Despite these losses since the 1970s, the volume of growing stock (a measure of standing forest biomass) grew by more than 75 percent while industrial output of wood products more

[1] Robert Huggett is a Research Assistant Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695. David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695. Ruhong Li is a Research Associate, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695. John Coulston is a Supervisory Research Forester, Forest Inventory and Analysis Research Work Unit, Southern Research Station, U.S. Department of Agriculture Forest Service, Knoxville, TN 37919. Shan Liu is a Research Assistant, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695.

than doubled over the last half of the 20th century (Wear and others 2007).

The expansion of timber harvests in the South outpaced that of all other regions of the United States. As of 2007, the South's timber output was more than twice 1952 levels. About 60 percent of all timber produced in the United States was from southern forests (Smith and others 2009) compared to about 40 percent in 1962, indicating a shifting of production capacity to the region as well as increased output. This relocation of productive activity reflects the South's comparative advantage in growing timber and a new product mix that favors smaller diameter trees. While softwoods comprise a majority of harvests (69 percent), hardwood harvests are also substantial.

This chapter explores the ongoing and potential future changes affecting southern forests. Several uncertainties cloud our ability to predict that future. As the South's economy expands, population and attendant urbanization continue to outpace all other regions. At the end of the 20th century, shifts in market demand slowed the steady progression of timber harvesting. New policies pursue new demands for timber to provide cellulose-based bioenergy. Anticipated climate changes raise key questions about the future productivity and composition of forests. And although forests are by their nature dynamic, there have been both an acceleration and an interaction of changes in southern forests that cannot be understood without comprehensive analysis.

A modeling system designed to forecast the interactions of various social, economic, and biophysical drivers and the structure and extent of future forests is used in this chapter to explore the implications of the changes that will affect southern forests (see text box on following page, table 5.1, and fig. 5.1). Key to the system is a set of scenarios, called

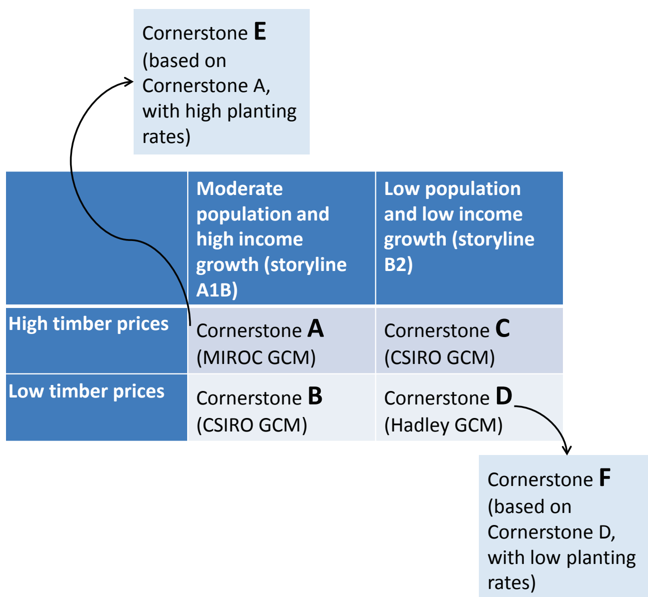


Figure 5.1—The six Cornerstone Futures defined by permutations of two 2010 Resources Planning Act (RPA) Assessment/Intergovernmental Panel on Climate Change storylines and two timber price futures; and then extended by evaluating increased and decreased forest planting rates.

Table 5.1—Definition of Cornerstone Futures used in the Southern Forest Futures Project, based on two storylines from the 2010 Resources Planning Act (RPA) Assessment and three general circulation models

Cornerstone Futures		RPA Storylines			General circulation model	Timber prices	Planting rates
Tag	Label	Label	Economic growth	Population growth			
A	High growth/high prices	A1B	High	Moderate	MIROC	Increasing	Base
B	High growth/low prices	A1B	High	Moderate	CSIRO	Decreasing	Base
C	Low growth/high prices	B2	Low	Low	CSIRO	Increasing	Base
D	Low growth/low prices	B2	Low	Low	Hadley	Decreasing	Base
E	High growth/high prices/high planting	A1B	High	Moderate	MIROC	Increasing	High
F	Low growth/low prices/low planting	B2	Low	Low	Hadley	Decreasing	Low

The Cornerstone Futures

The Southern Forest Futures Project uses six Cornerstone Futures (labeled with letters A to F) to provide alternative scenarios regarding the future of several exogenous variables (table 5.1). These are based on a combination of county-level population/income projections from the Resources Planning Act (RPA) and Intergovernmental Panel on Climate Change (IPCC) Assessments, assumptions about future timber scarcity, and assumptions about tree planting rates (see chapter 2 for details).

Two RPA/IPCC storylines, labeled A1B and B2 are used for the Cornerstones. B2 provides a lower rate of population growth (a 40 percent increase between 2010 and 2060), and A1B provides a somewhat higher rate of growth (60 percent). Income growth is higher with A1B. Both of these storylines are connected to detailed global economic/demographic scenarios that are described in the IPCC and RPA reports (IPCC 2007a, 2007b; USDA Forest Service 2012).

Timber price futures either address increasing or decreasing scarcity with an orderly progression of real prices for timber: either increasing or decreasing in real terms at one percent per year from a base in 2005 through 2060. We also hold the real returns to crops constant throughout the forecasts for all Cornerstone Futures.

Another element of the storylines embedded in these Cornerstones is the climate forecasted using general circulation models (GCMs) applied to the assumptions of the storylines. Forecast variables include changes in temperature, precipitation, and derived potential evapotranspiration downscaled to counties. We utilize three different GCMs in constructing the Cornerstones to address the potential variability in spatial distribution of resulting changes to forests. More detail on climate inputs to the forecasts is contained in chapters 2 and 3.

In figure 5.1, the six Cornerstone Futures are displayed in a diagram that emphasizes their key variables. Cornerstones A-D are defined by the matrix formed by intersecting RPA/IPCC storylines A1B and B2 with increasing and decreasing timber price futures as described above. These four Cornerstones use historical tree planting rates following harvests (by State and forest type) to forecast future planting. Cornerstones E and F depart from these four by either augmenting planting rates for Cornerstone A (E) or by decreasing planting rates for Cornerstone D (F).

Cornerstone Futures, which were developed to represent a broad range of plausible futures (chapter 2). For each Cornerstone Future, the modeling system simulates changes in forest area, shifts among forest types, the amount and distribution of forest biomass, harvest removals, and changes in the forest carbon pool. To the extent possible, we examine variation across the five subregions of the South and focus on the spatial distribution in forest conditions. These findings provide a foundation for further exploration of timber markets (chapter 9), bioenergy futures (chapter 10), and impacts on wildlife, biodiversity, and forest communities (chapter 14).

METHODS

The results examined in this chapter are based on the U.S. Forest Assessment System, a modeling system designed to forecast alternative futures for U.S. forests.[2] The U.S. Forest Assessment System is a forward-looking adjunct to the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture, and was implemented by research and development staff of the Forest Service. The FIA program provides nationwide monitoring through repeated inventories that provide consistency over time and a high level of detail. The U.S. Forest Assessment System accounts for changes driven by multiple vectors including biological, physical, and human factors to generate forecasts of forest inventories. The modeling approach is designed to address changing climate, market-driven timber harvesting, and land use changes along with changes driven by successional transitions in forest conditions.

A general schematic of this modeling system (fig. 5.2) starts with a set of internally consistent combinations of social, economic, and technology forecasts defined as the Cornerstone Futures (also called Cornerstones in this book) for this application of the U.S. Forest Assessment System. Linked to the Cornerstones are various general circulation models (climate models, or GCMs), each selected to define a climate forecast that is consistent with the Cornerstone. Also linked are data from a forest inventory server, which defines starting conditions for all plots in the forest inventory.

The modeling framework at the center of this system (middle column of fig. 5.2) shows how future forest conditions are driven by biological dynamics—such as growth and mortality—which in turn are affected by climate factors. In addition, human choices regarding allocations among land uses and the disposal of forest land, timber harvesting, and forest management also affect changes in forests. The interplay of all of these factors yields a set of outputs, each

[2] Because of data limitations the U.S. Forest Assessment System does not yet address changes in forest conditions in Texas and Oklahoma outside of their eastern survey units that are heavily forested.

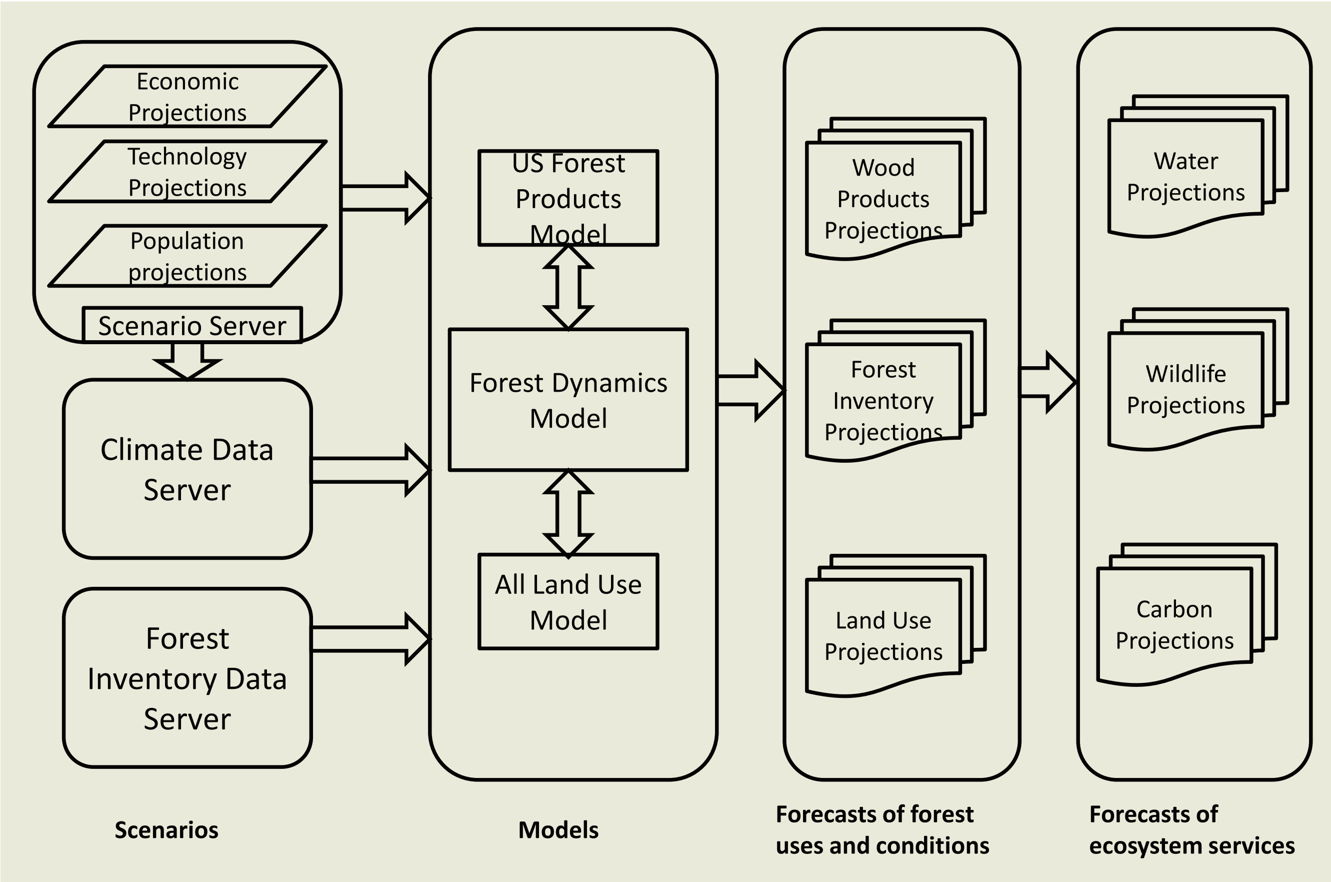


Figure 5.2—Schematic of the U.S. Forest Assessment System.

of which describes forest projections that are consistent with the flow of forest products and land uses. Changes in water, biodiversity, and other ecosystem services can also be derived from the forecasted changes in forest conditions and land uses. Many of these are described in subsequent chapters.

The forest dynamics module of this framework provides the outputs discussed in the results section of this chapter. Within this module the future of every plot in the forest inventory is projected in a multiple stage process (see Wear and others [2013] for details on modeling approaches). A harvest choice model assigns a management intensity choice (no harvest, partial harvest, or final harvest) based on timber prices (from a forest products module) and the condition of the plot (Polyakov and others 2010). The age of each plot is determined for the next period, and if harvested, the plot is determined to be naturally regenerated or planted. Forecasted climate including temperature and precipitation is assigned and forest conditions on the plot are inferred based on the harvest/no harvest decision, age, and climate selection.

Planting probabilities are based on the frequency of planting on harvested plots based on the forest type and State for the most recent inventory period. Given the high planting levels observed over this period, forecasted rates were adjusted downward by 50 percent for Cornerstone Futures A-D. The high-planting Cornerstone Future (E) uses 75 percent of the historical planting rates while the low-planting Cornerstone Future (F) uses 25 percent.

To incorporate forest market data, we adopted a simplified process that specifies a price trajectory for each Cornerstone Future and provides input both on individual plot-harvest decisions and on the overall supply of timber. Consistent with theory, higher prices yield more harvesting and larger timber supplies; lower prices yield smaller timber supplies. Harvest choice models are based on empirical analysis and are consistent with harvesting behavior observed in the late 1990s and early 2000s.

The land use module (fig. 5.2) described in chapter 3 (see also Wear 2011) simulates changes in all uses of land and is driven by population and income growth along with the prices of timber products. Projections of forest area from the land use module feed into the forest dynamics module and the projection of future market conditions. Changes forecasted at the county level for non-Federal land are based on National

Resources Inventory data (chapter 3) and are used to rescale the area represented by each plot in the county (also known as plot expansion factors).

The assignment of future plot conditions uses a resampling of historical plot records called whole-plot imputation (Wear and others 2013), which involves the selection of a historical plot with comparable conditions to represent each plot location in the future. The selected historical plot is as close as possible to the original plot location to allow for orderly changes in conditions, e.g., if plot conditions are forecasted to be warmer, the resampling algorithm would first look within the same survey unit to find a historical plot with similar temperature increases. Finding none, the algorithm would extend the search to adjacent units until an appropriate match is found. This process is repeated for every time step (or interval between measurements or projections) to generate plot forecasts over time. The inventory forecast is completed by coupling the plot forecast with the land use forecasts, which are applied to adjust the area represented by each non-Federal plot within each county (through the plot expansion factor described above).

The forest dynamics model is based on several probabilities, including probabilistic harvest choice, forest investment, and forest transition models that are implemented with random draws from probability distributions, and a whole-plot imputation that is based on a random selection of a subset of historical plots with replacement. Forecasts therefore may vary between runs of the model. The forecasts for the 50-year simulation in this chapter are based on 26 runs, one of which was selected as representative based on central tendency across several variables. The full suite of 26 runs offers information about the uncertainty of the forecasts and is used whenever confidence intervals are needed.

The time step of the simulation depends on the FIA inventories that underlie much of the modeling (Wear and others 2013). Because starting years and time step vary from State to State, the forecast periods are staggered across the region, e.g., a State might have a time step of 6 years starting in 2007, while another State might have a time step of 6 years starting in 2008. For reporting across the region, we selected 10-year intervals, each beginning with a zero-ending year, e.g., 1990, and then attached forecasts from the nearest year to the referenced decade—identical to how FIA assigns years for aggregate inventories (Smith and others 2007).

The reports and maps in this chapter show changing forest conditions for the forecast period (2010 to 2060) in enough detail to depict a complete forest inventory for each State in the South. We focused on forecasting the volume of forest biomass, the area of forests by type and age class, the carbon contained in above- and belowground pools, and removals from forests determined by forest product harvests and land use changes. Our approach was to summarize total changes for the South and their distribution across subregions.

DATA SOURCES

For each State, FIA plot records were available to populate the forest dynamics model and conduct the resampling. We required at least two inventory panels of matched plots, ideally with both derived from the continuous inventory design that was implemented in 1998 to replace complete-but-periodic inventories of the past with annual updates. Because of changes in the plot measurement approach, we determined that it was important to use two panels of comparable design to construct transition models for key variables. So when faced with the dilemma of only one available continuous inventory, we opted for panels from two older (periodic) inventories rather than rely on two different designs.

From publicly available plot tables located on the FIA Web site, we extracted raw data on plot characteristics, discrete landscape features, and measurements of trees larger than 1-inch d.b.h. We were also granted access to confidential plot location data, allowing us to conduct the plot matching needed to evaluate transitions over time. Expansion factors, the area associated with each plot, were attached to the plots with the appropriate tables. Each plot's county links it to the land use model (see chapter 3).

Because the FIA inventory is extensive, we performed some manipulations on the raw data to allow us to summarize values for analysis. Biomass variables, such as the volume and number of growing-stock trees, were calculated on a per acre basis using algorithms derived from Miles and others (2001) to account for changes in survey methodology over the years. For example, plots in the annual inventory panels were divided into components to capture condition-level details such as forest type. As a validation step we generated total values for States and survey units, which could then be compared with published reports and confirm the accuracy of the algorithms.

Changes in algorithms, recording, and measurement techniques created data anomalies in many inventories. We compared attributes across inventories in each State to determine where data adjustments were required. This was especially crucial when conducting the analysis of transitions.

Carbon estimates are attached to each historical plot using models developed and applied by FIA using the U.S. Forest Carbon Calculation Tool (Smith and others 2007). This tool incorporates estimates derived from field measures into the FORCARB2 model to provide carbon inventories that are consistent with standards developed by the

Intergovernmental Panel on Climate Change (Penman and others 2003).

We also attached ancillary grid-level climate data to each forested plot in the inventory. Historical climate variables for a 67-year period (1940 to 2006) were derived from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) database,[3] which provides monthly values. Climate forecasts for each of the Cornerstone Futures (chapters 2 and 3) derive from a database developed by Coulson and others (2010). To create the set of forecasted variables, climate projections or "deltas" from this database are applied to the 1961-1990 "normals" defined by the PRISM grid data to create the set of forecasted variables. For both the historical and forecasted series we create monthly county-level averages for precipitation, minimum and maximum temperatures, and potential evapotranspiration (Linacre 1977). Climate variables are assigned to each plot based on the county in which the plot is located and the age of the plot, e.g., a 40-year old plot in 2020 would have climate data averaged over the previous 40 years, which would include the history from 1980 to 2006 and the forecast from 2007 to 2020. Each plot represents several hundred acres of forest within a county so county averages may be more representative than more precise grid cell estimates.

To estimate timber harvest models, we calculated potential revenues from alternative treatments of each plot (full harvest, partial harvest, or deferred harvest). This required volume measures derived from the inventory records and timber product prices (chapter 2). Product prices were defined as the average of stumpage prices recorded during the observation period for each survey unit and reported by Timber Mart South, a region-wide price tracking service funded by the Frank W. Norris Foundation. The starting year for price projections is 2006.

[3] http://www.prism.oregonstate.edu/

RESULTS

Forest Area Forecasts

Forecasts of forest area change derive from the land use analysis contained in chapter 3.[4] All Cornerstone Futures predict declines in forest area with losses ranging from 4 to 21 million acres (2-10 percent) by 2060, the result of population- and income-driven urbanization and of changes in the relative price of timber products (fig. 5.3). The smallest loss of forest area is forecasted for Cornerstone C, which has the lowest population growth and income growth resulting in lowest urbanization, and increasing timber prices resulting in shifts of some rural land toward forest uses. The largest loss of forest area is forecasted for Cornerstone B, where

[4] The magnitudes of forest area changes reported in this chapter differ from those in chapter 3 because (1) the analysis in chapter 3 is based on National Resource Inventory data benchmarked in 1997, while this chapter translates those projections into FIA data benchmarked in 2010; and (2) while the NRI measures only non-Federal land uses, the FIA data address all ownerships.

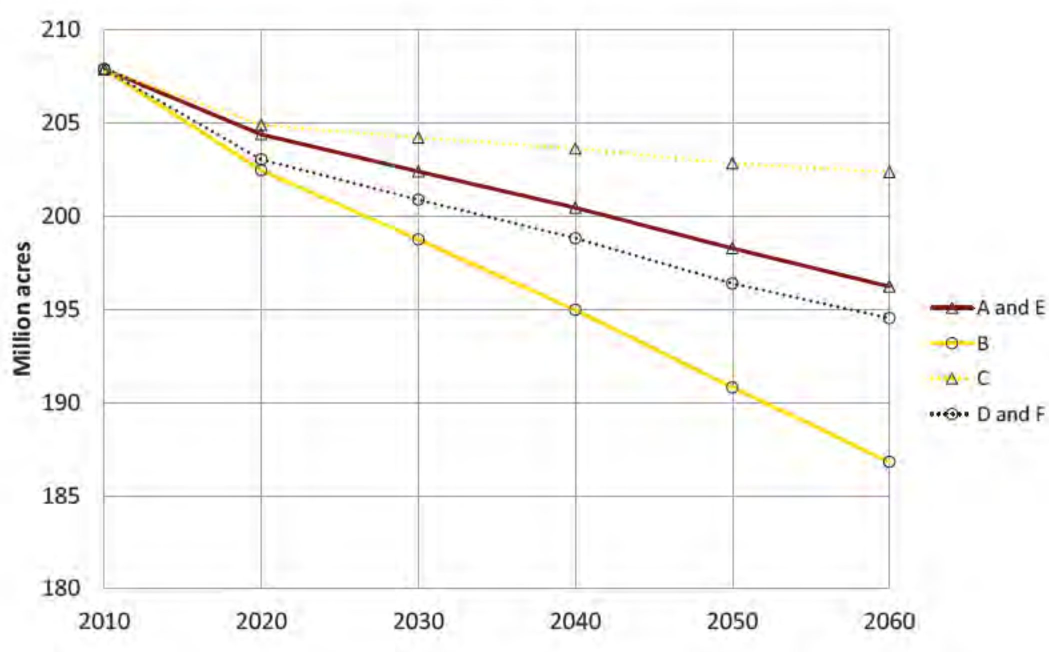


Figure 5.3—Forecasted total forest area, 2010 to 2060, by Cornerstone Future. Cornerstones A and E share a land use model, as do cornerstones D and F. The figure shows the overlapping trajectories for these.

population growth is moderate but income growth is strong (resulting in high urbanization), and timber prices are falling (resulting in shifts of forest land to agricultural uses). Figure 5.3 also shows that price effects dominate the projection of forest area, with the highest forest loss associated with Cornerstones that have decreasing prices (B, D, and F); the three Cornerstones with the lowest forest loss have increasing prices (A, C, and E).

Forest losses are especially high in a few areas of the South (fig. 5.4). For all Cornerstone Futures forest losses are concentrated in the Piedmont from northern Georgia though North Carolina and parts of Virginia, the Atlantic and Gulf of Mexico coastal areas, and the area surrounding Houston. The income-fueled urbanization in Cornerstones A and B spreads low intensity forest losses across a broader area of the South (chapter 3). For all Cornerstones, the number of acres lost is largest in the Coastal Plain and smallest in the Mississippi Alluvial Valley and the Mid-South. The percent of acres lost is largest in the Piedmont followed by the Appalachian-Cumberland highlands and the Coastal Plain.

Forest area change also varies across the five forest management types: planted pine, natural pine, oak-pine, upland hardwood, and lowland hardwood. The upland and lowland hardwood types are forecasted to comprise between 51 and 53 percent of all forests in 2060, a decline from about 54 percent in 2010 (fig. 5.5). The greatest changes however are found among the softwood types (planted pine, natural pine, and oak-pine). These forest dynamics are heavily influenced by management for forest products, which in turn is driven by timber market conditions, and by the rate of forest planting.

Planted pine–Of the five forest management types in the South, only planted pine is forecasted to increase in spite of overall declines in forested area. The South now contains 39 million acres of planted pine (about 19 percent of total forest area), the culmination of an upward trend that started in the 1950s. Our projections of planted pine are driven by urbanization, timber prices, and planting rates (fig. 5.6). Cornerstone E, characterized by a relatively high level of urbanization as well as high timber prices and planting rates, produces the largest expansion in planted pine (though at rates lower than those experienced in the 1990s) and yields an increase of 28.2 million acres by 2060 (about 560,000 acres per year). Under this Cornerstone, 34 percent of forests would be planted pine in 2060. Conversely, Cornerstone F, characterized by a relatively low level of urbanization as well as low timber prices and planting rates, yields the smallest gain in planted pine area with an increase of 7.8 million acres by 2060 (24 percent of forest area). The remaining Cornerstones have projections that are intermediate to these results. They cluster around the forecast for Cornerstone D with its lower timber prices and slower urbanization: a gain of 16.8 million acres (about 0.3 million acres per year) with planted pine comprising 28 percent of the forest acreage in 2060.

Natural pine—Forecasted losses in the area of naturally regenerated pine forest types mirror the gains in planted pine forests and are therefore related, albeit inversely, to the condition of forest products markets (fig. 5.6). The largest decrease in natural pine—a loss of 58 percent from 31.5 million acres in 2010 to 13.5 million acres in 2060—is associated with Cornerstone E, which has the highest planting rates. The smallest decline occurs with Cornerstone F, with its lower timber prices and planting rates, but losses are still substantial—7.6 million acres or 25 percent from 2010 to 2060. Regardless of the Cornerstone evaluated, naturally regenerated pine types are forecasted to decline, continuing a trend that has dominated forest type dynamics since the 1960s.

Oak-pine—The area of the oak-pine forest management type also declines for all Cornerstone Futures, with a similar pattern of change but smaller acreage and percent changes than is forecasted for natural pines (fig. 5.6). As with natural pine, oak-pine is more heavily influenced by timber market conditions than by urbanization rates. Oak-pine declines range from 8.5 million acres (38 percent) to 3.9 million acres (17 percent) by the year 2060.

Upland hardwood—At more than 80 million acres in 2010, upland hardwoods are the predominant forest type in the South, more than double the area of the next largest forest type. Upland hardwoods are forecasted to decline for all Cornerstone Futures (fig. 5.6), and variations in forecasts are associated more with the rate of urbanization than with timber market futures. The three Cornerstones with the lowest upland forest loss are associated with lower urbanization (Cornerstones C, D, and F), and the three with the highest loss are associated with the higher urbanization forecasts (Cornerstones A, B, and E). Loss of upland hardwood forests ranges from 5.9 million acres (about 8 percent) for Cornerstone C to 11.2 million acres (14 percent) for Cornerstone B. For Cornerstone E, which is also characterized by high timber prices but with even higher rates of planting, the projected total area of planted pine forest would be nearly equal to upland hardwood forests in 2060, as the stimulating effects of price and planting on the pine type combines with the depressing effects of urbanization on the hardwood type.

Lowland hardwood—The area of lowland hardwood forests is also more sensitive to the rate of urbanization and less sensitive to forest products markets than the softwood types. For this forest management type (fig. 5.6), forecasts indicate losses ranging from 1.7 million acres (5 percent) to 4 million acres (12 percent) by 2060 from a base of 32 million acres in 2010. The relative ranking of change

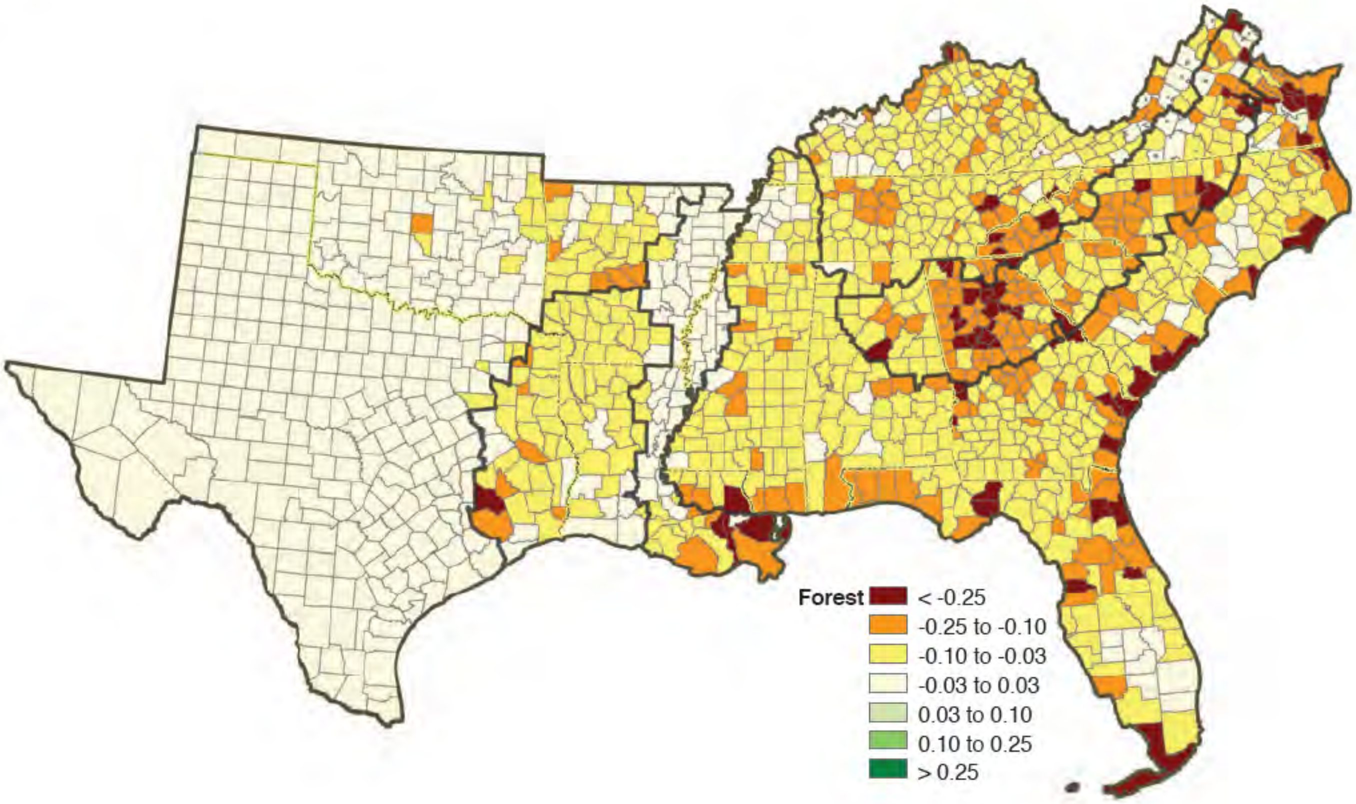


Figure 5.4—Forecasted change in the proportion of county in forest land, 1997 to 2060, for Cornerstone B, which is characterized by high urbanization and low timber prices.

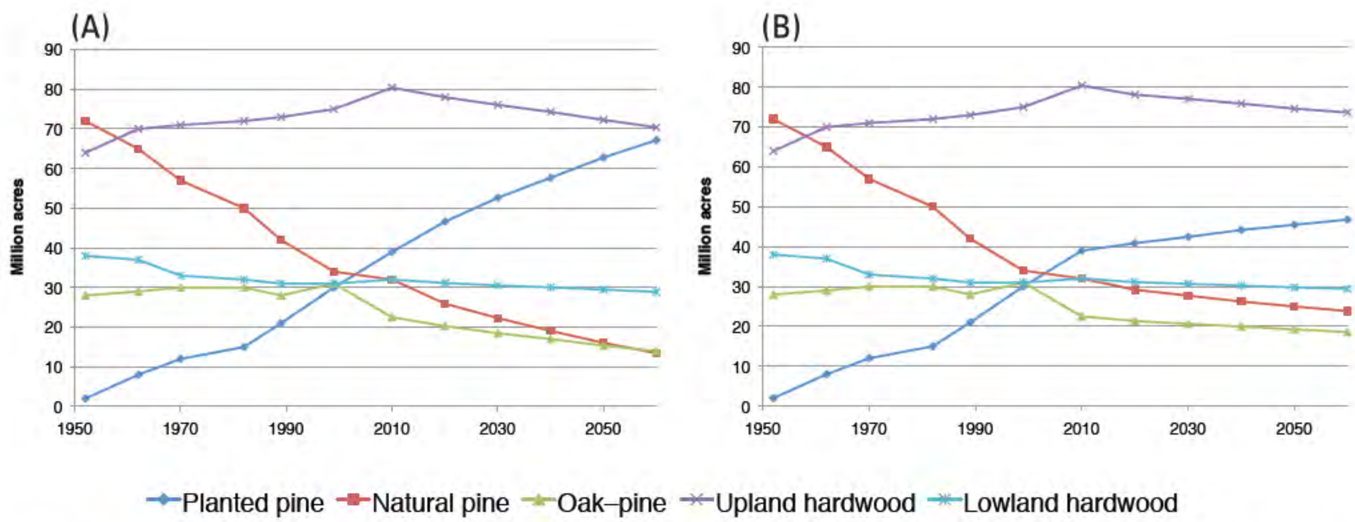


Figure 5.5—Forecasted forest area by forest management type, 1952 to 2060, for (A) Cornerstone E, which is characterized by high urbanization, high timber prices, and more planting; and (B) Cornerstone F, which is characterized by low urbanization, low timber prices, and less planting.

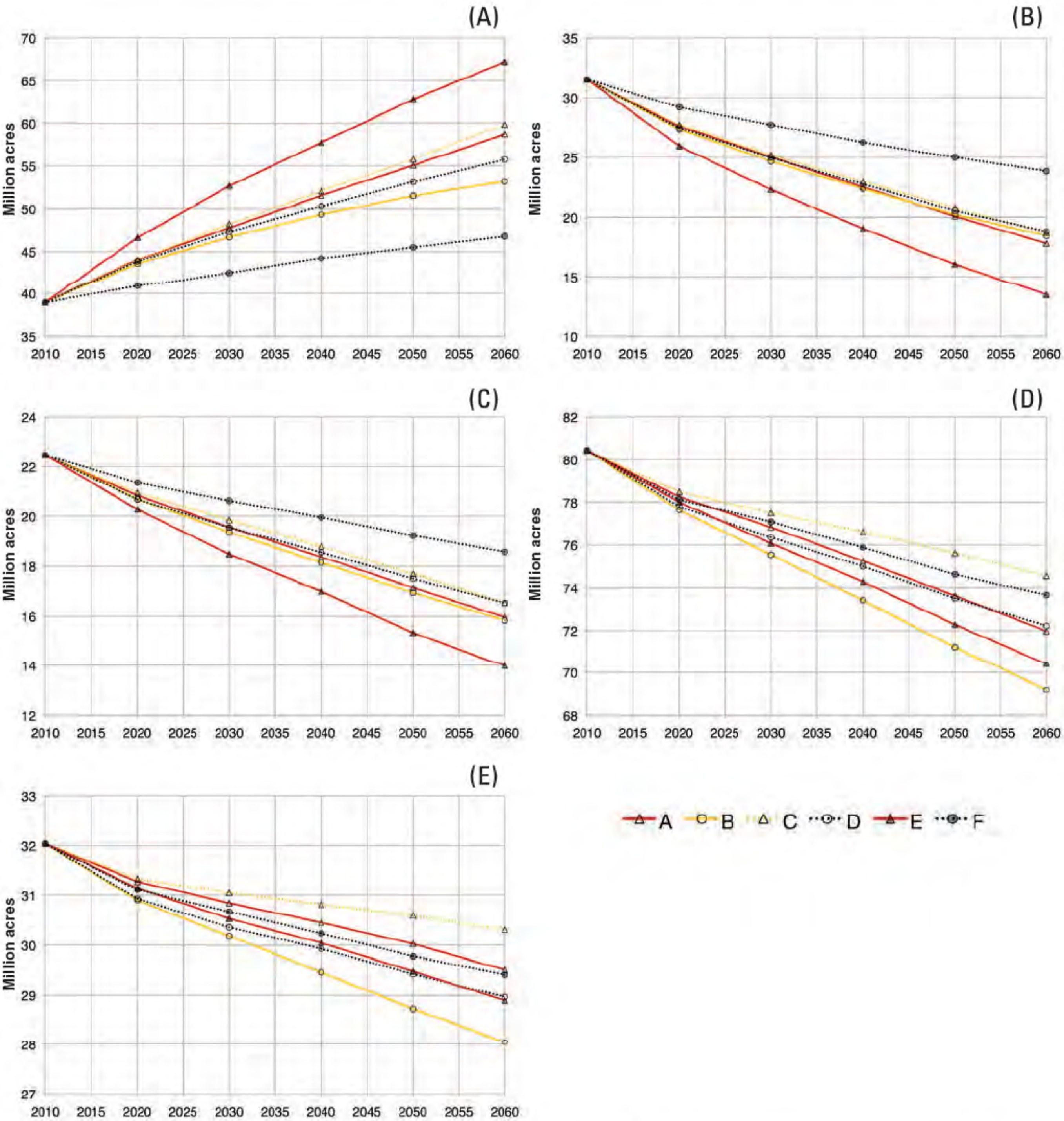


Figure 5.6—Forecasted forest area of Cornerstone Futures, 2010 to 2060, for (A) planted pine, (B) natural pine, (C) oak-pine, (D) upland hardwood, and (E) lowland hardwood management types.

across Cornerstone Futures is identical to the forecasts for upland hardwood types. Lowland forests lose proportionally less area than the other forest types that experience losses.

The forecasts of forest type dynamics vary across the Futures Project subregions (figs. 5.7, 5.8, and 5.9). Forest losses, especially concentrated in the Piedmont and Appalachian-Cumberland regions (figs. 5.7), and intensive management in the Coastal Plain influence forest types differently. The Coastal Plain, with 82 percent of planted pine in 2010, experiences the greatest growth in planted pine area, from 32 million acres to 43 million acres. Declines in naturally regenerated pine are greatest in the Coastal Plain as well. Upland hardwood losses are greatest in the Piedmont and in the Appalachian-Cumberland subregion reflecting the influence of urbanization on these types. Changes in lowland hardwood types are more evenly spread across the South.

Forest Biomass Forecasts

Of the various metrics available for measuring biomass changes for a site in a forest inventory, we opted to focus on the volume of growing stock because it is a useful index both for timber analysis and for measuring other ecosystem services. Total growing stock volumes are forecasted to change in response to both land use changes and timber harvesting levels (fig. 5.10). From a base of about 292 billion cubic feet in 2010, inventories increase at most by about 11 percent in 2060 under the low-urbanization/low-timber-price Cornerstone D. The smallest increase in total growing stock inventories is found with the high-urbanization/high-timber-price Cornerstone A, with an increase in volume to 2030 and then a decline over the remainder of the forecast period. Under this Cornerstone, the volume in 2060 is about 1 percent higher than values observed in 2010.

Patterns of change differ between hardwood and softwood components of the inventory and generate generally countervailing changes. Under all Cornerstones, softwood growing stock inventories increase (fig. 5.11). For the low-urbanization/low-timber-price Cornerstone D, softwood inventories increase from a base of about 121 billion cubic feet in 2010 to as much as 148 billion cubic feet (37 billion cubic feet or 22 percent). The smallest increase is 15 percent (18 billion cubic feet) for the high-urbanization/high-timber-prices Cornerstone A.

Hardwood growing stock inventories reveal different patterns of change. Starting from about 171 billion cubic feet in 2010, hardwood growing stock volumes peak somewhere between 2020 and 2040 for all Cornerstones and then decline to the year 2060 (fig. 5.11). The most pronounced declines are for Cornerstones A and E, both of which have high rates of urbanization and high timber prices. Declines for these Cornerstones are in the range of 15 billion cubic feet (9 percent) from 2010 to 2060. Cornerstones F and D result in increases of 3 billion cubic feet (2 percent) for the same period.

These changes in growing stock volume depart from historical patterns of volume accumulation in the South. Between 1963 and 2010 southern forests accumulated about 2.5 billion cubic feet per year or roughly 70 percent. Hardwood forests accounted for most of this biomass accumulation (61 percent). Although growth is projected to continue over at least the next 10 years, growing stock volume reaches a maximum and then declines somewhat over the following 40 years (fig. 5.12), with hardwood growing stocks declining, especially in response to urbanization (Cornerstone A), while softwood volumes increase only slightly.

Figures 5.13, 5.14, and 5.15 show county-level changes in growing stock volume from 2010 to 2060 for the high-urbanization/high-timber-prices Cornerstone A. While softwood growing stock increases overall, areas with large increases in planted pine (fig. 5.8) show declines in softwood growing stock volumes as older naturally regenerated pine forests are replaced by younger planted pine forests (fig. 5.14). Declines in hardwood growing stock volumes between 2010 and 2060 are more widespread and generally organized by urbanization patterns (fig. 5.15). Eastern Kentucky and far western Virginia show the greatest gains in hardwood growing stock volumes.

Forest Carbon Forecasts

We estimate the carbon stored in southern forests in 2010 at about 12.4 billion tons, including carbon stored in eight pools: down trees, standing dead trees, litter, soil organic carbon, live trees aboveground and belowground, and understory plants aboveground and belowground. Aboveground live trees and soil organic material comprise 80 percent of the total carbon stock. Forecasts of future forest carbon stocks reflect changes in the amount of forest area and the composition of the forest inventory. However, the model tracks only the carbon pool in forests and does not account for carbon transfers to agricultural and other land use pools. Likewise, the model does not account for carbon that leaves forests as products and may remain sequestered for long periods of time in housing or other end uses (e.g., Heath and others 2011).

Changes in forest carbon pools reflect both changes in growing stock volumes and changes in forest area (figs. 5.16 and 5.17). Under most Cornerstones, tree carbon peaks in 2020 and then levels off or declines; the exception is the low-urbanization/high-timber-prices Cornerstone C whose forecast peaks in 2030. At most, the forest carbon pool in 2060 is 5 percent smaller than the pool in 2010 (a net emission of about 600 million tons). Carbon accumulates as a result of net biomass growth on forested lands (fig. 5.17.F), but

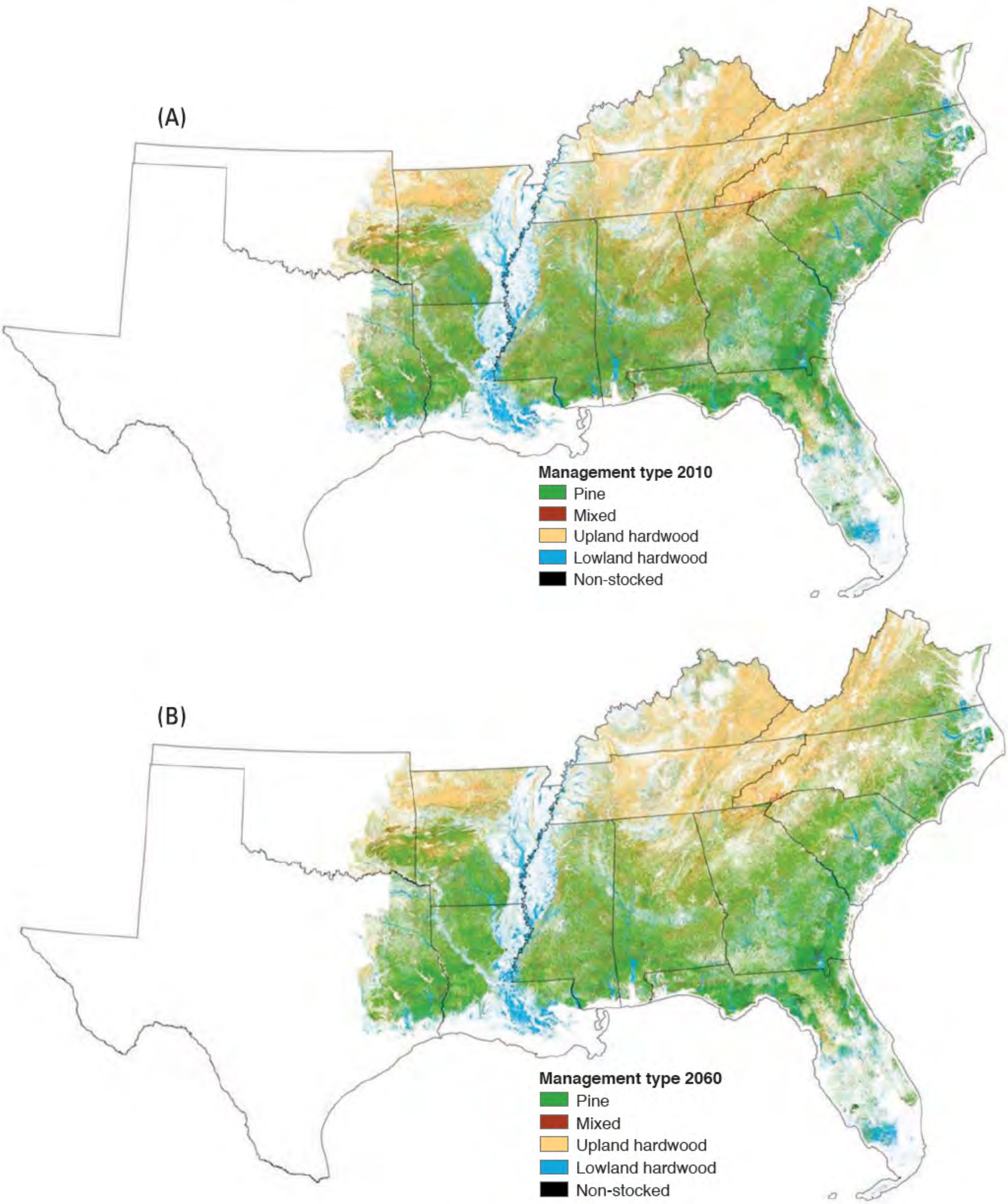
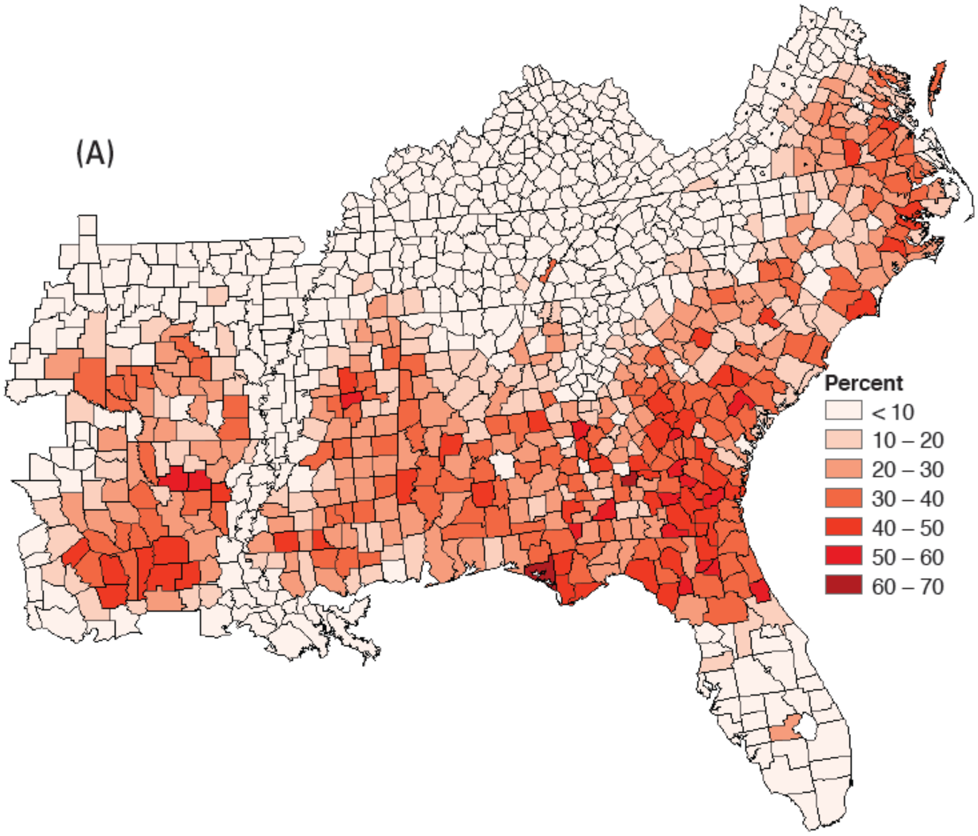


Figure 5.7—County-level presence of forest types (A) for 2010 and (B) forecasted for 2060 under Cornerstone A, which is characterized by high urbanization and high timber prices.



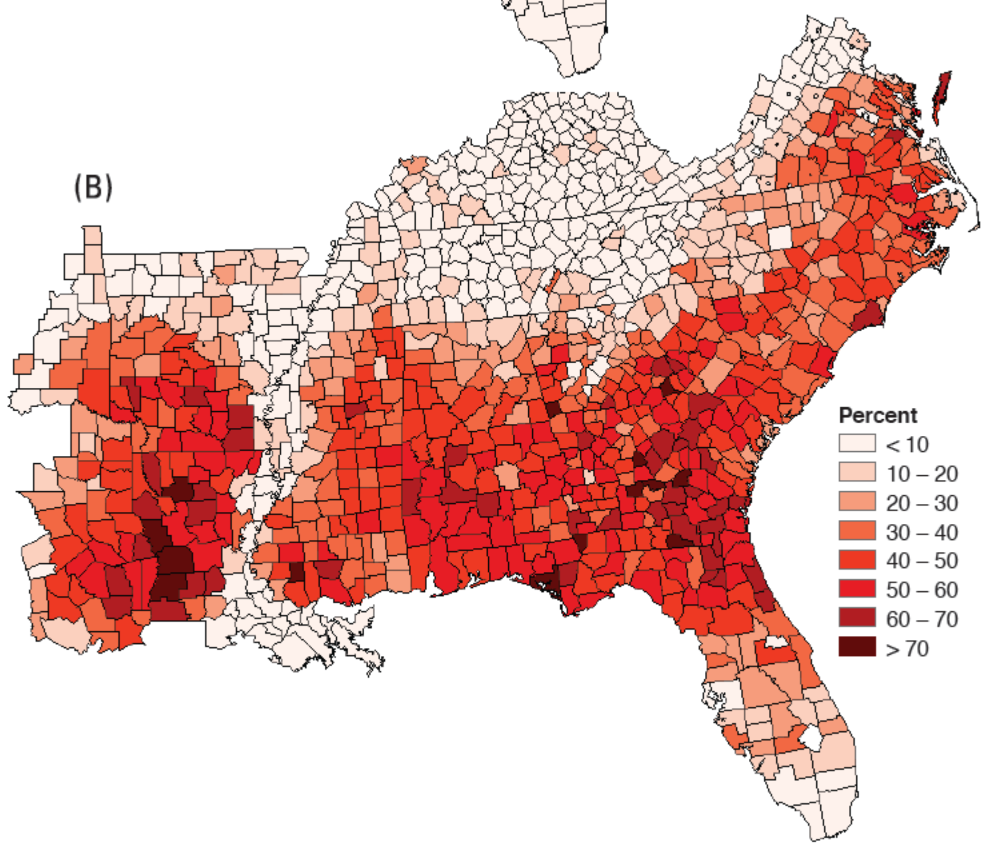


Figure 5.8—Forest land in planted pine (A) estimated for 2010 and (B) forecasted for 2060 under Cornerstone E, which is characterized by high urbanization, high timber prices, and more planting.

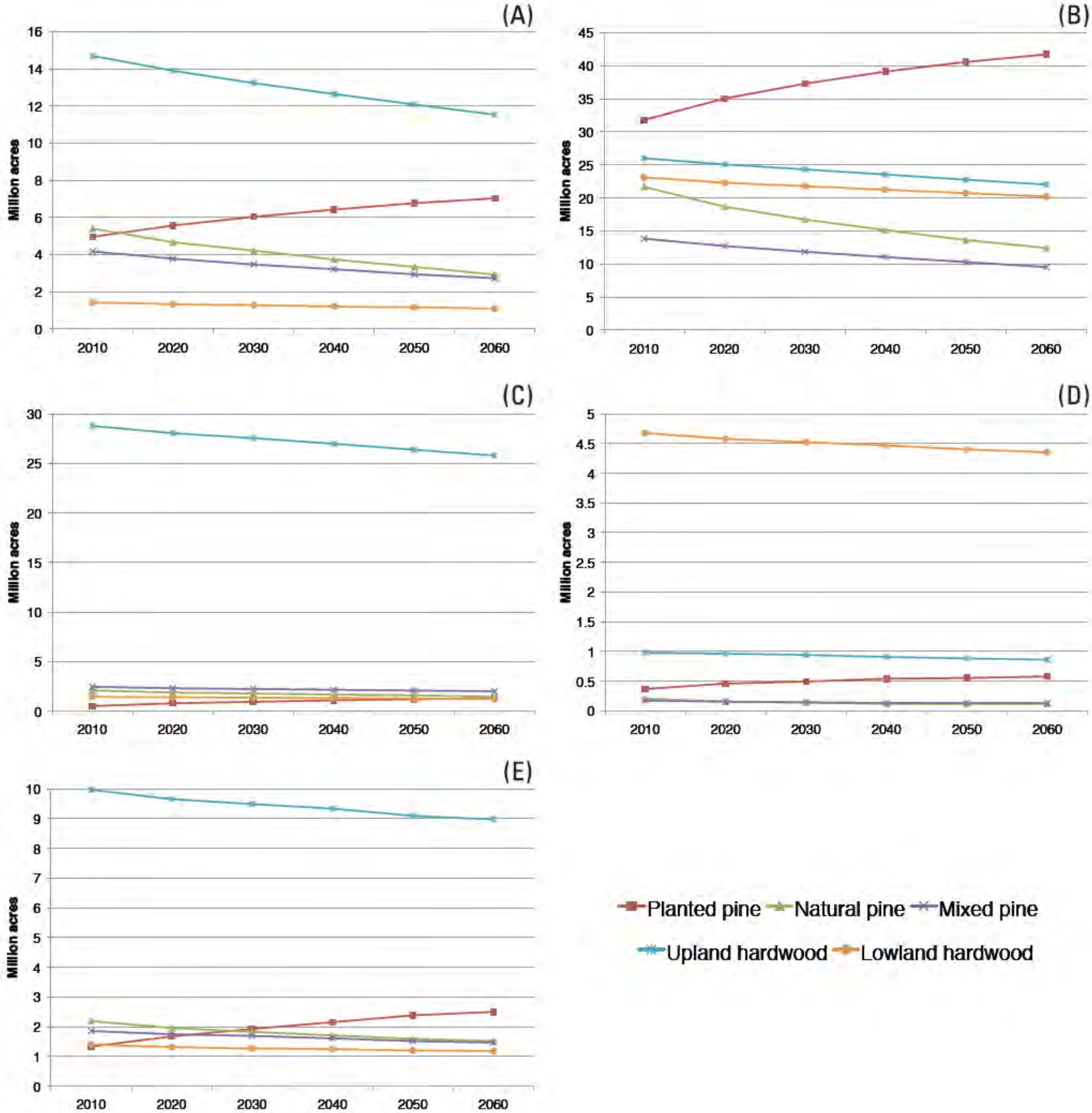


Figure 5.9—Forecasted forest area by forest management type, 2010 to 2060, for (A) Piedmont, (B) Coastal Plain, (C) Appalachian-Cumberland highlands, (D) Mississippi Alluvial Valley, and (E) Mid-South under Cornerstone B, which is characterized by high urbanization and low timber prices.

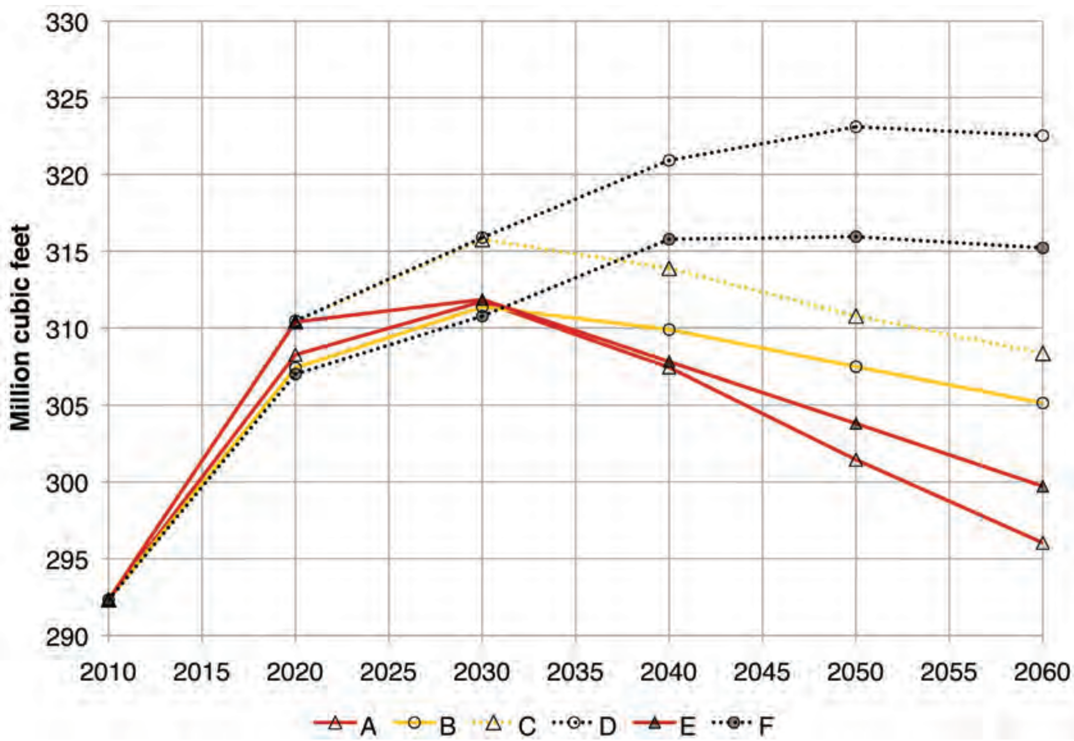


Figure 5.10—Total growing stock volume, 2010 to 2060, by Cornerstone Future.

these gains are offset by the loss of forested land through urbanizations (i.e., the loss of soil carbon shown in fig. 5.17.D).

The clustering of carbon forecasts in Figure 5.16 reveals the interplay of urbanization and timber prices. The forecasts with the highest amount of carbon in 2060 are for the low-urbanization Cornerstones (C, D, and F). The lowest carbon forecasted is for the high-urbanization Cornerstones (A, B, and E). However, within each of these triplets the lowest amount of carbon is associated with low timber prices (Cornerstones B, D, and F) while higher timber prices and resulting intensive forest management lead to higher carbon sequestered in the forest pool. This suggests that urbanization patterns dominate the forecasts of carbon storage while stronger forest product markets can ameliorate carbon losses.

Forest Removals Forecasts

Removals from growing stock are forecasted to increase for all Cornerstone Futures reflecting both land use changes and timber harvesting (fig. 5.18). From 2010 to 2060, removals are forecasted to increase by as much as 85 percent (the high-urbanization/high-timber-price/more-planting Cornerstone E) and as little as 35 percent (the low-urbanization/low-timber-price/low-planting Cornerstone F). The dominant factor that affects the number of removals is the price projection for timber that is associated with each Cornerstone. The most removals are associated with high price Cornerstones (A, C, and E) while the lowest removals are associated with low price Cornerstones (B, D, and F). Even with declining prices, harvests are projected to increase, reflecting previous forest investments, maturation of forest inventories, and removals associated with forest losses.

The forecasts generate distinctly different removal patterns for hardwoods and softwoods (fig. 5.19). Softwood removals are forecasted to increase steadily over the projection period and at rates comparable to recent history. For hardwoods, forecasted removals increase from 2010 to 2020 and then level off for most Cornerstones. The increase in the first decade reflects the recovery from suppressed removals leading up to and during the “great recession” (2005 to 2010). Trends in later decades reflect a decline in hardwood growing stock inventories, most especially in the pulpwood size classes.

Among products, softwood pulpwood removals are the most variable across Cornerstones, with forecasts ranging

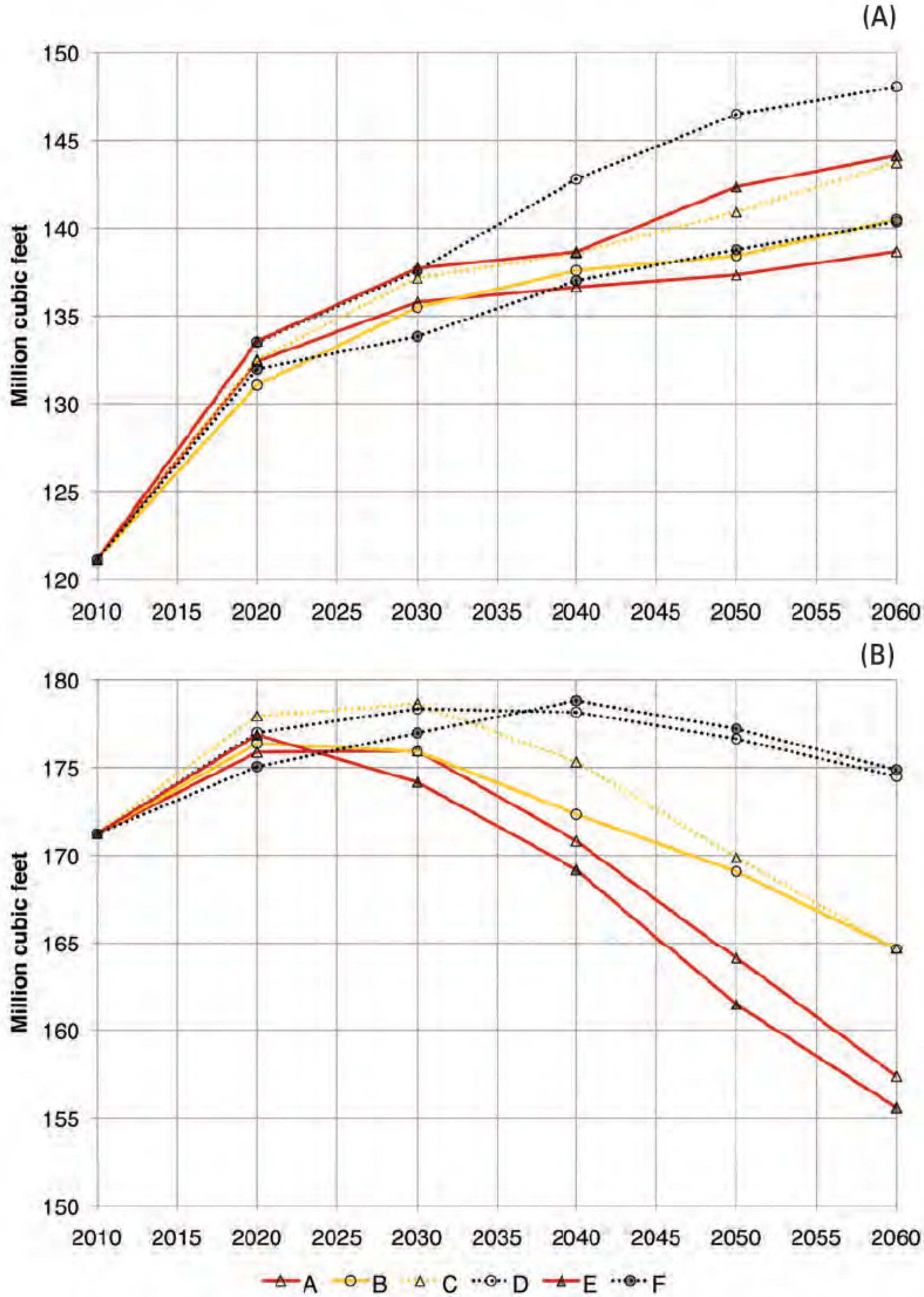


Figure 5.11—Total growing stock volume, 2010 to 2060, for (A) softwoods and (B) hardwoods by Cornerstone Future.

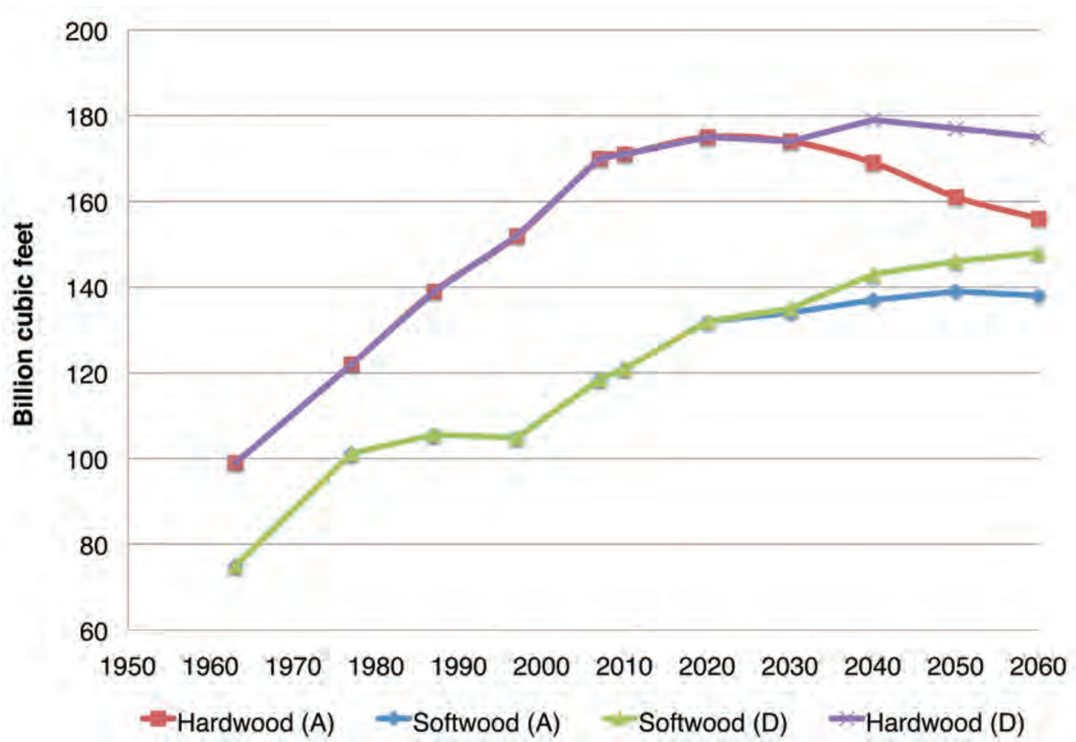


Figure 5.12—Historical (1962 to 1999) and forecasted (2020 to 2060) hardwood and softwood growing stock inventories, for Cornerstones A and D.

between 2,800 million cubic feet for the low-planting future of Cornerstone F and 3,900 million cubic feet for the high-planting future of Cornerstone E by 2060 (see chapter 9 for a discussion of timber supply and timber market forecasts related to the Cornerstone Futures). Historically, because the pines are the dominant plantation species, pine pulpwood has been the most price-responsive timber product in the South.[5] Over the long run, the high-price futures of Cornerstones A and C produce more pulpwood than the low-price futures of Cornerstones B and D, and the high-prices/more-planting future of Cornerstone E produces the most substantial increase in softwood pulpwood output (about 56 percent).

Softwood sawtimber removals also show strong growth potential across the Cornerstones and are also strongly affected by price forecasts (fig 5.19). In contrast to pulpwood however, sawtimber output levels off over time and is not strongly influenced by planting rates. Naturally regenerated sites are maturing in the South, resulting in growth-induced supply increases. This explains why it is possible for softwood sawtimber output to remain stable or increase with decreasing prices. Softwood sawtimber output eventually levels off as the area of natural pine declines over time.

While still separated by low and high price Cornerstones, hardwood removal forecasts vary much less than softwood removals (figs. 5.20). After increasing from 2010 to 2020, hardwood removals are forecasted to decline for the low price Cornerstones (B, D, and F). For the high price Cornerstones (A, C, and E), removals increase until 2030, when they begin to level off. In contrast to the softwoods, direct investment in southern hardwood forests has been negligible, and none is projected for the future. The result is a steady drop in hardwood forest area and in hardwood growing stock inventories.

When considered together, growing stock and removal forecasts indicate a continuation of some important historical trends. Removals are forecasted to increase substantially in spite of a leveling off of inventories (fig. 5.21). This reflects an ongoing transition from a forest mining approach to an agricultural model of forest production. Planted pine management allows for more production from a smaller land base with a more frequent capture of forest growth. This means lower inventories on the ground compared to naturally regenerated forests.

[5] Econometric studies show that sawtimber products are the most price-responsive in the short run. However, in the long run, investments in new pine plantations have led to substantial increases in pulpwood production.

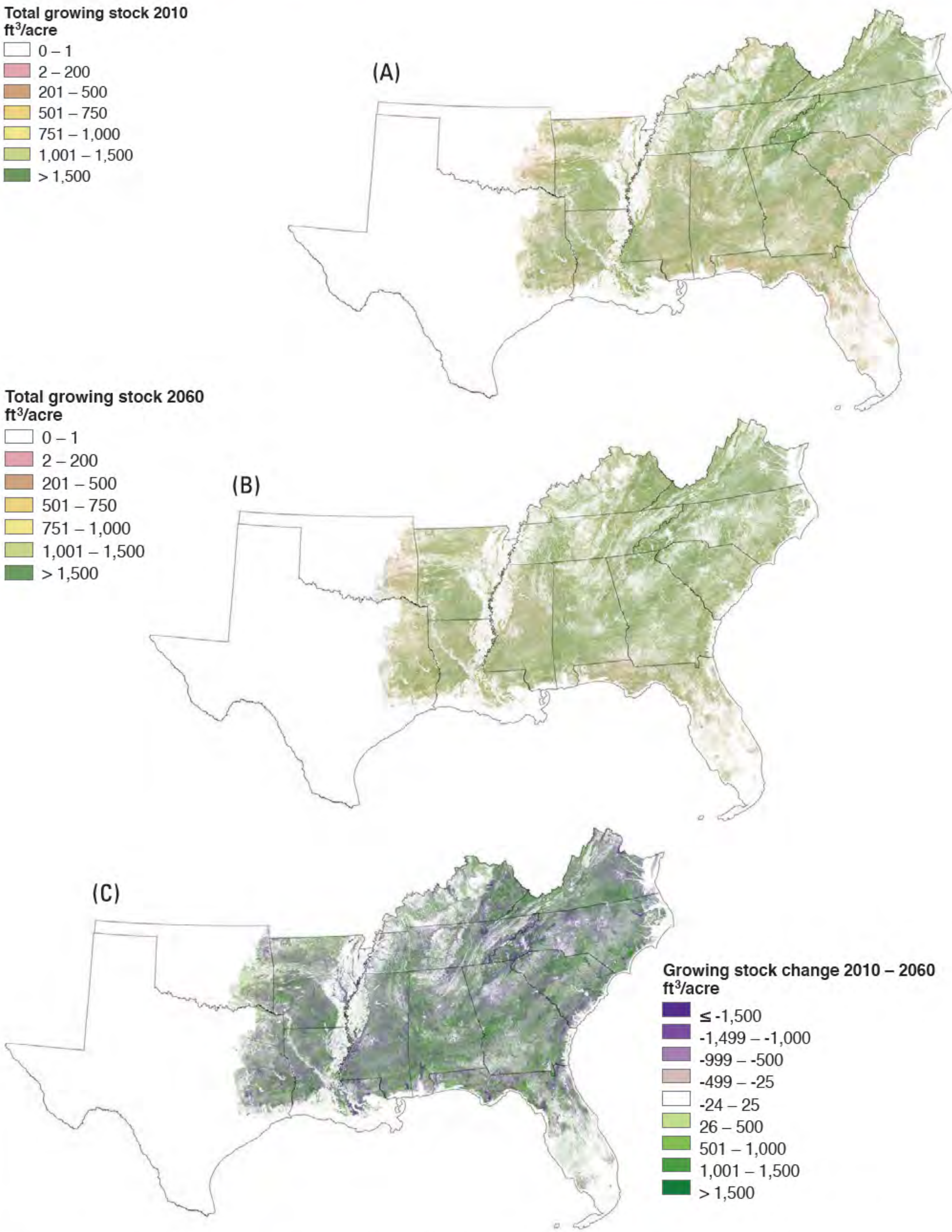


Figure 5.13—County-level density of total growing stock volume (A) for 2010 and (B) forecasted for 2060, and (C) change in total growing stock between 2010 and 2060 under Cornerstone A, which is characterized by high urbanization and high timber prices.

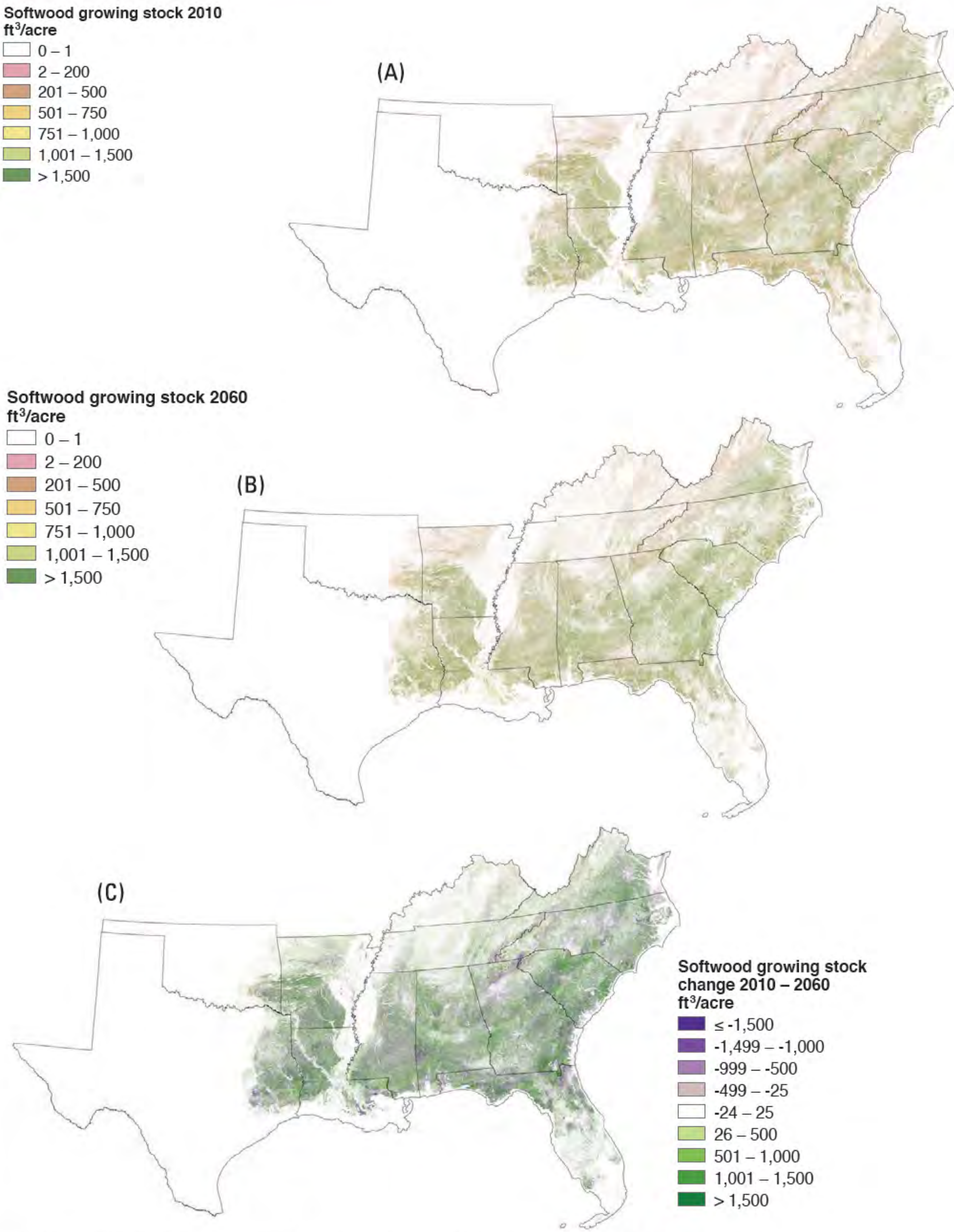


Figure 5.14—County-level density of softwood growing stock volume (A) for 2010 and (B) forecasted for 2060, and (C) change in softwood growing stock between 2010 and 2060 under Cornerstone A, which is characterized by high urbanization and high timber prices.

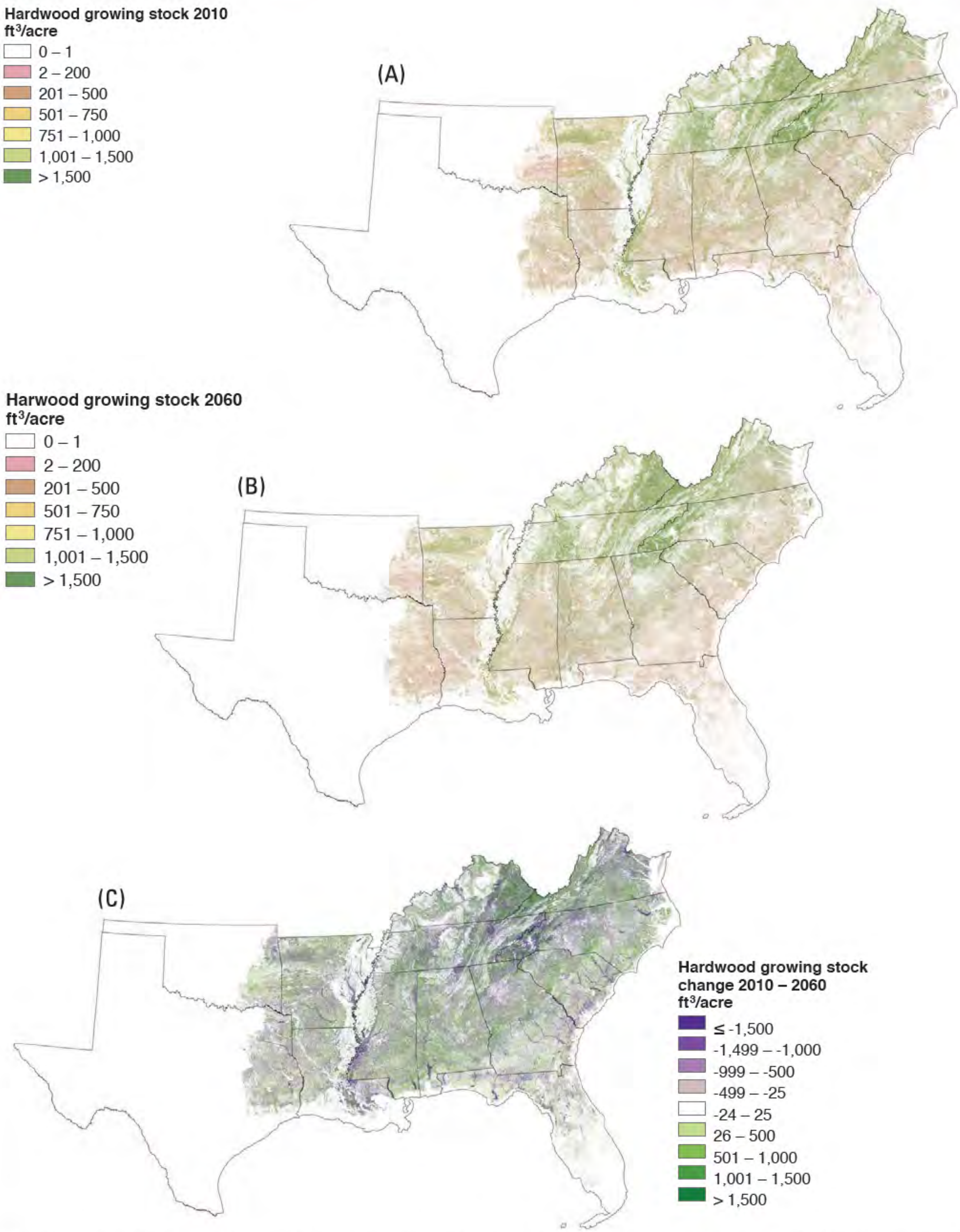


Figure 5.15—County-level density of hardwood growing stock volume (A) for 2010 and (B) forecasted for 2060, and (C) change in hardwood growing stock between 2010 and 2060 under Cornerstone A, which is characterized by high urbanization and high timber prices.

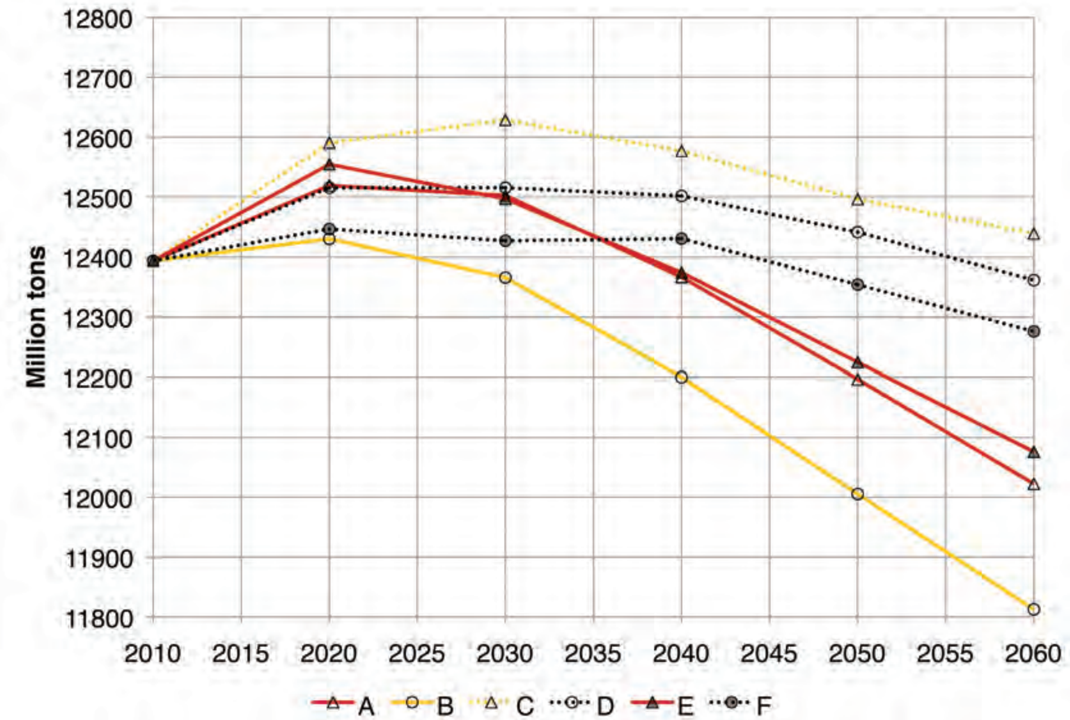


Figure 5.16—Total forest carbon stock, 2010 to 2060, by Cornerstone Future.

Forest Condition Forecasts

The U.S. Forest Assessment System is designed to replicate inventories across broad areas—e.g., aggregates of at least several counties—and for broad forest type groupings. However, the resampling/imputation approach does provide some insights into how drivers of change may alter forest composition at a finer scale, e.g., figure 5.22 shows forest forecasts of hardwood types for the high-urbanization/low-timber-price Cornerstone B, which leads the other Cornerstones in declines of forest area. For this Cornerstone, all hardwood types are forecasted to lose 16 million acres (14 percent) but not all of the forest types lose area at the same rate. Oak-hickory loses about 1 percent compared to 10 percent or more for all other forest types. The most substantial losses are for the other hardwood and yellow-poplar types, which lose 26 percent (6 million and 4 million acres, respectively). Digging a bit deeper, losses of the yellow-poplar forest type are expected to be about 25 percent in the Coastal Plain (1.4 million acres) and the Appalachian-Cumberland subregion (1 million acres), compared to a more substantial loss of 34 percent in the Piedmont (1.6 million acres).

The forecasted area of softwood types is shown in figure 5.23. Loblolly-shortleaf pine is the dominant type and its area stays roughly level through the forecast period. Although overall forest area is expected to decline and softwood removals are forecast to increase, continued investment in plantations enables this type to maintain its area. Longleaf-slash pine is forecasted to increase slightly while oak-pine is expected to decline. All other types exhibit very little change.

Another element of forest conditions that may be especially important for wildlife is the age class distribution of forest types (chapter 6). Figure 5.24 shows forecasts of age classes for broad forest types for the high-urbanization/high-timber-prices/more-planting Cornerstone E. Early-age forests are those that are less than 20 years old, mid-age forests are between 20 and 70 years old, and old-age forests are greater than 70 years old. Because Cornerstone E has the largest change in forest management types (fig. 5.5) and the most harvesting (fig. 5.18), it is a "best" case for the production of early-age forests.

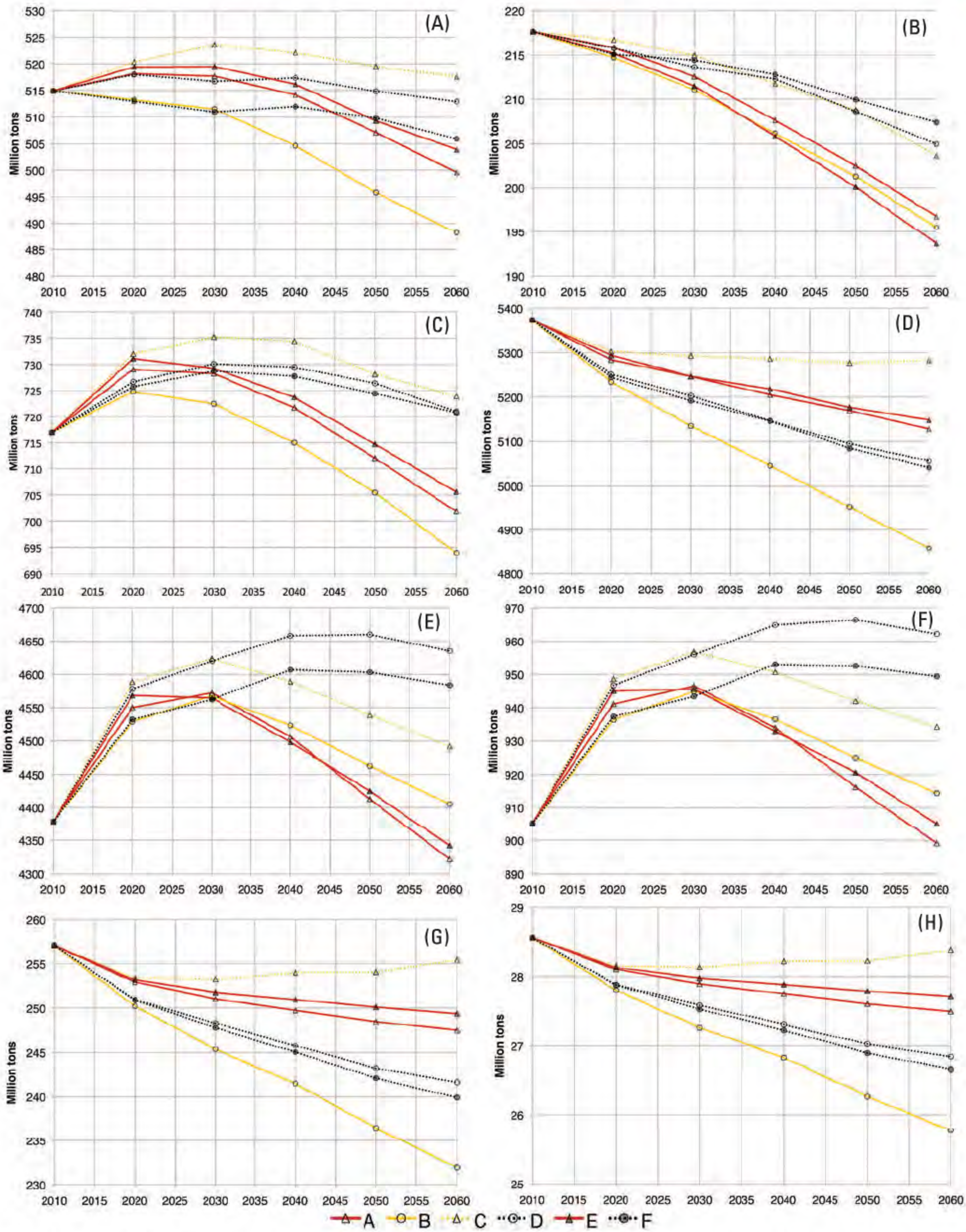


Figure 5.17—Forecasted forest carbon stock, 2010 to 2060, by Cornerstone Future for (A) down trees, (B) standing dead trees, (C) litter, (D) soil organic carbon, (E) live trees aboveground, (F) live trees belowground, (G) understory plants aboveground, and (H) understory plants belowground.

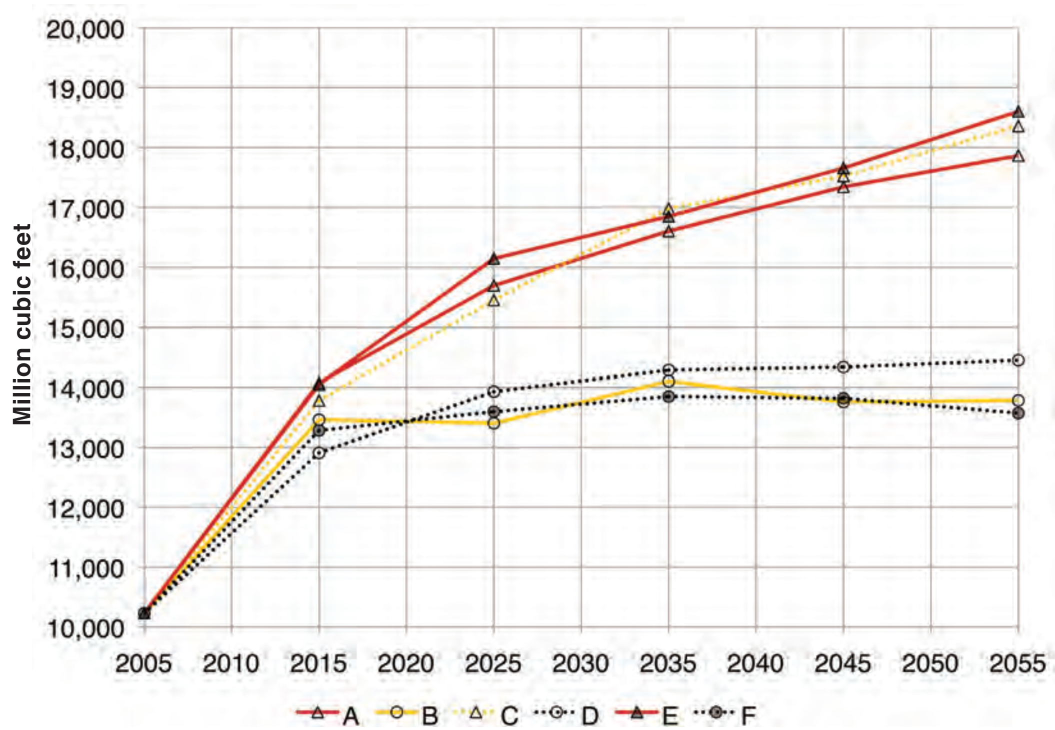


Figure 5.18—Forecasts of total removals from growing stock, 2010 to 2060, by Cornerstone Future.

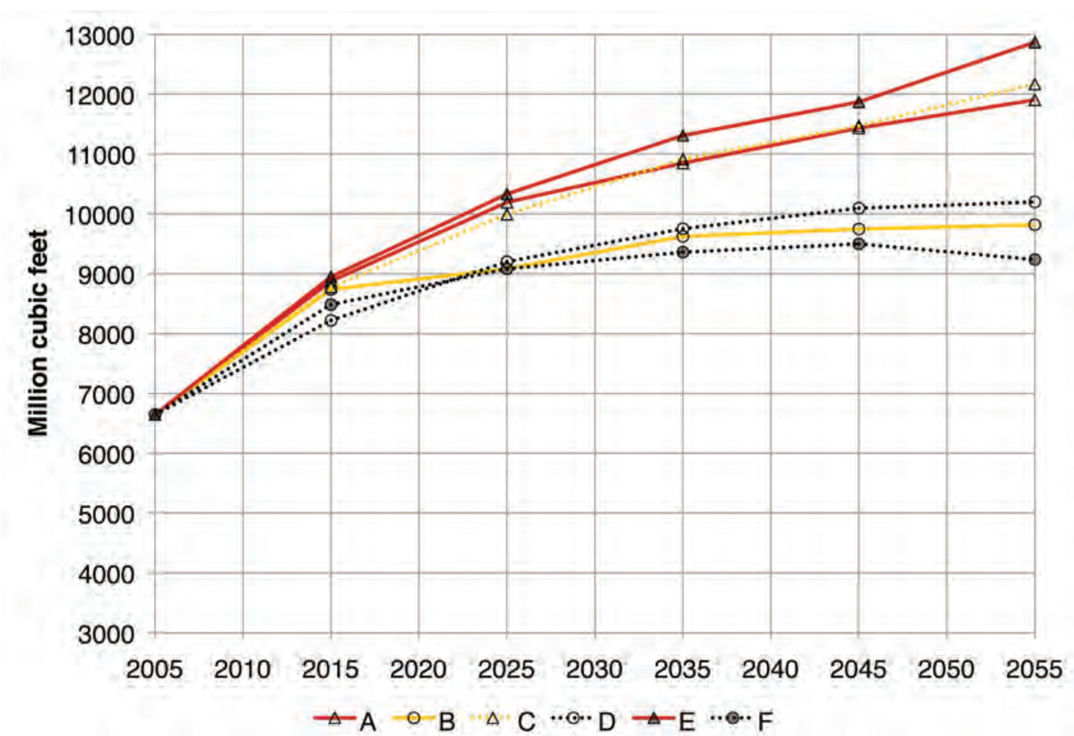


Figure 5.19—Forecasted removals from softwood growing stock, 2010 to 2060, by Cornerstone Future.

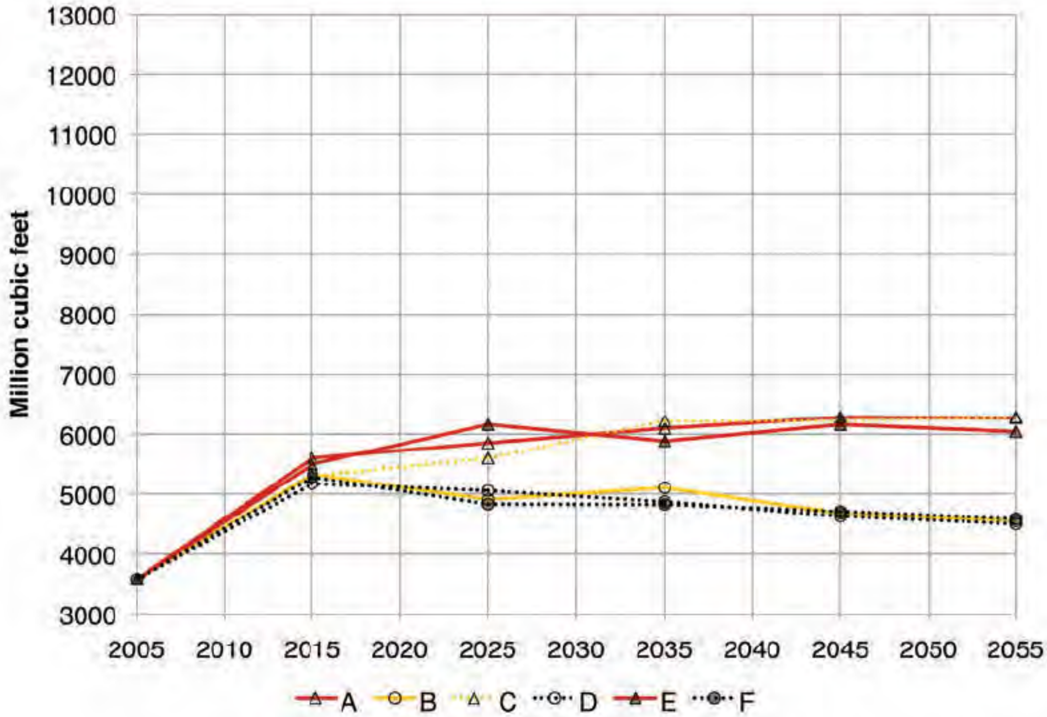


Figure 5.20—Forecasted removals from softwood growing stock, 2010 to 2060, by Cornerstone Future.

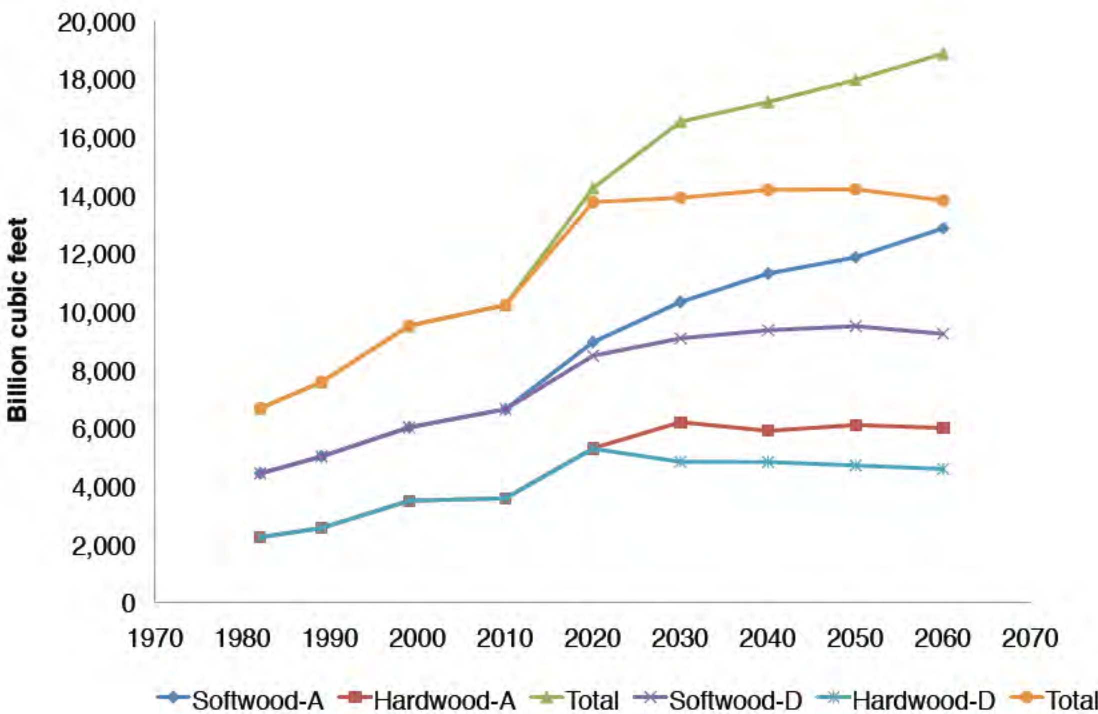


Figure 5.21—Historical and forecasted hardwood and softwood removals for Cornerstone A, which is characterized by high timber prices; and Cornerstone D, which is characterized by low timber prices.

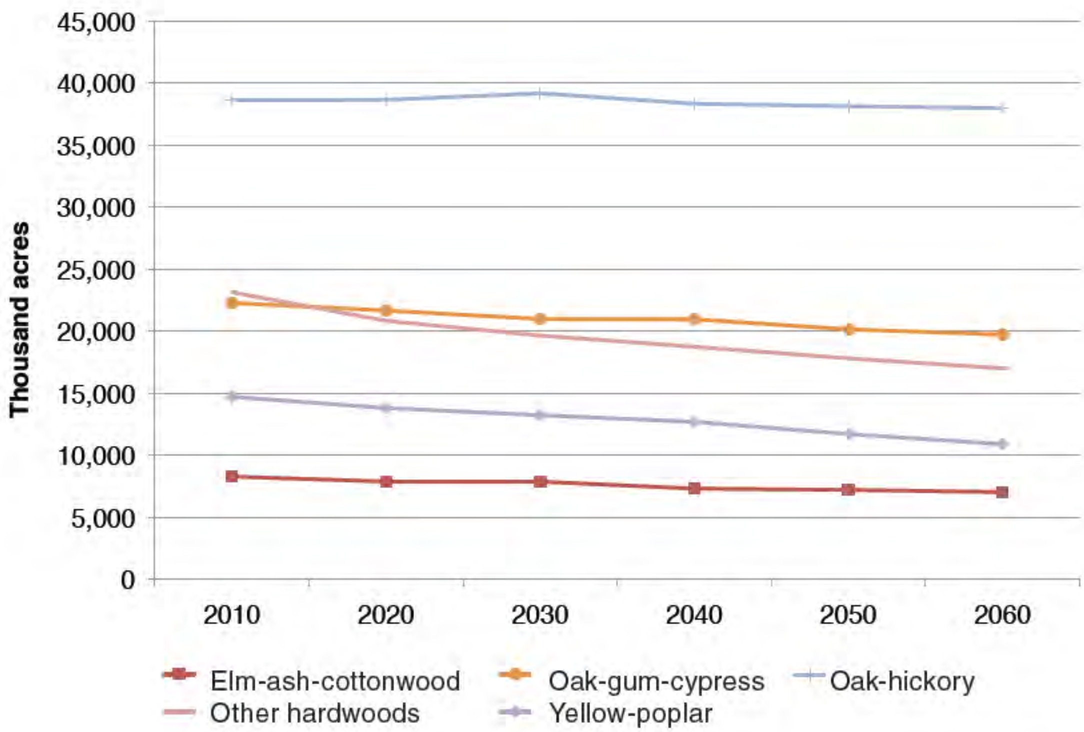


Figure 5.22—Forecasts of the area of hardwood forest types, 2010 to 2060, for Cornerstone B, which is characterized by high urbanization and low timber prices.

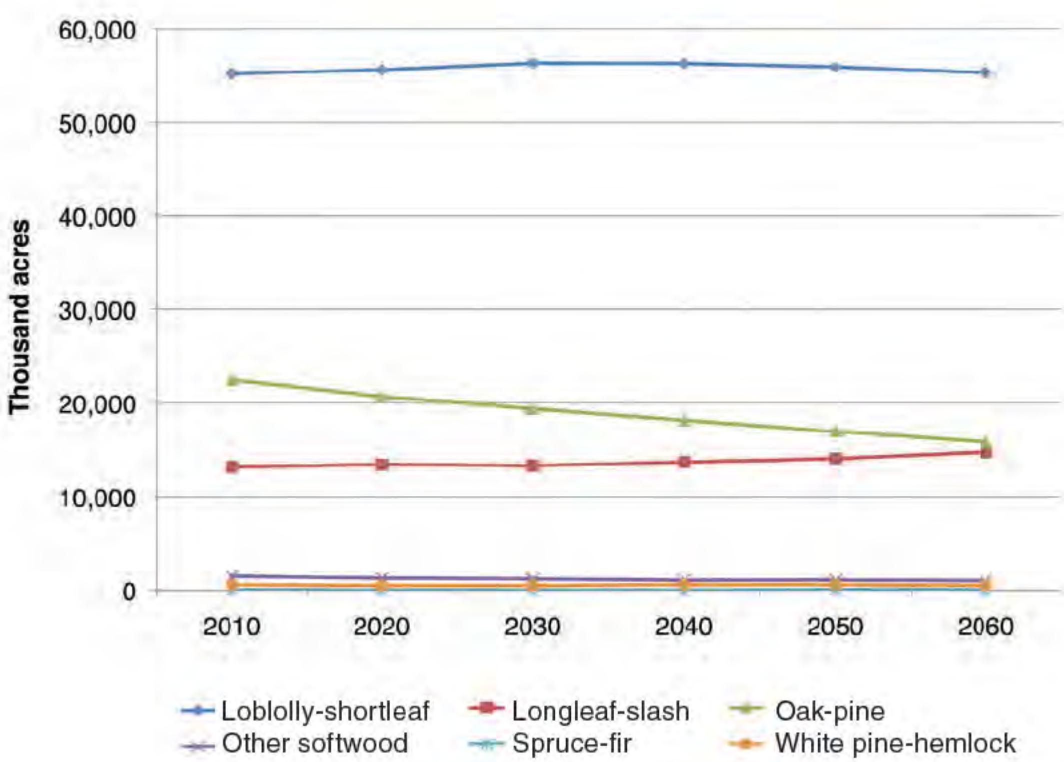


Figure 5.23—Forecasts of the area of softwood forest types, 2010 to 2060, for Cornerstone B, which is characterized by high urbanization and low timber prices.

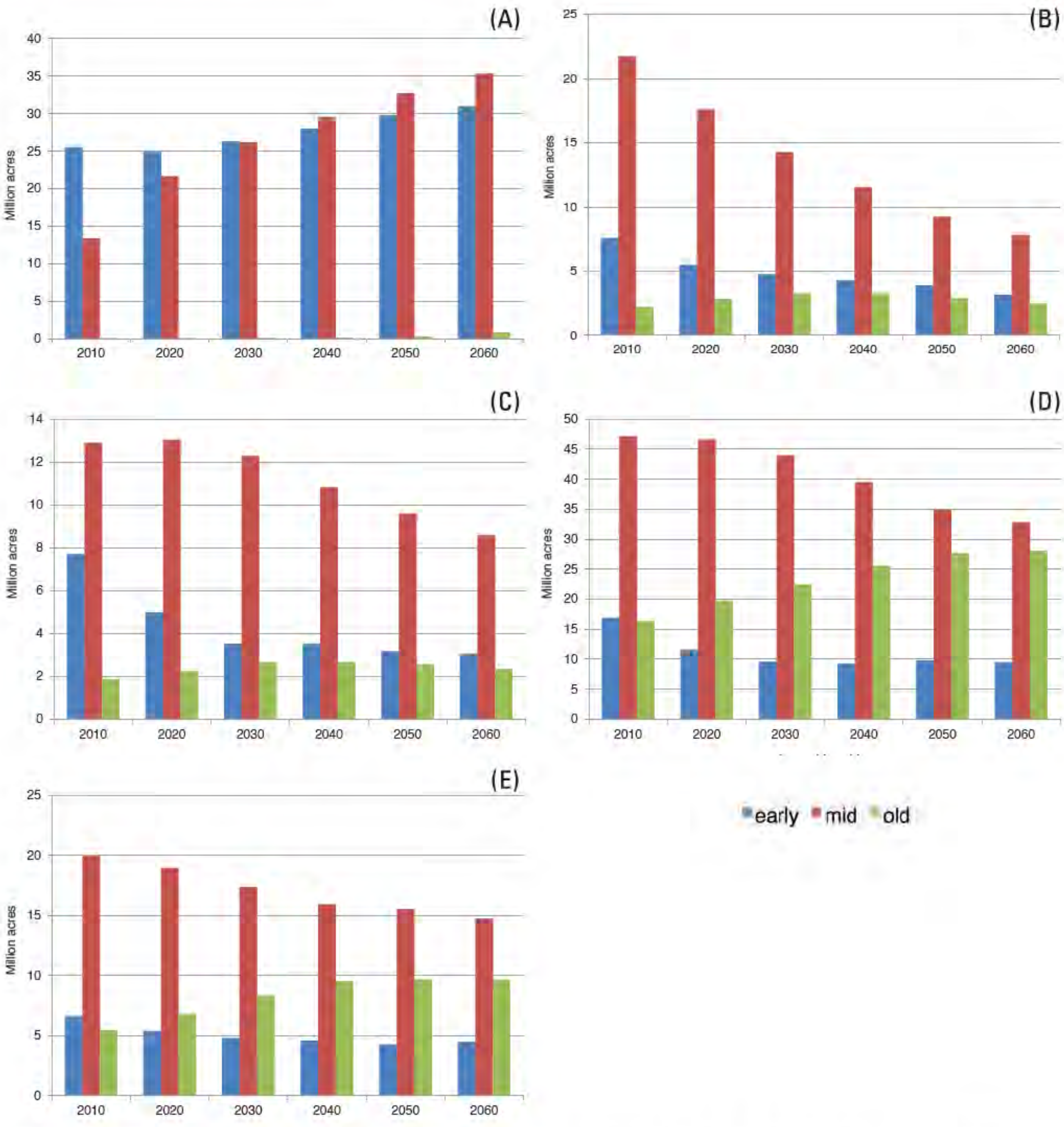


Figure 5.24—Forecasts of forest age classes, 2010 to 2060, for (A) planted pine, (B) natural pine, (C) oak-pine, (D) upland hardwood, and (E) lowland hardwood management types under Cornerstone E, which is characterized by high urbanization, high timber prices, and more planting.

With the exception of planted pine, all forest types are forecasted to experience a decline in early-age forests throughout the forecast period for Cornerstone E. Planted pine forests are forecasted to shift their age-class distributions toward more mid-age forests as the rate of planting declines from its peak in the late 1990s. Mid-age forest area increases strongly, while early-age forest area increases at a more moderate rate. There are practically no acres of old-age forest in the planted pine forest type.

High harvest rates and conversion to planted pine in Cornerstone E shifts the age-class distribution of the naturally regenerated pine types. The area of old-age natural pine stays relatively constant while mid-age forests decline by 13 million acres (about 64 percent) and early-age forests decline by about 4.5 million acres (58 percent). Oak-pine shows a similar pattern of age class changes.

In contrast to the softwoods, hardwood forecasts show an increase in old-age forests. For upland hardwoods, the area of mid-age forests is forecasted to decline by 14 million acres (down from 59 percent in 2010 to 47 percent in 2060). Over this same period, old-age forests are forecasted to increase by 12 million acres (up from 20 to 40 percent) and early-age forests decrease by 8 million acres (down from 21 to 13 percent). Overall, the shift among age classes reveals that the early-age component of the upland hardwood type declines by 44 percent at the same time that the old-age component increases by 71 percent.

The pattern of change for lowland hardwood forest types is similar to changes in upland hardwood forest types, but changes occur at different rates. The mid-age component of lowland hardwood forests declines by about 5 million acres (26 percent), the old-age component increases by about 4 million acres (77 percent), and the early-age component declines by about 2 million acres (33 percent). As with the upland forest types, while the total area of the forest type declines, the average age of the forest type increases.

Contrary to Cornerstone E, Cornerstone F (fig. 5.25) is characterized by less planting and a lower harvest rate (fig. 5.18). The results for Cornerstones E and F therefore bracket the age-class results for all Cornerstones. For Cornerstone F, the area of early-age planted pine declines over time (in contrast to increases simulated under Cornerstone E), and the age class distribution approaches a stasis.

Cornerstone F also results in less dramatic changes in area of natural pine when compared to Cornerstone E, with more stability in the early-age class, increases in the old-age class, and a 33-percent reduction in declines of the mid-aged class. This pattern is mirrored in the oak-pine age classes. For hardwood forest types, however, there is little difference between Cornerstones E and F. This indicates that management changes strongly influence the age structures of the softwood forest types but have little influence on the age structures of hardwood forest types.

DISCUSSION AND CONCLUSIONS

A number of forces of change will affect the development of forests over the next 50 years. The U.S. Forest Assessment System, which accounts for land use changes, climate change, and forest management, is used here to forecast forest conditions for six Cornerstone Futures. Each Cornerstone describes the future in terms of human population, personal income, climate, and the markets for products from rural land uses. Across all of these Cornerstones, total forest area declines and changes among broad forest management types are substantial. Among the five forest management types, only planted pine is expected to increase in area from 2010 to 2060. In 2010, planted pine comprised 19 percent of southern forests. By 2060 planted pine is forecasted to comprise somewhere between 24 and 36 percent of forest area. The midpoint of this range of growth (20-72 percent) is consistent with a recent study by Zhang and Polyakov (2010) that forecasts a 40 percent expansion in planted pine in the South.

Forest types are influenced differentially by urbanization and timber market dynamics. In general, hardwoods are more strongly influenced by urbanization, and softwoods are more strongly influenced by forest management. Although predicted rates of change vary, all forecasts reveal that land use changes and conversion to pine plantations will result in a continuing downward trend in naturally regenerated pine types. Hardwood types are most strongly influenced by urbanization and all Cornerstone Futures show declines in hardwood area that vary in direct proportion to rates of urbanization.

Nearly all forests in the South have been harvested at least once and much of the region's forests are the result of reforestation and an accumulation of biomass. After a long period of accumulating biomass, the South's forests are forecasted to reach a maximum by 2030 and then to either level off or decline.

Southern forests also define a large pool of terrestrial carbon amounting to 12.3 billion tons. Mirroring changes in growing stock volumes somewhat, this pool of carbon is forecasted to reach a peak from 2020 to 2030, and then decline over time. Urbanization patterns are the dominant determinates of the size of the future forest carbon pool, although stronger forest product markets can ameliorate carbon losses.

Forest forecasts address change in climate variables by associating forecasted, multiple year averages of temperatures, precipitation, and potential evapotranspiration

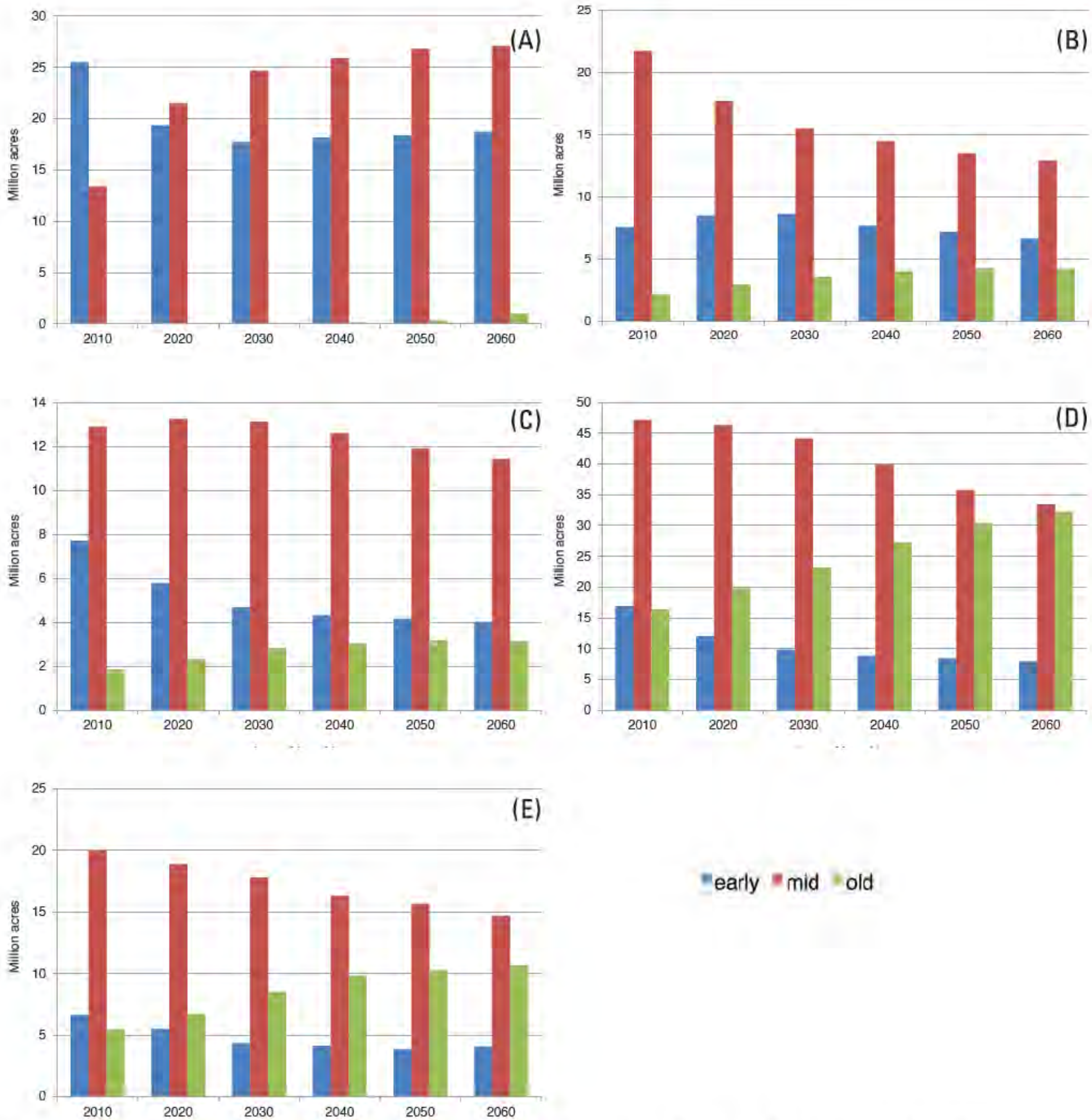


Figure 5.25—Forecasts of forest age classes, 2010 to 2060, for (A) planted pine, (B) natural pine, (C) oak-pine, (D) upland hardwood, and (E) lowland hardwood management types under Cornerstone F, which is characterized by low urbanization, low timber prices, and less planting.

with historical conditions. The potential effects of other changes, most notably CO_2 enrichment do not enter the analysis. Controlled experiments show increased productivity with CO_2 fertilization but also highlight the important interaction with nitrogen, precipitation, and other climate and site variables in determining response (McCarthy and others 2011). These types of impacts on productivity are relatively subtle compared to the variability of field inventory measurements and could not be factored into the forecasts. The potential effects of atmospheric carbon on forest biomass at a regional scale remains an important uncertainty.

The South produces the majority of timber products in the United States (more than 60 percent) including a diversity of both hardwood and softwood outputs. Forest management has increased harvesting throughout the South since the 1960s, and the output per unit of growing stock has increased as management has intensified. The most important factor in changing the productivity of southern forests is the expansion in the amount of planted pine forests. Because of increases in timber supply from 1990 to 2010, removals of forest biomass (growing stock) are forecasted to increase for all Cornerstones, even those that project decreasing prices. Removals of softwood pulpwood are responsive to futures for forest planting and product prices. Under a high price future, softwood pulpwood output would increase by 56 percent, roughly equal to the expansion in output observed between 1950 and 2000. These projections of removals are based on the price assumptions of the Cornerstone Futures and not on forecasts of demand. Timber harvest forecasts under various market conditions linked to the Cornerstones are discussed in chapters 9 and 10.

The combination of land use change, management intensities, and climate result in a number of changes in the composition and structure of the region's forests. The forest type composition of the broad forest management groups are forecasted to change and the age structure of these forests are also altered. Although the overall loss of upland hardwood acreage is forecasted to be in the range of 8 to 14 percent, the oak-hickory forest type remains essentially constant. The yellow-poplar forest type is forecasted to decline the most, with the highest losses forecasted for the Piedmont. The age and species structure of softwood forest types is most strongly influenced by forest harvesting and management tied to timber markets, while the future structure of hardwood forests is most strongly affected by urbanization-driven land use changes (increased population growth and income). Reductions of naturally regenerated pine forests are not equally distributed among age classes: mid-age and early-age forests decline but old-age forests remain relatively constant. For hardwoods, the age distribution of both upland and lowland hardwood types shift, with less of these forest types classified as early age and more classified as older age.

LITERATURE CITED

Coulson, D.P.; Joyce L.A.; Price, D.T. [and others]. 2010. Climate scenarios for the conterminous United States at the county spatial scale using SRES scenarios A1B and A2 and PRISM climatology. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/data_archive/dataaccess/US_ClimateScenarios_county_A1B_A2_PRISM.shtml. [Date accessed: January 10, 2011].

Heath, L.S.; Smith, J.E.; Skog, K.E. [and others]. 2011. Managed forest carbon estimates for the U.S. greenhouse gas inventory, 1990-2008. Journal of Forestry. 109(3): 167-173.

Intergovernmental Panel on Climate Change (IPCC). 2007a. Climate change 2007: synthesis report. Geneva, Switzerland. http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html. [Date accessed: January 24, 2012].

Intergovernmental Panel on Climate Change (IPCC). 2007b. General guidelines on the use of scenario data for climate impact and adaptation assessment. http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf. [Date accessed: January 24, 2012].

Linacre, E.T. 1977. A simple formula for estimating evaporation rates in various climates, using temperature data alone. Agricultural Meteorology: 409-424. Vol. 18.

McCarthy, H.R.; Oren, R.; Johnsen, K.H. [and others]. 2011. Re-assessment of plant carbon dynamics at the Duke free-air CO_2 enrichment site: interactions of atmospheric [CO_2] with nitrogen and water availability over stand development. New Phytologist. 185(2): 343-589.

Miles, P.D.; Brand, G.J.; Alerich, C.L. [and others]. 2001. The Forest Inventory and Analysis database: database description and users manual. Version 1.0. Gen. Tech. Rep. NC–218. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station. 130 p.

Penman, J.; Gytarsky, M.; Hiraishi, T. [and others], eds. 2003. Good practice guidance for land use, land use change, and forestry. Hayama, Kanagawa, Japan: Institute for Global Environmental Strategies for the Intergovernmental Panel on Climate Change. 502 p. http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm. [Date accessed: April 13, 2010].

Poylakov, M.; Wear, D.N.; Huggett, R. 2010. Harvest choice and timber supply models for forest forecasting. Forest Science. 56(4): 344-355.

Smith, J.E.; Heath, L.S.; Nichols, M.C. 2007. U.S. forest carbon calculation tool: forest-land carbon stocks and net annual stock change. Gen Tech. Rep. NRS-13. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 28 p.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture Forest Service. 336 p.

U.S. Department of Agriculture (USDA) Forest Service. 2012. Future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. RMRS-GTR-272. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 34 p.

U.S. Department of Agriculture (USDA) Forest Service. 1988. The South's Fourth Forest: alternatives for the future. For. Res. Rep. 24. Washington, DC: U.S. Department of Agriculture Forest Service. 512 p.

Wear, D.N.; Carter, D.R.; Prestemon, J. 2007. The U.S. South's timber sector in 2005: a prospective analysis of recent change. Gen. Tech. Rep. SRS-99. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 29 p.

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

Wear, D.N.; Greis, J.G. 2002. Southern Forest Resource Assessment: summary report. Gen. Tech. Rep. SRS-54. Asheville, NC: U.S. Department of Agriculture Forest Service. Southern Research Station 103 p.

Wear, D.N.; Huggett, R.; Li, R. [and others]. 2013. Forecasts of forest conditions in U.S. regions under future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-170. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 101 p.

Zhang, D.; Polyakov, M. 2010. The geographical distribution of plantation forests and land resources potentially available for pine plantations in the U.S. South. Biomass and Bioenergy. 34(12): 1643-1654.

CHAPTER 6.
Forest Ownership Dynamics of Southern Forests

Brett J. Butler and David N. Wear[1]

KEY FINDINGS

- Private landowners hold 86 percent of the forest area in the South; two-thirds of this area is owned by families or individuals.
- Fifty-nine percent of family forest owners own between 1 and 9 acres of forest land, but 60 percent of family-owned forests are in holdings of 100 acres or more.
- Two-thirds of family forest land is owned by people who have harvested and sold trees from their land. Assuming that corporate owners have harvested timber, then in all about 8 of every 10 acres of private forest land in the South is owned by individuals or organizations who have commercially harvested their timber.
- The average size of family forest holdings is 29 acres. Ongoing parcellation and fragmentation through estate disposal and urbanization will continue to alter forest management in the South.
- The forest products industry divested about three-fourths of its timberland holdings between 1998 and 2008, the largest ownership transition in the last century. The largest gain in ownership was realized by timber investment management organizations and real estate investment trusts.
- Forest products industry divestitures were likely driven by a combination of factors including mergers, alleviation of timber-scarcity concerns, new technologies for reducing the cost of fiber acquisition, redeployment of capital, and desire to reduce tax burdens.
- As a result of the transfer of holdings from the forest products industry to timber investment management organizations and real estate investment trusts, forest land held by corporations is now a more liquid asset class and will likely trade more frequently in the future. If this holds, individual corporate forest holdings could decline in size over time.
- Although the forest products industry land base was long perceived to be a stable and predictable component of the forest landscape in the South, corporate lands may become less stable and more changeable with implications for both timber and nontimber values of forest lands.
- Increased liquidity of forest assets argues for increased monitoring of ownership changes and of forest land transaction values to better understand the conservation implications of economic trends.

INTRODUCTION

Forest ownership in the South has evolved substantially over the past decade, raising questions about changes in the landowner objectives and approaches to forest management and ultimately about the retention of forest lands. How will ownership change in the future? What are the implications for forest management and forest sustainability? In this chapter, we examine the recent dynamics of forest ownership, develop forecasts of potential future changes, and identify some implications of these changes for forest conditions and management.

Although public ownership of forests in the South has grown slightly over the past 20 years, private owners continue to dominate, now holding 86 percent of forest lands in the region. Nevertheless the private group has experienced a dramatic change among commercial owners and an ongoing change dynamic within the family-held forest ownership group.[2] Since 2000, the forest products industry—defined as landowners who also own primary wood processing facilities, such as sawmills and pulp mills—divested most of its land base (roughly 40 million acres) either by outright sale or through a change in organizational structure. New types of corporate owners, primarily timber investment management organizations (TIMOs) and real estate investment trusts (REITs), now manage these lands using business models that differ from those of previous owners. At the same time, the area controlled by non-corporate owners, primarily family forest owners, has increased, and

[1]Brett J. Butler is a Research Forester, Forest Inventory and Analysis, Northern Research Station, U.S. Department of Agriculture Forest Service, Amherst, MA 01003; David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695

[2]The term family forest owners refers to "families, individuals, trusts, estates, family partnerships, and other unincorporated groups of individuals that own forest land" (Butler 2008).

this group is continuing to evolve in response to changing demographics and objectives. The dynamics of corporate and family forest owners within the context of ongoing urbanization and changes in landscape configuration may alter the operability of forested parcels and the desirability of holding forest lands for long periods of time.

The published literature offers little information about the factors that influence forest ownership dynamics. Most studies have been either descriptive, such as general forest assessments, or they examined timber harvesting or other specific landowner activities. This paucity of information has limited forest projections systems to simple sets of assumptions about the distribution of future forest land among ownership classes. In the projections presented in other chapters of this report (e.g., chapter 5), the area of Federal forest land is held constant and land use changes are allocated among the State, local, and private ownership categories according to their current distributions—as has been the methodology of previous projections systems (Haynes 2003). Although necessary, this approach ignores the dynamics of southern ownership patterns and their resulting impacts on land use and forest management. Therefore, we have collected and applied available information from ancillary studies to augment model results and to provide better insights into potential changes in private forest ownership.

Most forest assessments include some level of information on forest ownership patterns. One of the first timber resource assessments of the United States, conducted in the 1950s, included a separate chapter on the characteristics of forest owners (Josephson and McGuire 1958); and landowner information has become a standard element of other national (Smith and others 2009), regional (Wear and Greis 2002), and State-level (Conner and others 2004) forest assessments.

Apart from the general descriptions, there have been many studies that have examined specific owners and/or activities. Landowner surveys, focus groups, and personal interviews are common techniques for developing a deeper understanding of private forest owners (Hodgden and others 2007). The first forest ownership studies in the United States were conducted in the 1940s (Barraclough and Rettie 1950). National surveys of forest owners were conducted in 1978 (Birch and others 1982), 1993 (Birch 1996), and 2006 (Butler 2008). Unfortunately, comparisons across these studies are hampered by variations in questions asked, subject populations, and/or methodologies.

Many researchers have studied the management behaviors of specific private owners, including timber harvesting, reforestation, and timber stand improvement (Beach and others 2005); recreational access (Snyder and others 2008); forest certification (Kilgore and others 2007); biomass harvesting (Joshi and Mehmood 2010); and carbon sequestration (Fletcher and others 2009). Although their methods varied, most of the studies have taken an econometric approach to test hypotheses regarding landowner decision making.

Of the studies on forest ownership dynamics, parcellation has been a dominant topic, but most studies have focused on impacts (Germain and others 2007) rather than empirically testing the causes of parcellation. The exception was a study of State-level summaries by Mehmood and Zhang (2001) that showed correlation of parcel size with death rates, urbanization, income levels, regulatory uncertainty, and availability of financial assistance.

We know of no published research that has offered a theoretical framework for predicting forest ownership patterns and only a handful of studies that have quantified historical changes in ownership over time. Therefore, our approach in this chapter is to use information from existing studies on landowner behavior to explore the potential implications of a set of alternative futures (chapter 2).

METHODS

The analysis of ownership change relies heavily on surveys of forests and forest owners. We use forest inventory data from the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture (Bechtold and Patterson 2005) for foundational data on broad ownership classes; and the FIA National Woodland Owner Survey (Butler and others 2005) for insights into the characteristics, attitudes, and behaviors of family forest owners. Attributes examined include parcellation and its impact on resource availability, absentee ownership, public access to private lands, and intergenerational land transfers. We rely on existing literature and expert interpretation to describe potential consequences.

Our examination of the forest products industry divestiture involved use of an ownership database and geographic information system output from Lanworth, Inc., to generate estimates of total acres of ownership classified into the following categories: forest products industry, TIMOs, REITs, and other corporations. We use summaries of these data to evaluate totals and changes by subregion and State for 1998, 2003, and 2008. Although not entirely consistent with FIA records, the Lanworth database provides an index of change that is consistent across all Southern States for the selected time periods.

We base our discussion of the determinants of landownership change on a recent analysis[3] of timber industry trends in

[3] Wear, D.N. 2010. The disintegration of timber growing and wood products manufacturing in the United States. Draft manuscript on file. U.S. Department of Agriculture, Forest Service, 3041 Cornwallis Rd., Research Triangle Park, NC, 27713.

Definitions of owner types

Private forest owners—Families, individuals, corporations, and other private entities that own forest land (Butler 2008).

Corporate (private corporate)—An ownership class of forest land that is owned by entities that are legally incorporated (Smith and others 2009). This includes forest products industry, real estate investment trusts, and timber investment management organizations.

Family—Families, individuals, trusts, estates, family partnerships, and other unincorporated groupings of individuals who own forest land (Butler 2008).

Other private—Private forest owners other than corporations, families, or individuals. This category includes Native American lands, unincorporated partnerships, and clubs.

Public forest owners—Forest land managed by Federal, State, or local government agencies.

Federal—An ownership class of public lands administered by Federal Government agencies (Smith and others 2009). Examples include the U.S. Forest Service, Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Departments of Defense and Energy.

State—An ownership class of public lands owned by States or lands leased by States for more than 50 years (Smith and others 2009).

Local—An ownership class of public lands administered by counties or local public agencies, or lands leased by these governmental units for more than 50 years (Smith and others 2009).

the South. Our goal is to develop insights on the potential management and use implications of ownership changes by evaluating recent and ongoing research on structural dissimilarities of management by different types of forest ownership.

DATA SOURCES

Comparisons of forest conditions across ownership types are derived from FIA inventories, which are coordinated at the State level by crews measuring conditions on permanent forest inventory plots (Bechtold and Patterson 2005). The current design of the FIA inventory in the South involves a 5-year measurement cycle, with 20 percent of a State's plots visited every year.[4] We base our analysis on the most recent surveys within each of the 13 Southern States and on forecasts of forest inventories (chapter 5).

As a complement to its biophysical information, the FIA National Woodland Owner Survey collects information on: who owns the forest, why they own it, how they use it, and what they intend to do with it. From 2002 to 2006, the years of the data used in this chapter, 5,517 southern family forest owners responded to the survey representing a cooperation rate of 45 percent (Butler and others 2005; www.fia.fs.fed.us/nwos). The selection procedure for the survey is identical to that used to conduct the FIA forest inventory: (1) each State is divided into 6,000-acre hexagons, and within each hexagon a sample point is randomly placed; (2) remote sensing and ground truthing determines whether the point is forested, and if so, the landowner is identified through property tax records; (3) if the forest owner is private, then they are included in the sample, and 20 percent of them are contacted each year.

Because FIA inventories are conducted on a 5-year or longer rotation, rapid changes associated with forest products industry lands divestiture will be reported with a lag. To track the most recent changes in corporate ownership, we used the Lanworth proprietary databases of ownership and ownership transactions to estimate changes in the acreage owned by various corporate types of owners and the spatial distribution of those types.

Lanworth created three datasets for the South: (1) total acres classified into four corporate ownership subgroups by State for 2008; (2) total acres classified into four corporate ownership subgroups by State for 2003 and 1998; and (3) generated area density maps by county for the subgroups in 2008.

The Lanworth definitions of four corporate subgroups are as follows:

(1) Forest products industry (also known as vertically integrated timber products companies)— Publicly traded as well as privately held organizations that produce paper and/or wood products from forest resources and own or lease more than 100,000 forest acres across the South.

[4] In 1998, FIA's continuous design of periodic inventories (in place since the 1930s) was replaced by the annual inventory system. Full implementation of the annual system requires Federal appropriations as well as supplemental funds from each State. In practice, the cycle can range from 5 to 10 years, with more Southern States having approached full implementation than States in other regions.

(2) Timber investment management organizations (TIMOs)—Management companies that aid institutional investors in buying, selling, and managing their timberland investments. This category includes professionally managed funds which have 100,000 acres or more across the South.
(3) Real estate investment trusts (REITs)—Corporations that use the pooled capital of many investors to purchase and manage property. This category includes public and privately held REITs with assets of 100,000 acres or more across the South. Note that these data were compiled before Weyerhaeuser Corporation transitioned from a vertically integrated timber products company to a REIT.
(4) Other corporate—All other corporate businesses that have 100,000 acres or more of forest land across the South.

RESULTS

There are 32 million acres of publicly owned forests across the Southern United States; these acres represent 14 percent of the total forest land area (figs. 6.1 and 6.2). The agencies that control these lands include the U.S. Forest Service, the U.S. Fish and Wildlife Service, and the U.S. Department of Defense as well as various State and local government agencies. These forests are not subject to development pressures as private lands are, but they are subject to the needs of society and the resulting laws and regulations that govern their use.

By all measures, the South is dominated by private ownership. Over 5 million private forest owners across the region hold 200 million acres of forest land, 86 percent of the total forest land area. Within this category is a diversity of owners ranging from large, multi-national corporations with acreage in the hundreds of thousands to families and individuals with a few acres.

On average, families and individuals own two out of every three acres of private forest land. The remaining one-third of the private acreage, 66 million acres, is owned by corporations, conservation organizations, partnerships, and tribes; and it is the corporations that own the bulk of these acres. Within this corporate category are the traditional, vertically integrated timber products companies, but an increasing amount of acreage is owned by TIMOs and REITs. Organizations in the other private ownership category have a diversity of reasons for owning forest land. Conservation organizations may own particular parcels to protect special features of the landscape. Many camps and churches own land to offer their members rustic and secluded environments. Hunting and other clubs may own land for specific recreation purposes.

Family Forest Owners

There are two very distinct ways of looking at family forest owner statistics: numbers of owners and numbers of acres. Looking at the distribution of family forest owners by size of forest holdings (fig. 6.3) shows that nearly 60 percent of family forest owners own between 1 and 9 acres. But looking at the distribution of *acres* shows that 60 percent of all family forest land is in holdings of 100 acres or more. Both ways of looking at the data can be useful, depending on the topics being addressed; often they should be considered together.

On an acreage basis, family legacy, aesthetics, and land investment are the primary reasons that family forest owners give for owning forests (fig. 6.4). On an ownership basis, aesthetics, part of home, and privacy are the most important reasons. Knowing their reasons for owning is important for learning what motivates people and leads into what their concerns are—critical information for understanding, communicating with, and assisting family forest owners.

When trying to understand owners, it is also important to be cognizant of the demographics involved. Compared to the general population, family forest owners tend to be older, better educated, and have higher incomes. According to the National Woodland Owner Survey statistics, 69 percent of family forest owners are men. A caveat needs to be added about the instructions on the survey, which specified that one person, the primary decision maker, answer the questions. If that person was a married man, there would be no way to indicate if his wife is a co-owner of the land, possibly skewing the results on gender.

Although timber production is not a primary objective of most family forest owners, two-thirds of all family forest land is owned by people who have commercially harvested some of their trees. But only 18 percent of the family forest land is owned by someone who has a written forest management plan. The number of owners who have received management advice is significantly higher, but at 42 percent, still represents less than half of all family forest land. The numbers are even less encouraging when viewed from the number of owners perspective: only 3 percent of the family forest owners have a written management plan and only 13 percent have received forest management advice. These data raise important questions about owners' abilities to maximize benefits from their land and decrease the likelihood that they are leaving it in the best possible shape to meet future needs.

Much of the family forest land has been owned for relatively long periods of time (fig. 6.5); related to this fact, and correlated to the relatively advanced age of many owners

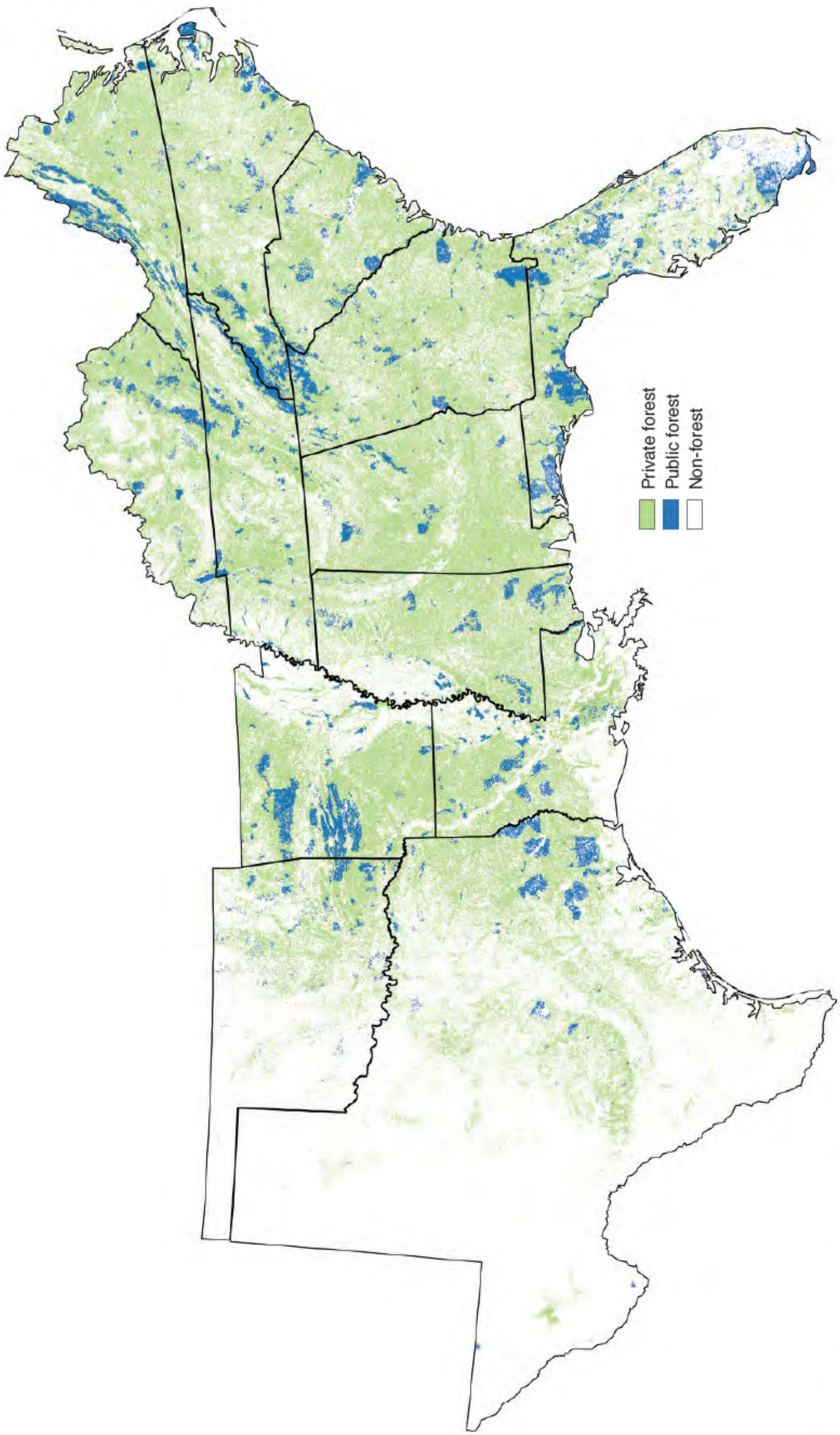


Figure 6.1—Forest ownership across the Southern United States, 2006.

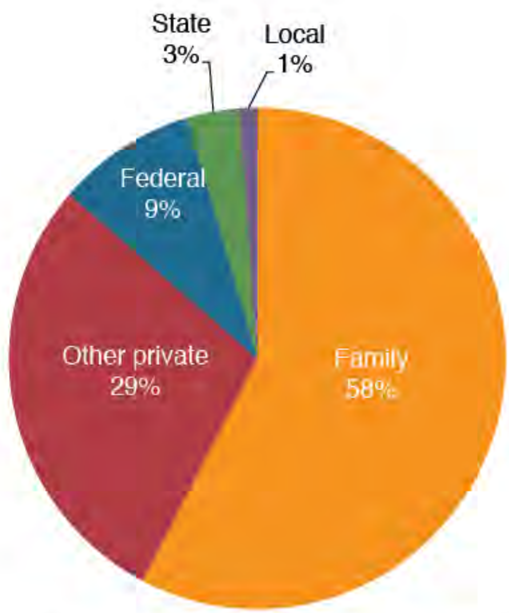


Figure 6.2—Distribution of forest ownership (percent) in the Southern United States, 2006.

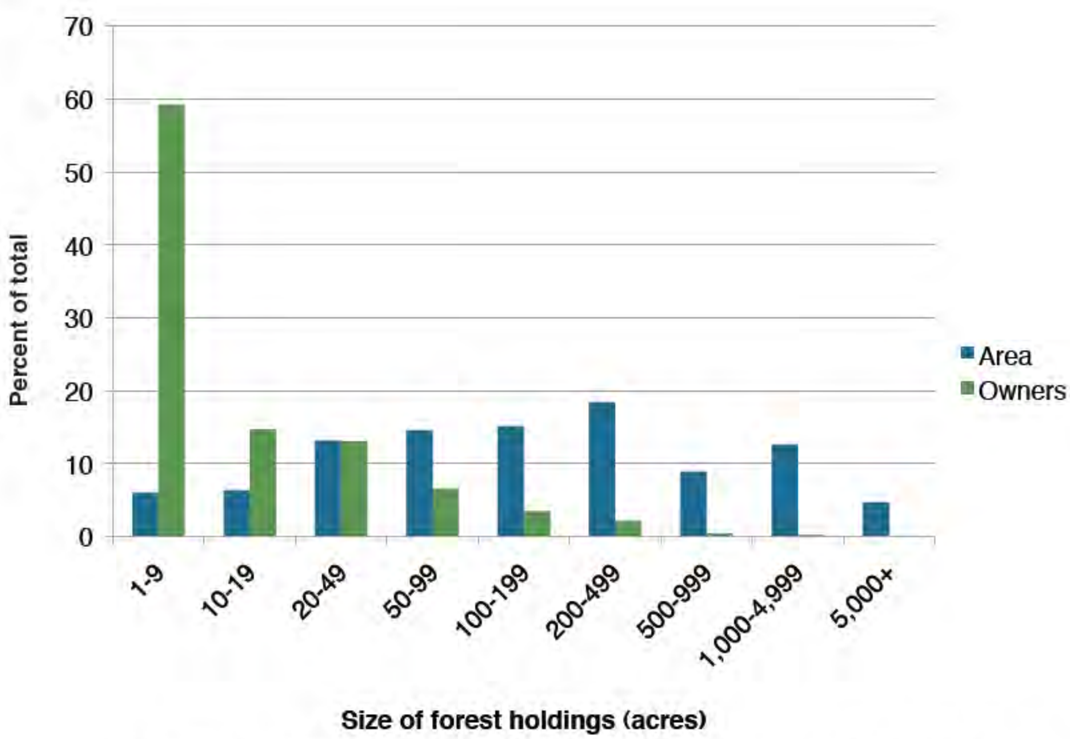


Figure 6.3—Percent of family forests by total area and number of owners in each of nine size classifications for the Southern United States, 2006.

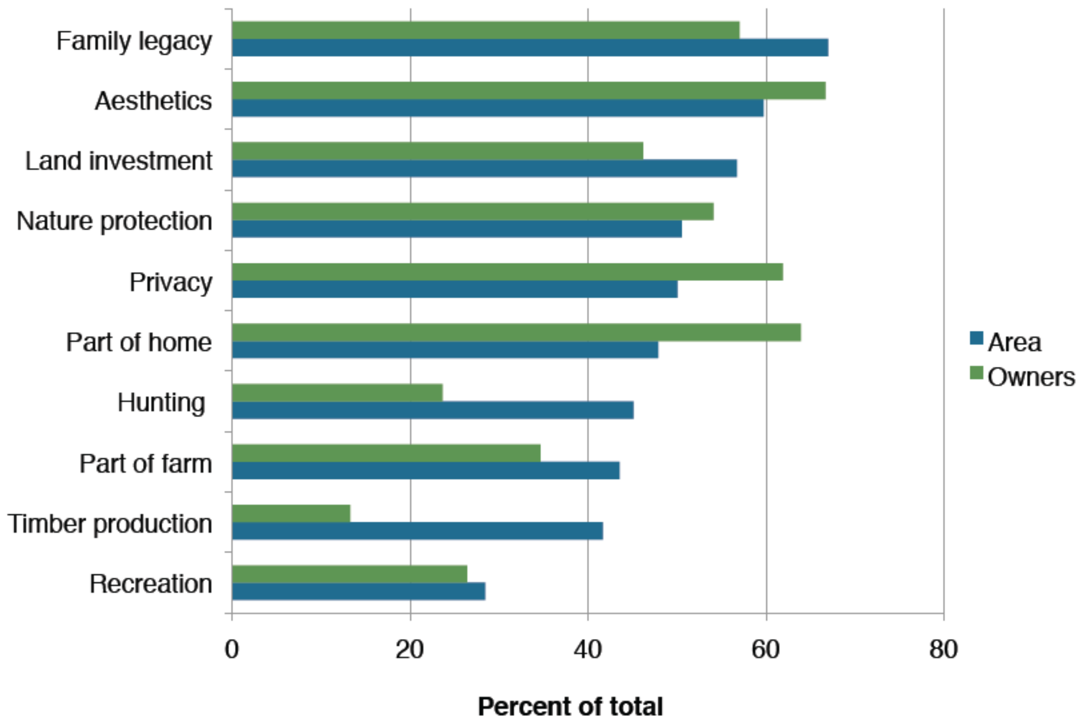


Figure 6.4—Reasons for owning southern family forests as a percent of total area and total number of owners, 2006.

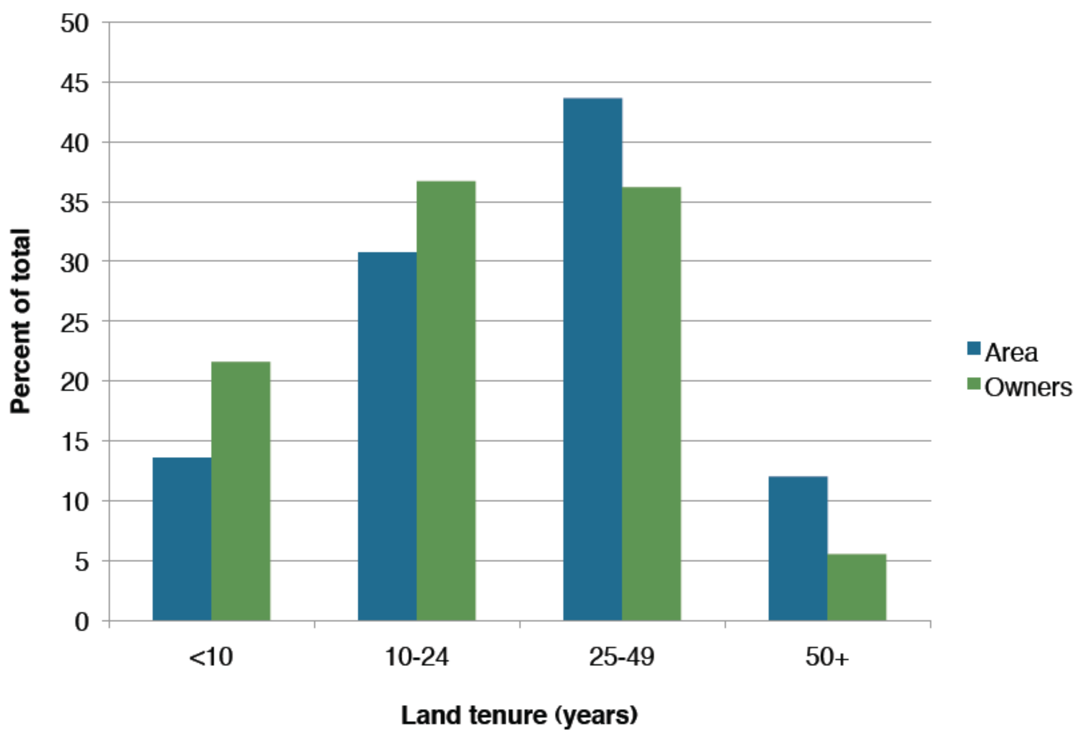


Figure 6.5—Length of ownership of southern family forests as a percent of total area and number of family forest owners, 2006.

(34 percent of the family owners, who own 47 percent of the family forest land, are 65 years of age or older), it is not surprising that 11 percent are planning to pass on their land (19 percent of total family forest land) in the near future (fig. 6.6). It is at this point of transfer that land use often changes, as well as changes in management practices. Family legacy is an important objective, but it is also a major concern (fig. 6.7); owners are uncertain about their heirs' desires to keep the land, whether they can afford to hold it, and whether an equitable transfer will be possible.

The often stark contrast between acreage and ownership statistics, as shown by differences in the relative ranking of ownership objectives or other characteristics, is an indication that the size of forest holdings is important. Size is the single most predictive variable collected on the National Woodland Owner Survey. The average size of family forest holdings is 29 acres. Economies of scale can make it difficult to implement traditional forestry tools on small acreages, and in some circumstances, traditional prescriptions will conflict with owners' objectives. Continued parcellation of forest holdings will likely exacerbate these issues.

Averages can be misleading and are usually not the best way to understand large, diverse groups. To determine whether naturally occurring subgroups of family forest owners exist, the Sustaining Family Forest Initiative conducted a multivariate, hierarchical analysis that identified four attitudinal subgroups: woodland retreat, working the land, supplemental income, and uninvolved owners (Butler and others 2007). Woodland retreat owners are most interested in the amenity values their forests provide and more likely to have their home associated with their forest land. Working the land owners are multiple objective owners; they are interested in a combination of amenity and financial values. Supplemental income owners are interested in earning money from their land, either through timber harvesting or land sales, and tend to have larger properties. Uninvolved owners tend to not have strong ownership objectives. Understanding the desires and concerns of these subgroups will improve policies, programs, services, and outreach efforts aimed at forest sustainability.

Historical Family Ownership Dynamics

Dynamics of family forest ownership patterns happen across different spatial and temporal scales. At the broadest scales, family forest ownership is fairly stable. But within this group, many family forest owners are selling or otherwise transferring land to other family forest owners, either within their families or outside of them.

Family forest ownership dynamics are the result of a combination of personal/familial circumstances and broader social factors and market conditions. Most family forest owners have a deep love of their land. They know why they own it, and many know what they want for the future of their land, but many will also be confronted with challenges and opportunities, only some of which are known. Because of increasing population pressures and ensuing increases in property values, owners can be faced with increased taxes, increased offers for their land, and changes in the rural environment.

Family legacy is an important objective for many family forest owners, but may also be one of their greatest concerns and challenges. For many family forest owners, their property is their largest financial asset. If medical, educational, or other expenses arise, they may be forced to do things with their land than they would not do otherwise. And even for those who have no immediate financial needs or objectives, a (seemingly) lucrative offer can be difficult to refuse.

Historical Corporate Ownership Dynamics

In the late 1990s, the forest products industry held about 20 percent of the forest land in the South (Conner and Hartsell 2002). Since then, this ownership subgroup has dropped to less than 5 percent, representing the most rapid recent change in forest ownership and management. This loss resulted mainly from companies selling their forest assets and sometimes changing their corporate structure. Regardless of approach, however, these transactions fundamentally altered how the involved forests and land were managed. Separating forest management from the forest processing industry changes both the long-term objectives of owners and the structure of forest investments.

According to the Lanworth data, corporate ownership changed dramatically from 1998 to 2008 (fig. 6.8) and has continued to change since then—an example is the Weyerhaeuser Corporation conversion from a vertically integrated timber products company to a REIT in 2010. During that period, the forest products industry ownership declined by roughly 70 percent from 23.4 million to 7.5 million acres (table 6.1). TIMOs captured most of these lands as their acreage increased from 2.2 million to 13.4 million acres. The holdings of REITs increased by about 20 percent while the “other corporate” ownership remained relatively constant. The total corporate forest ownership group as defined by Lanworth declined by about 10 percent over this period, ostensibly as non-corporate entities acquired some lands during divestiture. For example, we know that conservation organizations such as The Nature Conservancy acquired some of the land offered in these sales.

From 1998 to 2008, TIMO acreage grew from 7 percent to 45 percent of the corporate ownership group (fig. 6.9). This change mirrors the decline from 71 percent to 25 percent in forest products industry holdings over the same period.

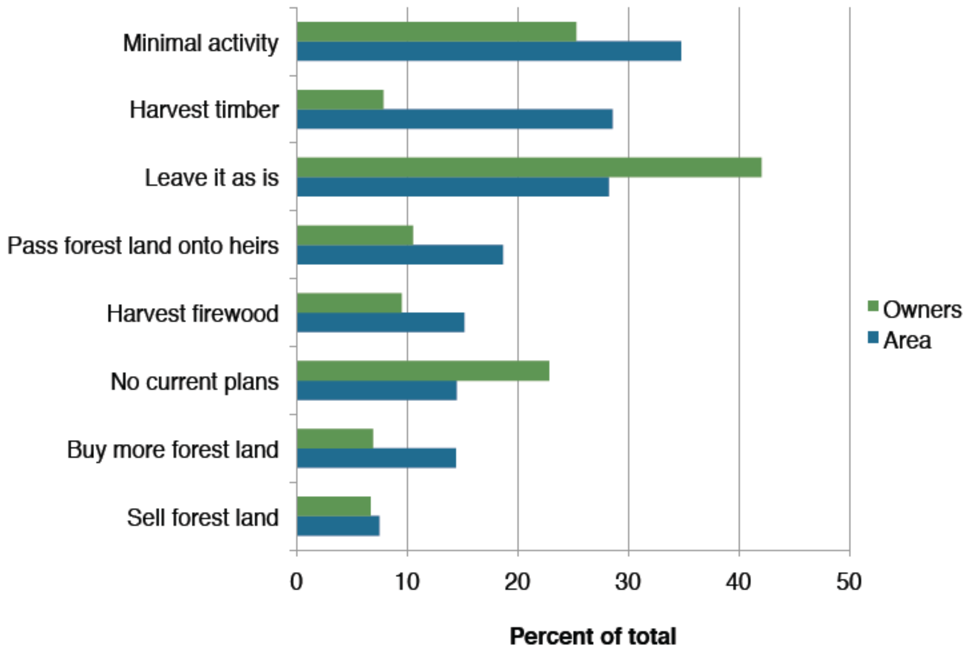


Figure 6.6—Future plans of southern family forests as a percent of total area and number of family forest owners, 2006.

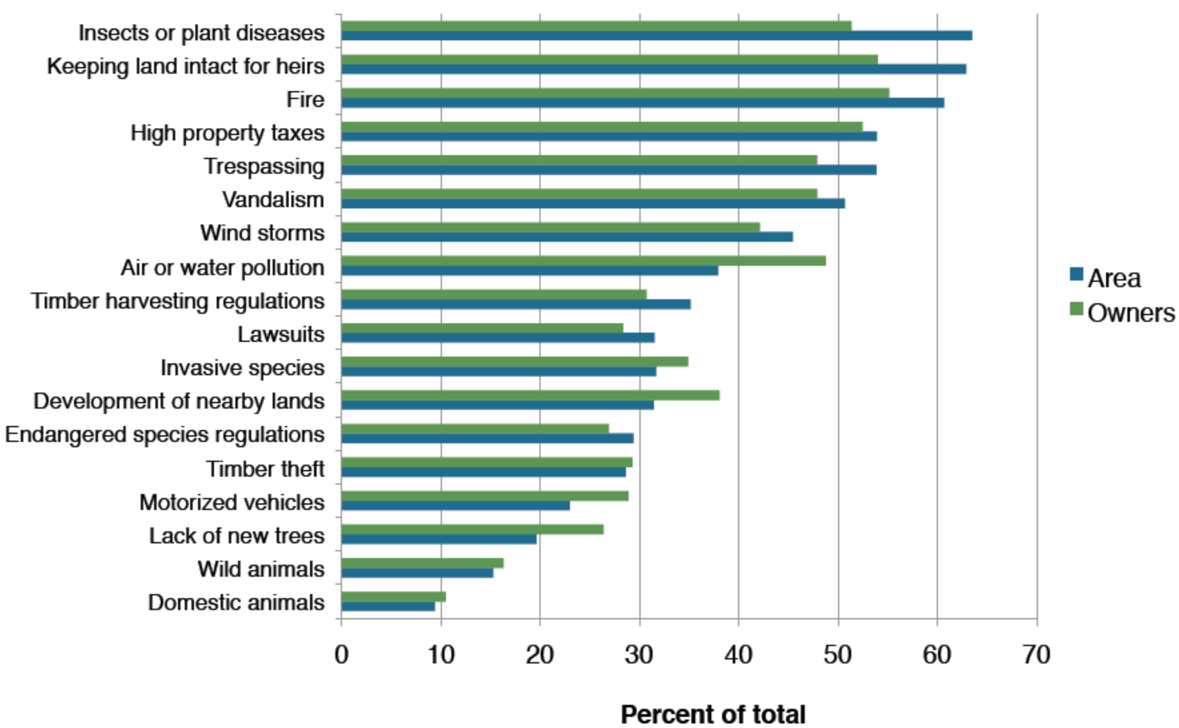


Figure 6.7—Concerns of southern family forests as a percent of total area and number of family forest owners, 2006.

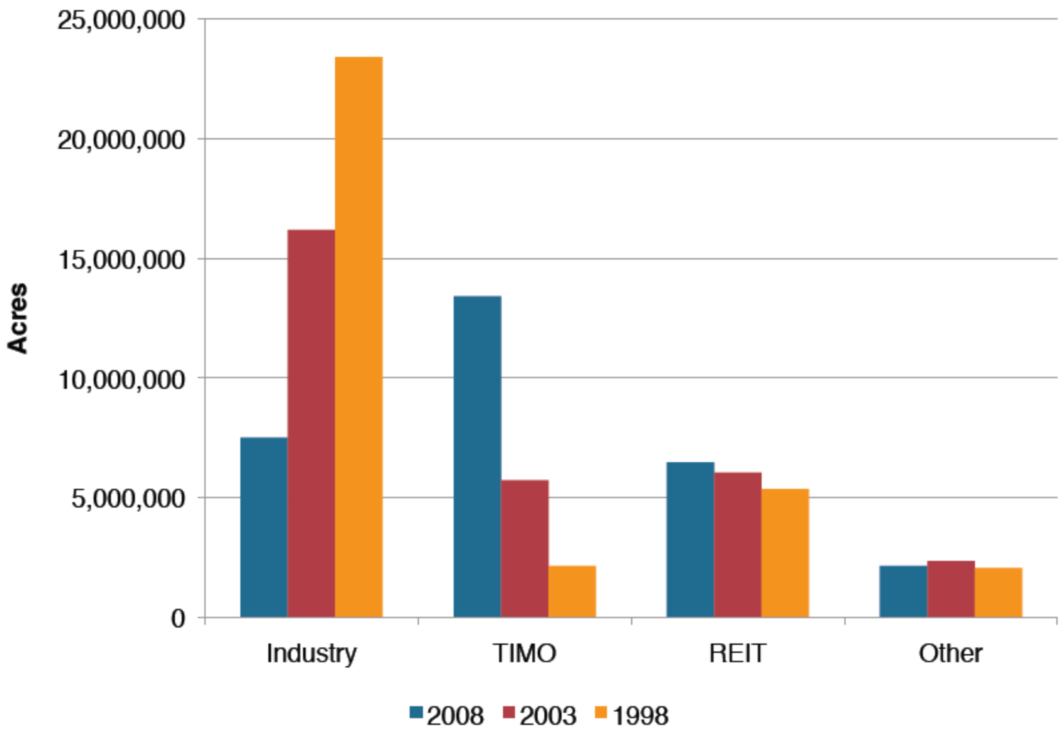


Figure 6.8—Corporate forest ownership for forest products industry (also known as vertically integrated timber products companies), timber investment management organizations (TIMO), real estate investment trusts (REIT), and other corporate in 1998, 2003, and 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

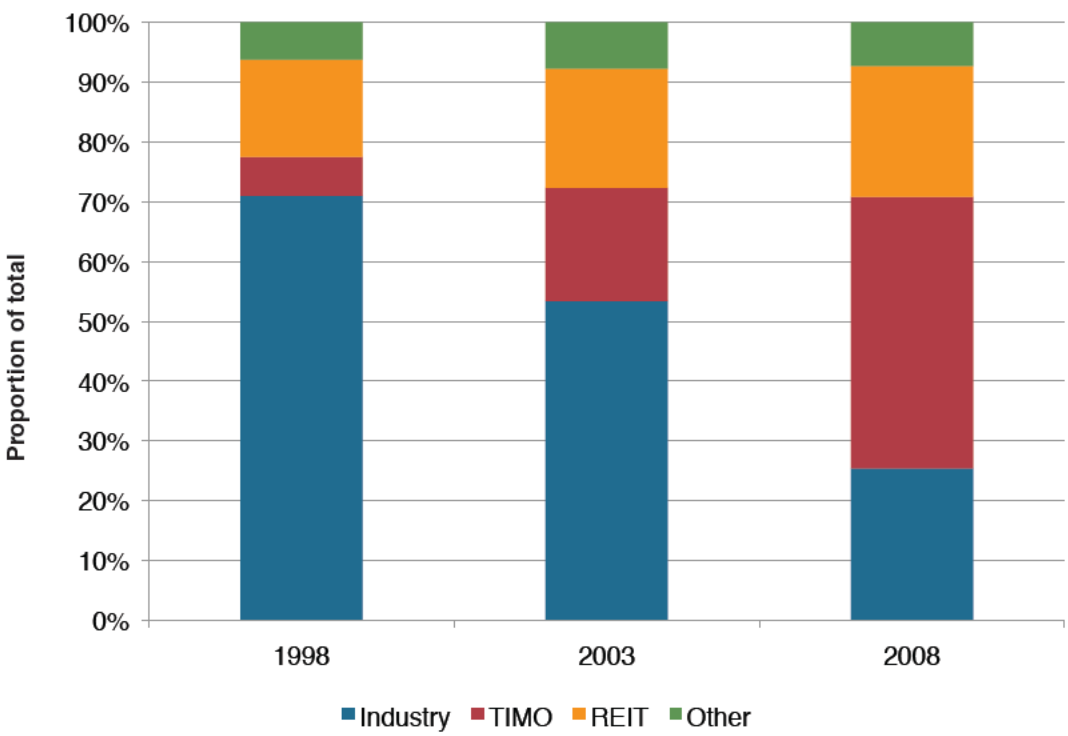


Figure 6.9—Proportion of corporate forest ownership by subgroup, 1998, 2003, and 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

Table 6.1–Corporate forest ownership subgroups by State, 1998 and 2008

State	Total corporate		Forest products industry		Timber investment management organizations		Real estate investment trusts		Other corporate	
	1998	2008	1998	2008	1998	2008	1998	2008	1998	2008
	acres									
Alabama	4,360,000	4,160,000	3,240,000	1,264,000	772,000	2,115,000	348,000	555,000	0	227,000
Arkansas	3,931,000	3,671,000	2,440,000	1,545,000	213,000	892,000	1,220,000	1,212,000	57,000	22,000
Florida	2,516,000	2,068,000	1,006,000	0	209,000	496,000	564,000	913,000	737,000	658,000
Georgia	4,348,000	3,889,000	2,478,000	518,000	0	827,000	1,707,000	2,272,000	163,000	272,000
Kentucky	440,000	334,000	220,000	0	0	333,000	8,000	0	212,000	1,000
Louisiana	4,225,000	4,085,000	3,591,000	1,690,000	126,000	1,739,000	509,000	473,000	0	182,000
Mississippi	3,119,000	2,885,000	2,025,000	875,000	401,000	1,019,000	694,000	686,000	0	304,000
North Carolina	1,598,000	1,343,000	1,581,000	560,000	0	749,000	17,000	9,000	0	25,000
Oklahoma	1,172,000	973,000	645,000	509,000	391,000	368,000	15,000	37,000	121,000	59,000
South Carolina	1,665,000	1,417,000	1,426,000	391,000	43,000	737,000	197,000	189,000	0	100,000
Tennessee	1,109,000	625,000	1,053,000	0	0	614,000	8,000	0	48,000	10,000
Texas	3,588,000	3,332,000	3,022,000	0	0	3,007,000	56,000	133,000	510,000	193,000
Virginia	931,000	787,000	687,000	163,000	0	521,000	24,000	0	220,000	103,000
Total	**33,002,000**	**29,569,000**	**23,414,000**	**7,515,000**	**2,155,000**	**13,417,000**	**5,367,000**	**6,479,000**	**2,068,000**	**2,156,000**

Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.

These changes are not evenly spread across the South. Texas had the greatest decline of forest products industry ownership (about 3 million acres) while Alabama, Georgia and Louisiana lost about 2 million acres each (fig. 6.10). Increases in TIMO ownership were similar to regional trends with gains of 3 million acres in Texas, 1.5 million acres in Louisiana, and 1.6 million acres in Alabama (fig. 6.11). The spatial distribution of corporate owners also differs by type of owner.[5] The forest products industry is most heavily focused in south central areas—in Arkansas, Louisiana, Mississippi, and Alabama (fig. 6.12). REITs are concentrated in these same States but their ownership also extends into Georgia, Florida, and South Carolina (fig. 6.13). TIMO ownership is even more diffuse but has an especially high concentration in eastern Texas and the west central parts of Louisiana (fig. 6.14).

The causes behind the divestiture of forest products industry lands are debated and likely have varied across the many corporations involved. Forest-land divestitures involve dismantling vertically integrated operations in the wood products industries, in effect disintegrating company missions by dissolving the bond between timber growing operations from wood processing operations—indicating a change in the perceived economic advantages of maintaining the production of raw materials within the corporate boundary. We can assume that the vertically integrated companies had realized benefits that exceeded the costs incurred by coordinating two very different business models (also known as transaction costs). To understand the causes of the divestitures we must understand how the benefits of holding timberland area diminished relative to these transaction costs. To be sure, this trend toward disintegration is not limited to forestry and was especially pronounced in banking, information technology, and manufacturing sectors of the economy. The following paragraphs describe some of the key factors[6] that may have influenced decisions to sell.

Consolidation through mergers and divestitures—Multiple acquisitions and consolidations occurred in the forest products sector ahead of forest-land divestiture. Corporations merged and then consolidated their production around fewer product lines. This shift away from horizontally integrated manufacturing may have reduced the amount of timber from corporate land that could be effectively processed into products. Acquisitions also generated considerable debt that could be reduced through land sales.

Alleviation of timber scarcity concerns—A fundamental change in perceptions about timber supplies occurred during the 1990s, with focus shifting from impending scarcity of raw materials to a view that private owners are price-responsive and reliable in supporting increased demands for production (Wear and Prestemon 2004). Changes in production technologies may have also contributed to alleviating concern about scarcity, as oriented strand board and other new products can be produced with smaller logs than required by older products such as plywood. In times of scarcity, forest products industry land could buffer short-term market shortages, but in the face of resource abundance, this insurance value of company timberlands would diminish considerably.

Transaction technologies—New information technologies that reduce the costs of transacting and finding sellers of materials have had far-reaching effects on the structure of production in many sectors of the economy. The best example of this ability to reduce transaction costs within the wood products sector may be the development of Geographic Information Systems that can sift through satellite imagery and ground based inventories to "discover" new sources of timber. These systems can leverage the efforts of procurement foresters to be quicker at locating owners with marketable timber and therefore reduce the costs of procuring timber on open markets. In effect, technology can make supply less uncertain, thereby reducing the insurance values of holding timberland.

Globalization—Much has been written about the effects of globalization on the U.S. economy. Favorable terms of trade, structural changes in governance, and shifts in comparative advantage, combined with the developments in transaction technologies described above, have all contributed to global shifts in production. But although expanded trade may affect the optimal scale of a company (by changing the extent of markets), increased trade alone does not necessarily affect its optimal structure as much as other aspects of globalization. To illustrate, globalization increasingly captures what Grossman and Rossi-Hansberg (2006) call an emerging "trade in tasks" among regions and countries. They argue that technological changes (primarily information technologies that enable communication of precise specifications coupled with transportation systems that offer timely delivery) have allowed the production process to be broken into smaller staged tasks that can be performed in disparate locations. This encourages the separation of production stages—such as wood growing and wood product manufacturing—which has been observed in increased exports of U.S. hardwood lumber for the manufacturing of furniture (Wear and others 2007).

[5] We defined the concentration of ownership by calculating the ratio of ownership acres to total forest acres in each county. High concentration counties are among the top third of these ratios, moderate is defined by the middle third, and low is defined by the lower third.
[6] Wear, D.N. 2010. The disintegration of timber growing and wood products manufacturing in the United States. Draft manuscript on file. U.S. Department of Agriculture Forest Service, 3041 Cornwallis Rd., Research Triangle Park, NC, 27713.

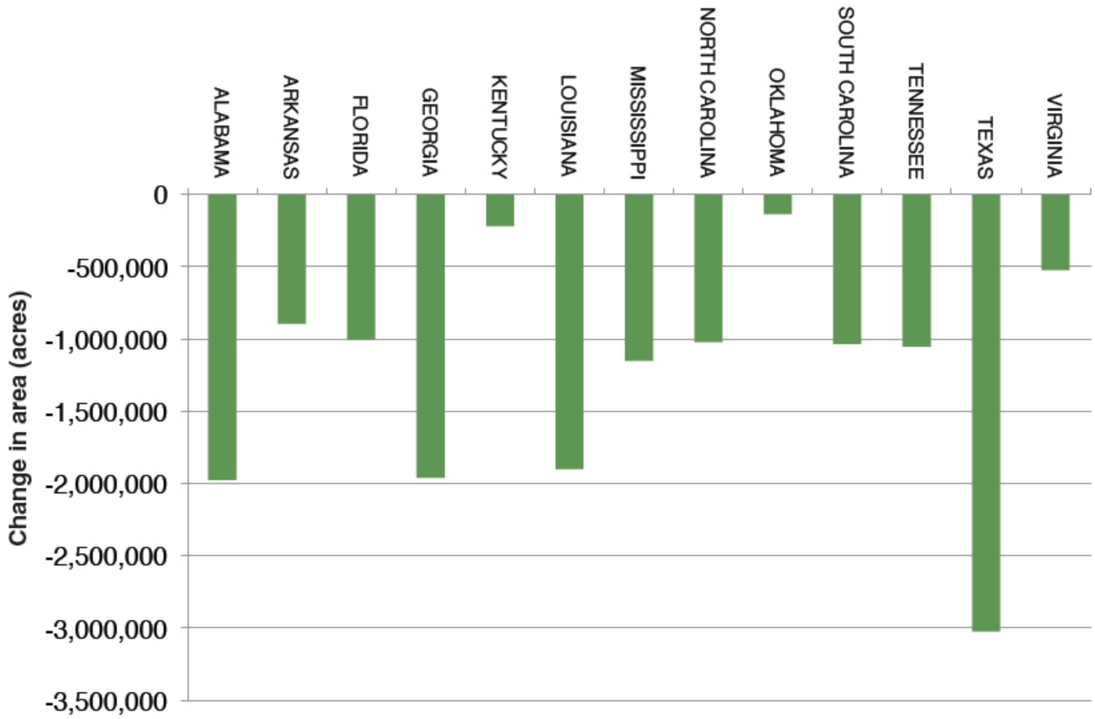


Figure 6.10—Change in forest products industry ownership by State, 1998 to 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

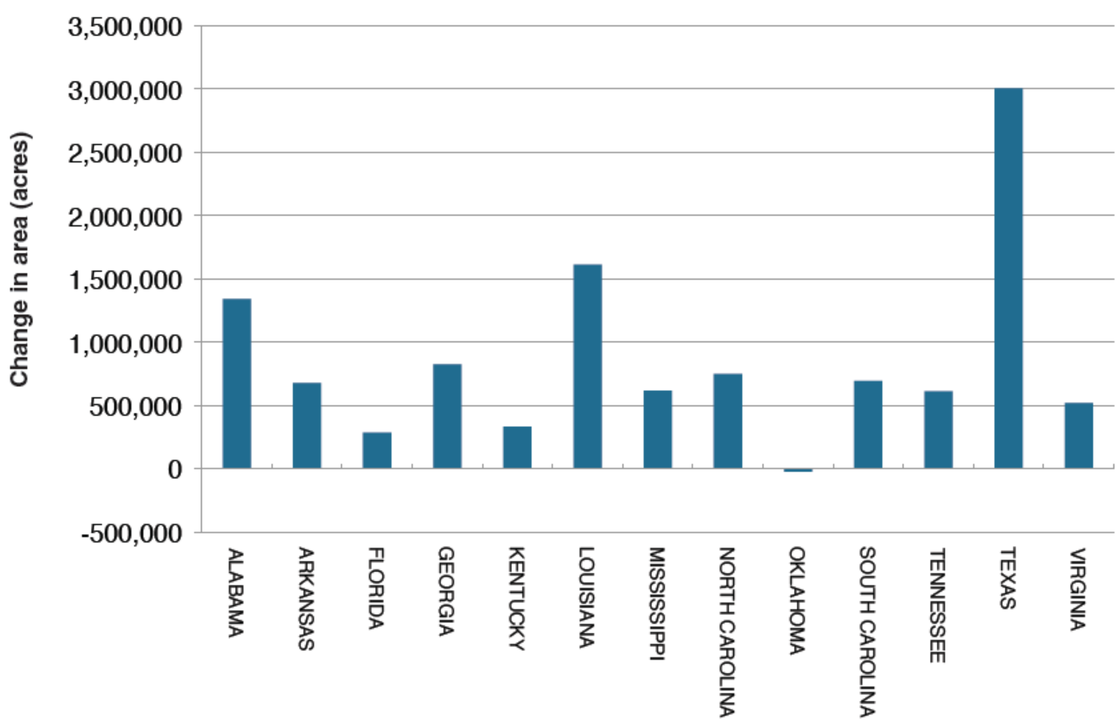


Figure 6.11—Change in timber investment management organization ownership by State, 1998 to 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

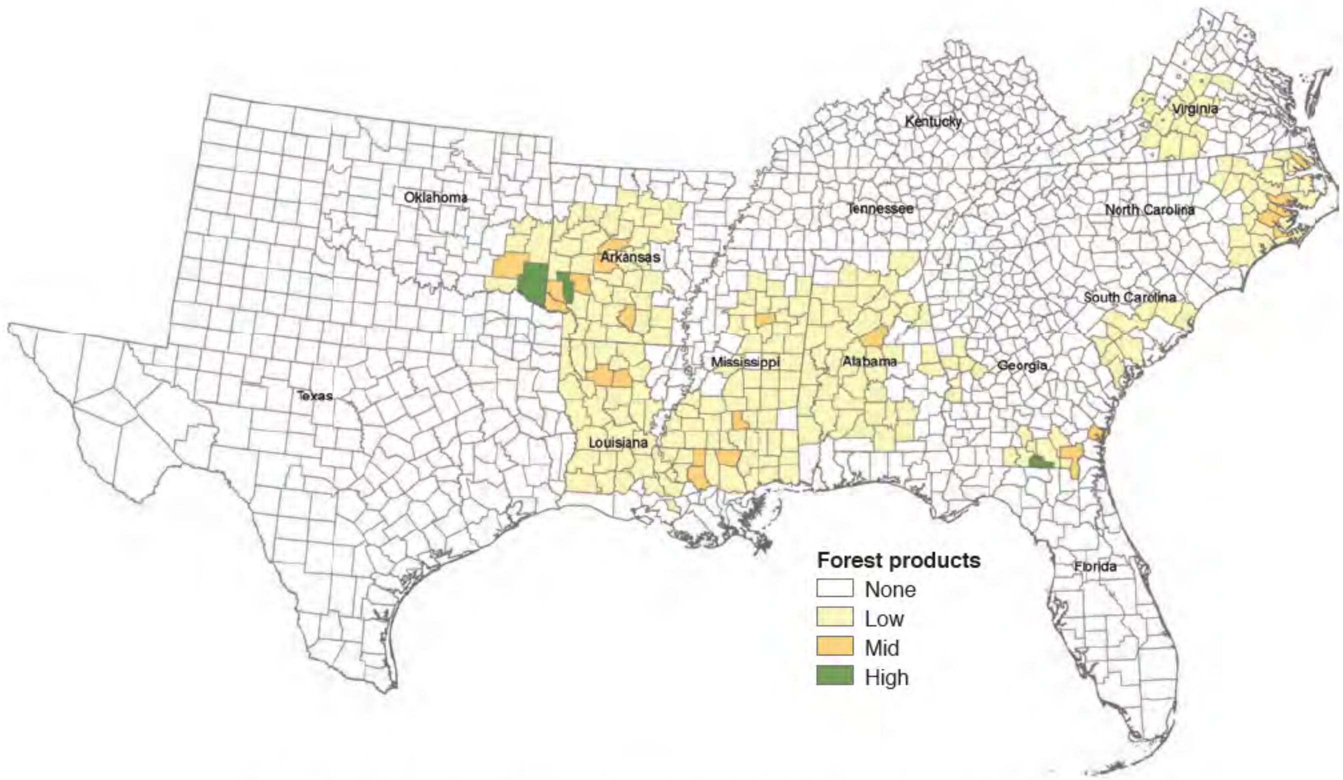


Figure 6.12—Concentration of forest land owned by the forest products industry, 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

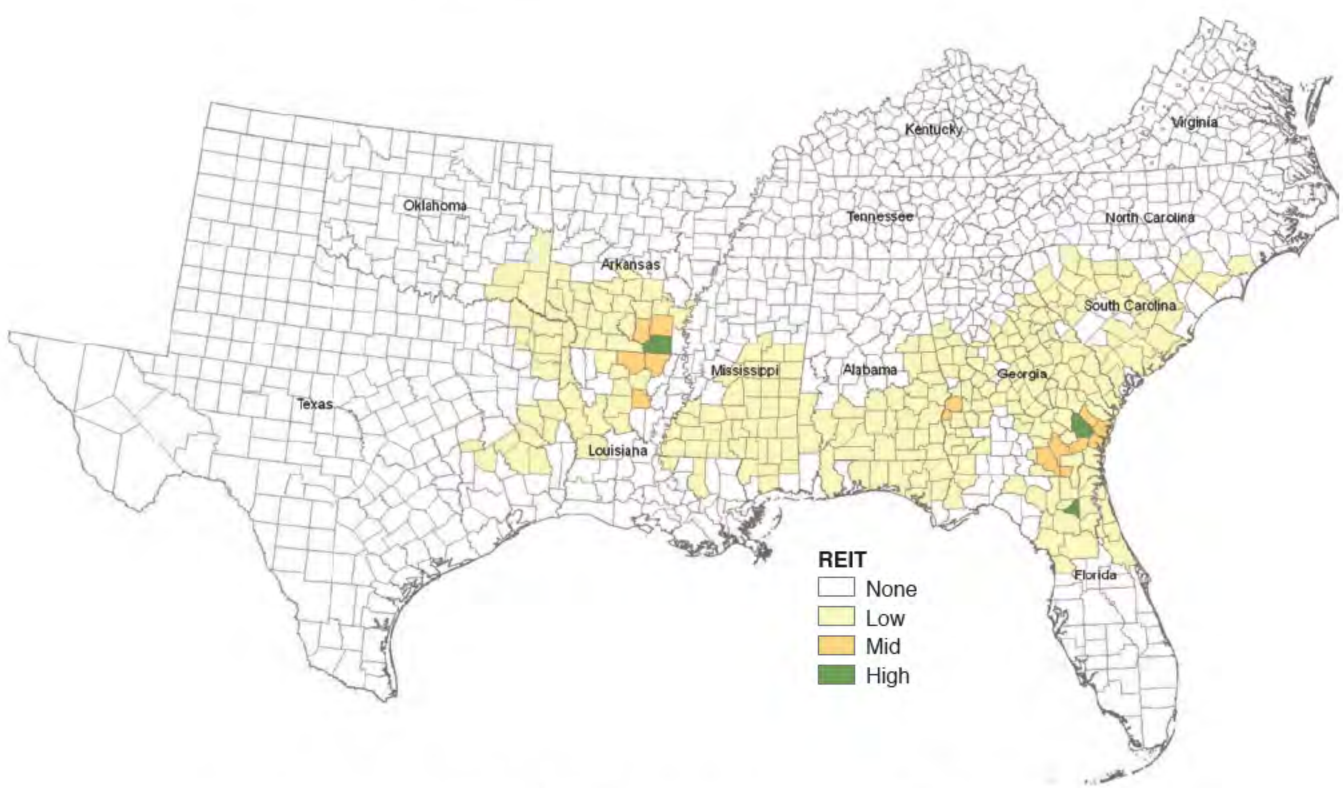


Figure 6.13—Concentration of forest land owned by real estate investment trusts, 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

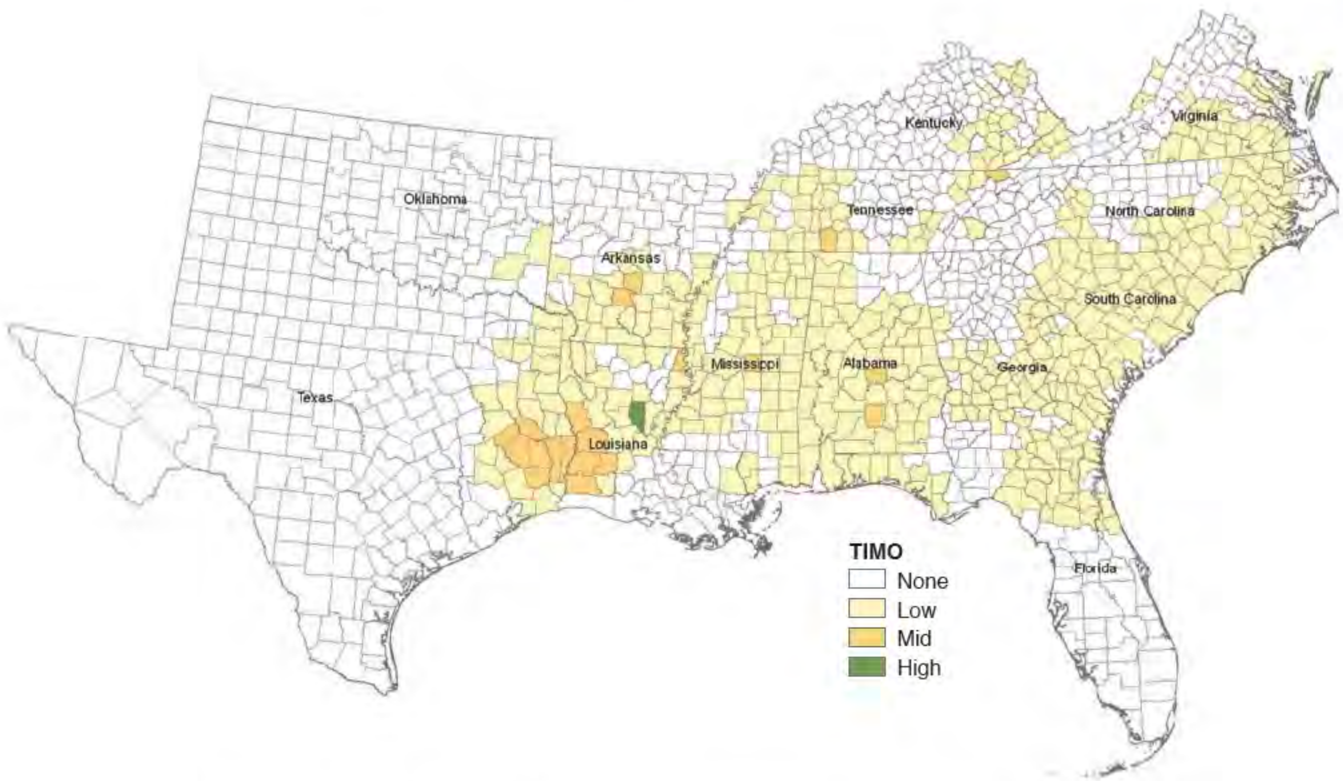


Figure 6.14—Concentration of forest land owned by timber investment management organizations, 2008. (Source: Lanworth Inc. On file with: David Wear, U.S. Department of Agriculture, Forest Service, North Carolina State University, PO Box 8008, Raleigh NC, 27695.)

Taxes—A key factor in divestiture transactions has also been differential taxation that factored into forest products industry decisions to hold versus dispose of forests. Wood products companies, like other corporations, are required to pay corporate income taxes on their revenues and shareholders pay capital gains and income taxes, resulting in an oft-cited double taxation of returns. Most of the individual investors, pension funds, and other institutions that have purchased forest products industry timberland through TIMOs are not subject to the corporate income tax. This difference in total tax burden means that investors would place a higher value on timberland than a wood products company, whose timber growing income is reduced by taxes. Until recently, the forest products industry valued timberland based on the economics of timber growing and on values related to supply assurance and uninterrupted production. As this premium dissipated, wood products companies saw the value of selling their timberlands and thereby capitalizing on the preferential tax treatments of pension funds and other investors.

Future Ownership Dynamics and Implications

Under all future forest projections, the area of forest land is expected to decrease. Public lands are scarce in the South, and the nature of public ownership virtually eliminates the likelihood of significant acreage decreases in this group. Therefore, the loss, which ranges from 5.5 million to 21.1 million acres, will be concentrated on private lands. Under Cornerstone D, a prediction of moderate forest loss (chapter 5), the South is projected to lose 12.2 million acres of private forest land. The largest decreases, in both percentage and absolute terms, are in Florida, Georgia, and North Carolina—States with the largest projected increases in population and urbanization. All States are projected to lose forest land under Cornerstone D, but at between 4 and 6 percent, losses for Alabama, Arkansas, Louisiana, Mississippi, and Texas are projected to be lower than the regional average. This pattern of change for the region as a whole and for individual States holds for other Cornerstones as well (chapters 3 and 4).

Although the net area of forest land is projected to decrease, the area of some forest types is expected to increase. The area of planted pine could increase between 20 percent and 72 percent to as much as 33 percent of total forest area over the 50-year projection period. Increases in planted pine are expected across all ownership groups, but the greatest acreage gains are on private forest lands. Modeling restrictions preclude disaggregation of changes into specific private ownership groups. But planted pine requires an upfront investment, which in the South at least, is a general indicator of owner intent—commercial production of timber.

What then are the implications for corporate lands of these transactions and the factors that have driven them? Perhaps most importantly, changes in production and transaction technologies suggest that timberland assets will likely be much more liquid in the future. This trend is reinforced by the form of new ownerships and the structure of many investment vehicles for timberland—large shares of timberland portfolios are commonly held as closed end funds that must be sold after a specified time period (Zhang and others 2012).[7] There is little reason to believe that we have observed a once-only episode in timberland sales. Rather, the emerging investment models for forests indicate that timberland will be traded much more frequently in the future than ever in the past. More rapid turnover of timberland might eventually raise concerns about the stability of timber markets.

It seems clear that the transition from large-block ownership by the forest products industry is irreversible. Because technological changes have permanently changed cost structures, the capacity and desire for internal control of timberland have likely been permanently eroded. Furthermore, because divestiture often results in fragmentation of ownership, it is quite unlikely that any future owner could stitch together a forest estate comparable to the pre-divestiture holdings.

Forest land provides many social benefits beyond timber production, including watershed protection (chapter 13), biodiversity (chapter 14), and recreation (chapters 7 and 8). Increased timberland liquidity suggests the possibility of changes in the availability of these benefits. Large-block industrial ownerships provided many conservation benefits, including some of the largest contiguous stretches of forest habitats in the South (Wear and Greis 2002). They provided de facto protections for resource sustainability that is now less certain as timberland ownership becomes more fragmented.[8]

TIMOs may seek to diversify the risks associated with their forest holdings, providing a strong disincentive for the practice of holding land in the large contiguous blocks that was typical of forest products industry owners. Risk management strategies spread investments across space (e.g., to avoid damage from hurricanes and fires) and perhaps across species (to mitigate, for example, losses from insect and disease outbreaks)—both of which would also address market-based financial risks, but at a cost of increasing forest parcellation and eventual forest fragmentation.

[7] TIMOs also manage open-ended investor accounts without a predetermined holding period.
[8] It is too early to determine how these changes in ownership will be translated into changes in on-the-ground forest management. Shifts in management are uncertain and will ultimately hold strong influence over the future path of forest conditions in the South.

It is important to remember that the investors represented by TIMOs came very rapidly into forest investments based on the perception of countercyclical returns and the attractiveness of land as an investment. Changes in these perceptions and valuations might just as easily lead them away from forest investments. Again, the implication of their actions is increased liquidity of forest assets and more rapid change in landscape conditions in the future. The economic downturn of 2008 to 2009 is a reminder that external conditions can rapidly change the relative position of various investments.

Future conservation strategies need to anticipate these changes in corporate owned forests. Divestiture provided a unique opportunity for conservation purchases of unprecedented size (Weinberg and Larson 2008). Still the ability to protect biodiversity, water, and other values that depend on large blocks of contiguous forest have been and will continue to be challenged by these forces that fragment forest ownership. Effective conservation in these dynamic landscapes may require new approaches, for example, emerging partnerships between investment and conservation interests.

The future of family forest lands depends on personal, familial, social, and market forces that will unfold with the inevitable land transfers from one owner to the next. It is at these points of transfer when land use and forest management are most likely to change. Although many family forest owners want to keep their land intact for future generations, they are not certain they will be able do so. Mater and others (2005) showed that many of the next generation owners are not attached to the land and have little interest in maintaining the family legacy, implying another tendency toward liquidity. That being said there are still many potential heirs and new owners who are interested in maintaining the land in forest cover. Continued population pressures and the continued desire of people to want to live in the country will continue the parcellation of family forest land. And with parcellation often comes new development, such as homes and the roads and other infrastructure that they require. This will create challenges for wildlife, wildfire control, recreation, and forest management. Not only will the parcels be smaller, they will also more likely be surrounded by development, which can create regulations or other obstructions that further hinder traditional management practices.

It is uncertain who the future family forest owners will be, but given historic trends, there will likely be more of them, the average size of their forest holdings will decrease, and the importance of amenity values will continue to increase. It is also likely that more of them will have urban or suburban backgrounds and be absentee owners. Although many will still be willing to harvest trees from their land, if current trends of smaller parcels and changing objectives continue, harvesting is likely to decrease. And it is likely that land values, either monetary or non-monetary, will continue to increase for recreation (such as hunting), nontimber forest products (such as pine straw), water protection, carbon sequestration, and other nontraditional uses.

Family forest owners will continue to dominate the forested landscape of the South for the foreseeable future. Many of the growing pressures on landowners will be felt by family owners first and most intensively. Therefore it behooves all who are interested in the future of the South's forests to understand this group of owners, their dynamics, and the factors affecting them. In effect, they hold the future of southern forests in their hands and need assistance if they are to continue their tradition of stewardship.

We need to be cognizant of owners' objectives and circumstances. Whether they own a 10-acre home lot or a 400-acre investment property will have a large impact on what issues are important to them, the use/management that they deem appropriate, and what can be done with their land. In short, there will be an urgent need to develop programs and tools that are tailored for specific types of family forest owners—providing them what they need, when they need it, and how they want it—so that family forest owners can continue to provide the goods and services that society has come to expect.

DISCUSSION AND CONCLUSIONS

Unlike the western regions of the United States, the South's forests are dominated by private owners. Private ownership is diverse with roughly a third in corporate ownership and the remainder owned by more than 4 million families or individuals. Forest holdings vary considerably in size with most owners (59 percent) holding fewer than 10 acres. Most forest land (60 percent) is however, in holdings of 100 acres or more.

Forecasts indicate a loss of 5.5 million to 12.2 million acres of private forest land in the South by 2060. With expanded urbanization growing outward from city centers, we expect an increased fragmentation of remaining forest holdings. Ongoing parcellation through estate disposal and the tax increases associated with urbanization will continue to alter forest management in the South. In particular, areas of concentrated urbanization could begin to see reductions in timber harvesting and planting in small inoperable holdings, and reductions in prescribed burning because of health and safety concerns and ordinances.

Family forest owners cite a variety of reasons for holding forests. These include legacy, aesthetics, and land investment. About two-thirds of family forest land in the South is held by owners who have harvested timber from their forests in the past. When combined with corporate ownership, about 8 of every 10 acres of private forest land in the South are owned by corporations, families, individuals, or others who have commercially harvested.

The divestiture of forest lands by the forest products industry from 1998 to 2008 is the most substantial transition in forest ownership of the last century. This divestiture substantially altered the ownership and objective structure of the corporate ownership group because much of the land shifted to TIMO and REIT owners. A number of economic factors likely influenced the decisions of forest products companies to sell their land. An analysis of these factors suggests that the transition from large block industry ownership to a more spatially varied and fragmented ownership is irreversible in the foreseeable future.

As a result of transition from the forest products industry to TIMOs, corporate owned forest land is now a more liquid asset that could trade more frequently in the future, and the size of individual holdings could continue to decline. While the forest products industry land base had been a stable and predictable component of the southern landscape, the "new" class of corporate forest lands may be less stable and more changeable with implications for nontimber values, such as water quality, sensitive plant and animal communities, and recreation availability. The economic forces that led these new forest owners to acquire land could cause rapid shifts in ownership in the future. For example, a sustained decline in commodity prices, such as the 50 percent reduction in softwood pulpwood prices since 1998 (chapter 4), could reduce the profitability of timberland management and drive away investors. Conversely, policy driven increases in biomass demands for energy production or the emergence of additional revenues from markets for ecosystem services could reverse recent downward trends (chapter 10).

Over the past 2 decades, ownership dynamics have been largely among owner types within the corporate and family owner groups (and not from one group to another). Our analyses of anticipated changes are consistent with this history. Structural changes in ownership—transferring land among major groups—might be possible depending on the driving forces, and would have far reaching effects. For example, increasing scarcity of recreation and concern for other quality-of-life aspects of forests could lead to public acquisition of private forest land, especially at State and local levels. A substantial decline in timberland profitability could lead to a shift in ownership from corporate to family forest owners. These are both within the realm of plausibility but have not yet been observed to any great degree.

Tax policy has had important influence on the structure of corporate forest ownership, notably the shift from industry to other forms of corporate owners. Policy in the form of income and property taxes likewise influences the allocation of land to forests and other uses and affects the optimal scale of forest uses. Environmental regulations can affect the feasibility of forest management thereby affecting the extent of commercial ownership. What's more, inheritance taxes influence the retention of large forest areas through generational transfers. These and other policy impacts on the type of ownership and parcellation of forests are discussed in chapter 11.

KNOWLEDGE AND INFORMATION GAPS

A number of questions remain about implications of changes in the corporate forest ownership group for forest management and forest conditions. In particular we posit that the change from forest products industry to TIMO ownership increases the liquidity of forest assets and that this might affect the long-term conditions of forests. Frequent sales of timberland could conceivably decrease the likelihood of long-term investments in forest production and productivity. Conversely, investments in these assets could lead to improvements that would be valued in future transactions because those investments would be fully capitalized in the sale prices of timberland. If so, efficient long-term investment would not be impeded by frequent land sales. This is a crucial question for the future of forests in the South, and one that could be answered through regular monitoring and analysis of timberland transactions over time, perhaps in concert with forest inventories.

Land use (and other land ownership) systems for projecting ownership dynamics typically use very simplistic assumptions because they lack solid theoretical modeling frameworks and empirical data for parameterizing and validating models. Building on existing land-use change and forest-management behavior models (Agarwal and others 2002, Beach and others 2005, Pocewicz and Nielsen-Pincus 2008) should pave the way for a first approximation of an ownership dynamics model. Full implementation of the newly designed annual FIA inventory system will add data to help resolve issues surrounding broad-scale ownership dynamics, but additional work will be needed to examine the dynamics within ownership groups. Most immediately, the transfer of lands from vertically integrated timber products companies to TIMOs and REITs and the intergenerational transfer of family forest lands are important dynamics that need to be better understood and monitored.

LITERATURE CITED

Agarwal, C.; Green, G.M.; Grove, J.M. [and others]. 2002. A review and assessment of land-use change models: dynamics of space, time, and human choice. Gen. Tech. Rep. NE-297. Newton Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Research Station. 61 p.

Barraclough, S.; Rettie, J.C. 1950. The ownership of small private forest-land holdings in 23 New England towns. Stn. Pap. 34. Upper Darby, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 32 p.

Beach, R.H.; Pattanayak, S.K.; Yang, J.C. [and others]. 2005. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Policy and Economics. 7(3): 261–281.

Bechtold, W.A.; Patterson, P.L. 2005. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p.

Binkley, C.S.; Raper, C.F.; Washburn, C.L. 1996. Institutional ownership of U.S. timberland: history, rationale, and implications for forest management. Journal of Forestry. 94(9): 21–28.

Birch, T.W. 1996. Private forest land owners of the United States, 1994. Resour. Bull. NE–134. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 183 p.

Birch, T.W.; Lewis, D.G.; Kaiser, H.F. 1982. The private forest land owners of the United States. Resour. Bull. WO–1. Washington, DC: U.S. Department of Agriculture Forest Service. 64 p.

Butler, B.J.; Tyrrell, M.; Feinberg, G. [and others]. 2007. Understanding and reaching family forest owners: lessons from social marketing research. Journal of Forestry. 105(7): 348–357.

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS–27. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 73 p.

Butler, B.J.; Leatherberry, E.C.; Williams, M.S. 2005. Design, implementation, and analysis methods for the National Woodland Owner Survey. Gen. Tech. Rep. NE–336. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Research Station. 43 p.

Conner, R.C.; Hartsell, A.J. 2002. Forest area and conditions. In: Wear, D. and Greis, J., eds. The Southern Forest Resource Assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 357-402.

Conner, R.C.; Adams, T.; Butler, B.J. [and others]. 2004. The state of South Carolina's forests, 2001. Resour. Bull. SRS–96. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 67 p.

Fletcher, L.S.; Kittredge, D.; Stevens, T. 2009. Forest landowners' willingness to sell carbon credits: a pilot study. Northern Journal of Applied Forestry. 26(1): 35–37.

Germain, R.H.; Anderson, N.; Bevilacqua, E. 2007. The effects of forest land parcelization and ownership transfers on nonindustrial private forest land forest stocking in New York. Journal of Forestry. 105(8): 403–408.

Grossman, G.M.; Rossi-Hansberg, E. 2006. The rise of offshoring: it's not wine for cloth anymore. In: The new economic geography: effects and policy implications. Kansas City, MO: Federal Reserve Bank of Kansas City: 59–102.

Haynes, R.W. 2003. An analysis of the timber situation in the United States: 1952–2050. PNW–GTR–560. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 254 p.

Hodgden, B.; Cusack, C.; Tyrrell, M. 2007. Literature review: an annotated bibliography of the literature on family forest owners. GISF Res. Pap. 002–R. New Haven, CT: Yale University, School of Forestry and Environmental Studies, Global Institute of Sustainable Forestry. 27 p.

Josephson, H.R.; Mcguire, J.R. 1958. Ownership of forest land and timber. In: Timber resources for America's future. For. Res. Rep. 14. Washington, DC: U.S. Department of Agriculture Forest Service: 289–321.

Joshi, O.; Mehmood, S.R. 2011. Factors affecting nonindustrial private forest landowners' willingness to supply biomass for bioenergy. Biomass and Bioenergy. 35(1): 186-192.

Kilgore, M.; Leahy, J.; Hibbard, C.; Donnay, J. 2007. Assessing family forest land certification opportunities: a Minnesota case study. Journal of Forestry. 105(1): 27–33.

Mater, C.M.; Sample, V.A.; Butler, B.J. 2005. The new generation of private forest landowners: brace for change. The Pinchot Letter. 10(2): 1–4.

Mehmood, S.R.; Zhang, D. 2001. Forest parcelization in the United States: a study of contributing factors. Journal of Forestry. 99(4): 30–34.

Pocewicz, A.; Nielsen-Pincus, M. 2008. Predicting land use change: comparison of models based on landowner surveys and historical land cover trends. Landscape Ecology. 23(2): 195-210.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO–78. Washington, DC: U.S. Department of Agriculture Forest Service. 336 p.

Snyder, S.A.; Kilgore, M.A.; Taff, S.J.; Schertz, J.M. 2008. Estimating a family forest landowner's likelihood of posting against trespass. Northern Journal of Applied Forestry. 25(4): 180–185.

Wear, D.N.; Carter, D.; Prestemon, J. 2007. The U.S. south's timber sector in 2005: a prospective analysis of recent change. Gen. Tech. Rep. SRS–99. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 29 p.

Wear, D.N.; Prestemon, J. 2004. Timber market research, private forests, and policy rhetoric. In: Rauscher, M.; Johnsen, K.; Doudrick, R., eds. Southern forest science: past, present and future. Gen. Tech. Rep. SRS–75. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 289–300. Chapter 24.

Wear, D.N.; Greis, J.G. 2002. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 635 p.

Weinberg, A.; Larson, C. 2008. Forest land for sale: challenges and opportunities for conservation over the next ten years. New York: Open Space Institute, Inc. 22 p.

Zhang, D.; Butler, B.J.; Nagubadi, R.V. 2012. Institutional timberland ownership in the U.S. South: magnitude, location, dynamics, and management. Journal of Forestry 110(7): 355-361.

CHAPTER 7.
Outdoor Recreation in a Shifting Societal Landscape

H. Ken Cordell, Carter J. Betz, and Shela H. Mou[1]

KEY FINDINGS

Population

- The South grew considerably faster (32.5 percent) in total population in the 18 years between 1990 and 2008 than the Nation as a whole (22.2 percent). The region has just over half of the country's non-Hispanic African American population (18.9 million) and is a close second to the Rocky Mountains in both the size and rate of increase of the American Indian population. Since 1990, the South (heavily influenced by Texas and Florida) surpassed the Pacific Coast (strongly influenced by California) in Hispanic population to lead the Nation, with growth especially high in North Carolina and Georgia.
- In the South, the baby boomer generation age groups (44-64 years old) have dominated all others in percent growth since 1990. The South and the Rocky Mountains were the only regions to outpace the national growth rate for every single age group.
- The greatest current density of population for the South is in Florida, in the Piedmont areas of North Carolina to Georgia, and in eastern Texas. Other high-density areas of the South include many of the coastal counties, both on the Gulf of Mexico and along the Atlantic Ocean.
- The highest growth in density of population (persons per square mile) has occurred down the Piedmont and Southern Appalachians from North Carolina to Alabama, along the coasts of Florida, and around the major cities of Texas. Some of this growth was substantial and exceeded the U.S. Census Bureau definition of an urban area, 500 persons per square mile. In areas like eastern Texas, higher concentrations of people in places near public lands and bodies of water are likely to put increasing pressures on these limited resources.
- With moderate growth, the population of the United States is projected to exceed 447 million people by 2060, an increase of more than 47 percent. For the same period, projected growth for the South is nearly 60 percent. The Atlantic States area in the South ranks second among its nine U.S. counterparts, at 68 percent forecast increase in population, followed by the Pacific Northwest with 63 percent. Of the 13 Southern States, Florida, Virginia, and Texas are projected to grow faster than the South-wide rate of 59 percent.

Recreation Demand

- One overriding recreation trend seems clear—what people now choose to do for outdoor recreation is different from choices made by and available to previous generations. Fishing and hunting, often considered widely popular and among the more traditional of outdoor activities, are still somewhat popular but are being replaced by other activities such as wildlife or bird watching and photography.
- For the South, the rate of growth for both the total number of outdoor recreation participants and total annual activity participation days exceeded those of the Nation. In the last decade, participants 16 years old and older increased about 11 percent, from about 68 million to 75 million, with their number of annual participation days increased by 41 percent. Average activity participation days per person across the full list of 60 activities rose from about 310 days per year to 393 days, a 27-percent increase. Some of the faster gains can be attributed to a slightly higher population growth rate than the Nation between 2000 and 2008. The number of people 16 years old and older increased from just fewer than 70 million to around 79 million, a 13-percent gain. In the United States, age 16+ population grew just under 10 percent, from 214 million to about 235 million.
- Of the most popular activities in the South (which has more than 30 million recreation activity participants), the top six activities were walking for pleasure, family gatherings outdoors, gardening or landscaping, viewing/photographing natural scenery, sightseeing, and visiting outdoor nature centers. Other popular growth activities included driving for pleasure, viewing/photographing flowers and trees, viewing/photographing wildlife (besides birds and fish), swimming in an outdoor pool, and picnicking. Activities oriented toward viewing and photographing nature (scenery, flowers/trees, and wildlife) have been among the fastest growing in popularity.

---

[1]H. Ken Cordell is a Pioneering Research Scientist, Carter J. Betz is an Outdoor Recreation Planner, and Shela H. Mou is a Computer Assistant with Pioneering Research Program, Southern Research Station, U.S. Department of Agriculture Forest Service, Athens, GA 30602.

- For moderately popular activities (10–30 million participants), the most popular were viewing or photographing birds, bicycling, gathering mushrooms/berries, warmwater fishing, visiting a wilderness, visiting a farm or agricultural setting, viewing and photographing fish, and day hiking. Growth has been especially strong for off-highway vehicle driving, gathering mushrooms and berries, and visiting farms or agricultural settings.
- Among activities having fewer than 10 million participants, camping at primitive sites, big game hunting, waterskiing, using personal watercraft, and equestrian activities were at the top and showed some growth. Kayaking was the fastest growing of these activities by a wide margin, followed by other water-based activities such as waterskiing and canoeing. Some activities posted declines during this decade.

Recreation Resources

- Less than 5 percent of Federal land, about 30.5 million acres, is in the South, 44 percent of which is managed by the Forest Service, U.S. Department of Agriculture. More than 92 percent of Federal land is located in the Western United States.
- While Federal acreage changes little over time, population changes greatly. In the South, Federal acres per 1,000 persons declined slightly faster than the national rate, with a 15.4 percent decrease in acres per 1,000 people since 1995.
- The South accounts for just 2.5 percent of the area of the National Wilderness Preservation System (NWPS), about 2.7 million of the over 109 million acres. Due to population growth, the South's per capita acreage of NWPS land has declined nearly 16 percent since 1995.
- National Wild and Scenic Rivers and National Recreation Trails are two specially designated Federal protected resource systems. Only 810 miles of National Wild and Scenic River miles are in the South (about 6 percent of all designated river miles), but the 31 percent increase in protected Southern river miles since 2000 trailed only the Rocky Mountains region.
- There are more than 6,500 National Recreation Trail System miles in the South, almost 33 percent of the system nationally. Further, the South led all regions with 84 percent growth in designated trail mileage since 2004, adding nearly 3,000 new trail miles.
- The South has just over 12 Federal recreation facilities per million people, or about 1 facility per 83,000 people, according to the Recreation Information Database maintained by the U. S. Department of the Interior. The South is fairly well represented in the number of Federal recreation sites with boating facilities.
- State park systems throughout the country have faced difficult budgetary pressures as a result of the economic recession of the late 2000s. Two of the most affected State park systems—Alabama and Georgia—are in the South.
- State park system areas total more than 2.2 million acres in the South. Throughout much of the region, especially in Florida and South Carolina, State park resources are situated within an hour's drive of most people.
- Nationwide, more than 8,800 local governments provide recreation and park services. Just under 29 percent of these services (2,552 local units) were in the South. The number of local parks and recreation departments per million people was up almost 18 percent in the South since 1997, higher than the national growth rate of 13 percent. Another indicator of local government recreation and park resources is conservation funding, which is tracked through ballot measures in all 50 States by the Trust For Public Land's LandVote database. Since 2000 in the South, more than 80 percent of 226 such measures passed to fund $5 billion worth of county and municipal government parks and recreation-related development, improvements, and land protection.
- Among nine outdoor recreation business categories tracked, five showed a decline in the number of establishments per million people from 1998 to 2007. Amusement/theme parks, recreational/vacation camps, and golf courses posted the largest declines in the South. Private-sector historical sites, nature parks, and zoos/botanical gardens showed the greatest gains. Private forest land, both family forests and that controlled by other private owners, is a significant outdoor recreation resource in the South. Each State has a recreational use statute that limits the liability of private landowners to open their land to public use, but the interpretation of what constitutes a recreational user varies by State. Recreation leases, particularly for hunting, are a common method of allowing public access to private forest land with mutual benefit to both land owners and lessees.
- Residents of most counties in the South have access to fewer than 1.5 acres of public land per person within 75 miles of their home county, except for relatively more accessibility in the Ozark Highlands and Virginia mountains. Within the 75-mile recreation day trip zone, the greatest water (non-ocean) area per capita is in counties along the Atlantic Ocean and the Gulf of Mexico.
- The pattern of non-Federal forest across counties shows that much of the South has abundant forest land area. But when expressed on a per capita basis, some of the metropolitan areas are found to have relatively little forest land close by. Parts of Arkansas, Louisiana, Mississippi, Alabama, and Georgia have relatively abundant per capita non-Federal forest land within 75 miles of residents' counties.

Projected Futures

- Federal and State park land area is expected to remain relatively constant over time. Currently in the South, 5 percent of the total area is Federal or State park land, less than 0.3 acres per person. By 2060, the Federal or State park land area per person is projected to decrease to 0.17 acres, about 63 percent of the 2008 level. Because of population growth, the projected decline is greater for the South than the Nation.
- Total non-Federal forest land area is expected to change with continuing conversions from forests and farmlands to cities and suburbs. Currently, more than 30 percent of total land area in the South is non-Federal forest, or 1.66 acres per person. By 2060, per capita non-Federal forest is predicted to decline to 0.95 acres per person, or 57 percent of the 2010 level. The projected decline is greater for the South than the Nation due to both population growth and increased development.
- Like Federal and State park land, total water area is expected to stay mostly constant. Currently, water area in the South is slightly more than 5 percent of the region's total surface area, or 0.28 acres per person. By 2060, per capita water area is predicted to decline to 0.18 acres per person, or 63 percent of the 2008 level. Similar to the other resources, the projected decline in water resources per capita is greater for the South than the Nation.

INTRODUCTION

During the scoping phase of the Southern Forest Futures Project (chapter 1), input from a cross-section of forest owners, forest users, and forestry professionals was analyzed to identify issues relating to the socioeconomic aspects of forest policy and management. The issues addressed in this chapter include:

- How are population and demographics changing?
- Where and how do population growth, changing demographics, changing land ownership, and other factors affect supply and demand for different types of outdoor recreation?

Described are recent trends, forecasts of population numbers, population demographic makeup, recreation participation of the population, and resources available in the South. The materials presented are adapted from the data, analyses, and reporting developed for the Forest Service 2010 Renewable Resources Planning Act Assessment (Cordell 2012). The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 mandates a periodic RPA assessment of the Nation's renewable resources on all public and private ownerships. Each RPA Assessment provides a snapshot of current U.S. forest and rangeland conditions and trends, identifies drivers of change, and projects 50 years into the future through analyses of recreation, water, timber, wildlife (biodiversity), and urban forest and range resources. As well, land-use and climate change are included. The 2010 RPA Assessment stresses the importance of climate change and has adapted three socioeconomic scenarios based on the framework for the fourth world assessment of climate change done by the Intergovernmental Panel for Climate Change (IPCC).

Historical Context

The agrarian way of life up through the middle of the 20th century meant that the majority of people in the United States worked out-of-doors and had little desire for leisure outdoors. After the Great Depression and World War II, however, Americans in large numbers shifted to manufacturing and other forms of livelihood. With shifting work lives, Americans took to the open road to see and experience "the great outdoors." This led to mounting pressures on recreation facilities and most public lands. Consequently, major efforts ensued beginning in the 1960s to study and understand Americans' growing pursuit of outdoor recreation.

The interest in better understanding trends in outdoor recreation continues into the 21st century (Cordell 2008). In our earlier publication, Outdoor Recreation for 21st Century America, we reported that Americans' participation in outdoor activities, including nature-based recreation activities, had been rising up through the early part of the first decade of this century (Cordell and others 2004). Overall, since the first nationwide assessment of outdoor recreation trends conducted by the Outdoor Recreation Resources Review Commission 1962, almost all forms of outdoor activity and public land visitation have been observed to be growing. Cordell (2008) observed as well that there were signs of shifts in Americans' outdoor recreation:

> "Both the NSRE (National Survey on Recreation and the Environment) and the National Survey on Fishing, Hunting, and Wildlife-Associated Recreation show that participation in some nature-based activities has declined. However, for many other activities there seems to be growing popularity. Some outdoor recreation activities have even demonstrated rather strong popularity growth. One such activity is visiting wilderness and other primitive areas (Cordell, Betz, and Green 2008)."

Because trends in nature-based and other outdoor recreation have far reaching implications, a close look at those trends and projected futures for the South is important.

Outdoor Recreation Defined

Outdoor recreation is recreation activity done out-of-doors, which can, of course, take many forms. Those many forms occur with different activities, settings, types of social engagements, equipment, and times which are chosen by the recreation participant. Recreation can be physically active or sedentary. Nature-based recreation participation as reported in this chapter and summarized for the South includes:

- **Visiting recreation and historic sites:** Visiting the beach, prehistoric sites, and historic sites; developed camping; swimming in lakes, ponds, and other bodies of water; visiting watersides besides beaches
- **Viewing/photographing nature:** Viewing or photographing birds, other wildlife, fish, natural scenery, and wildflowers, trees, and other plants; visiting "nature center" type facilities; sightseeing; gathering mushrooms, berries, and other plants; taking boat tours or excursions
- **Backcountry activities:** Backpacking, day hiking, horseback riding on trails, mountain climbing, visiting a wilderness or primitive area, primitive camping, mountain biking, caving, rock climbing, orienteering
- **Motorized activities:** Motorboating, off-highway vehicle driving, snowmobiling, using personal watercraft, waterskiing
- **Hunting and fishing:** Anadromous fishing (salt-to-fresh-water migratory fish, for example salmon, which does not occur in the South but does draw some participants from the region), coldwater fishing, warmwater fishing, saltwater fishing, big game hunting, small game hunting, and migratory bird hunting
- **Non-motorized boating and diving:** Canoeing, kayaking, rafting, rowing, sailing, surfing, windsurfing, snorkeling, scuba diving
- **Snow skiing and other winter activities:** Cross-country skiing, downhill skiing, snowboarding, snowshoeing, ice fishing

METHODS AND DATA SOURCES

Population and Demographic Trends and Futures for the South

U.S. Census Bureau historical data from the 1990 Decennial Census through the 2008 national population estimates from Census were analyzed to examine recent trends in population and demographic makeup. National and regional population totals and proportions are presented as tables. As well, maps are presented showing the distribution of the population among counties. Included in this chapter are data on population by race/ethnicity, population by age groups, current population density (persons per square mile), population density change since 1990, percent change in Hispanic population, percent change in non-Hispanic White population, and projected changes in population density from 2008 to 2060. For comparison with the South, selected statistics are also shown for the Northern, Rocky Mountain/Great Plains, and Pacific Coast regions. The Southern Region consists of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. The Census Bureau provides updated annual population estimates for States and counties each year between the decennial population censuses. Based on these updates, maps at county scale were produced for this chapter reporting on change in Hispanic and other segments of the South's population. Data consulted included:

- U.S. Census Bureau (2008a), SC-EST2008-alldata6: Annual State Resident Population Estimates for 6 Race Groups (5 Race Alone Groups and One Group with Two or more Race Groups) by Age, Sex, and Hispanic Origin: April 1, 2000, to July 1, 2008 (http://www.census.gov/popest/states/asrh/files/SC-EST2008-alldata6-ALL.csv)

- U.S. Census Bureau (2008b), CC-EST2008-ALLDATA-[ST-FIPS]: Annual County Resident Population Estimates by Age, Sex, Race, and Hispanic Origin: April 1, 2000, to July 1, 2008 (http://www.census.gov/popest/counties/asrh/CC-EST2008-alldata.html)

- State and county population from the 1990 Census were derived from Woods and Poole Economics, Inc. (2009).

Working from Census Bureau estimates, county-scale forecasts of population change were developed for three of the future scenarios defined by the IPCC's fourth climate change assessment. These three IPCC scenarios were adapted for use in both the national RPA Assessment and as Cornerstones for the Southern Forest Futures Project (chapter 2). They provided a useful framework for evaluating the sensitivity of forest and other resource trends to a range of feasible population growth futures. The IPCC scenario designations were labeled A1B, A2, and B2. County-level population growth projections were developed for each of these three scenarios for the 2010 RPA Assessment and are used for this Southern Forest Futures chapter (Zarnoch and others 2010). Percent change over the 50-year assessment period is shown only for the A1B moderate-level scenario. Under this scenario, total population in the United States is projected to exceed 447 million people by 2060, a growth of more than 47 percent.

Recreation Activity Trends

The primary source of data for recreation activity trends for this chapter is the National Survey on Recreation and the Environment (NSRE). NSRE is a general-population random sample telephone survey that asks Americans age 16 and older about their participation in outdoor recreation activities. The data presented in this chapter are from surveys conducted continuously from 1999 to 2009, with a brief interruption during 2004.

This chapter updates earlier estimates of trends in outdoor recreation overall (Cordell and others 2008) and in nature-based outdoor recreation in particular (Cordell 2008). Period trends are reported for 2000 (the midpoint year for the 1999–2001 data used) and 2008 (the midpoint year for the 2005–09 data). A general picture of Americans' participation in outdoor recreation was constructed by defining a "participant" as any person who engaged in at least one of 60 outdoor recreation activities being tracked one or more times during the 12 months prior to the date they were interviewed. A binary variable was created with a "yes" value assigned to respondents if they reported participation in one or more of these 60 activities. A similar indicator was used to determine nature-based activity participation using a shorter list of 50 activities typically occurring in natural settings. Previous estimates from the 1994-to-1995 period are included to indicate overall trends across two decades.

Recreation Resources

Federal resources—Federal outdoor recreation resources in the South are described in this chapter based on the latest available data from Federal land managing agencies. Nearly all Federal land in the South is open for public recreation. The four largest Federal land-managing agencies—the Forest Service (U.S. Department of Agriculture), the Bureau of Land Management (U.S. Department of the Interior), the U.S. Fish and Wildlife Service (U.S. Department of the Interior), and the National Park Service (U.S. Department of the Interior)—have real estate offices that maintain real property records on the size, location, and boundaries of agency holdings. The three Federal water management agencies—the U.S. Army Corps of Engineers, the Bureau of Reclamation (U.S. Department of the Interior), and the Tennessee Valley Authority—have much smaller land holdings.

Specially designated Federal land systems that are described in this chapter include the NWPS, the National Wild and Scenic River System, and the National Trails System. Current and past data from each of these systems was examined for trends in per capita availability.

Federal recreation sites and facilities are cataloged in an online database called the Recreation Information Database, better known through its portal as Rec.gov. An interagency coalition coordinated by the U.S. Department of the Interior gathers information on Federal recreation sites and/or facilities across all agencies. A standardized list of 22 separate recreation activities or attractions with binary (yes/no) availability appears on Rec.gov. Trend data are not available for the database because it is fairly new, originating around 2002. Moreover, it is an evolving source of information, which is populated by the various Federal agencies with varying levels of completeness and comprehensiveness.

State resources—State park system data that appear in this chapter are from two sources. The first source is the National Association of State Park Directors Annual Information Exchange survey which collects land, facilities, visitation, and other data from all 50 State park systems (parks, recreation areas, natural areas, historical areas, environmental education areas, scientific areas, forests, wildlife and fish areas, and other miscellaneous areas) and assesses the status of each State park system's resources, operations, and visits. The Exchange does not have individual State park unit information, such as size and location, but rather State summaries, with information about parks and recreation area classes tending to be the most consistent over time.

The second source is a State park database developed from printed and online sources (available from the lead author of this chapter), and includes acreage data and latitude/longitude geo-locations. The database focuses on the three most common types of State park system areas: parks, recreation areas, and historic sites.

Local government resources—Tracking these resources is complicated by the sheer number and variety of local jurisdictions that provide park and recreation services. The emphasis of many local agencies is as much on providing indoor leisure programs and services, as it is on outdoor recreation resources. For this chapter, it is assumed that all local government agencies listed as providing recreation services include management of outdoor recreation resources. The data source is the Census of Governments done every 5 years by the Census Bureau. This census classifies governments by the type of governmental unit and by services provided. Another data source for local government resources is the Trust For Public Land's LandVote database, which monitors conservation and parks-related funding nationwide via ballot measures and initiatives, particularly at the municipal and county levels of government.

Private recreation businesses and land—The Census Bureau's County Business Patterns (part of the Economic Census) provides data on the number of recreation business establishments (in addition to data on payroll and number of employees) for the full range of businesses as described in the North American Industry Classification System. Nine of these business classes are related to outdoor recreation and are summarized in this chapter. Number of business establishments per capita with percent change from the previous 1998 survey to their most recent survey of 2007 are provided.

The 2006 National Woodland Owner Survey, conducted by the Northern Research Station of the Forest Service, provides the most recent data on family forest owners in the United States. The survey assessed landowners' objectives, practices, and reason for owning their private forest land. Another Forest Service data source is the NSRE, sponsored by the Southern Research Station. The NSRE, a general population household telephone survey, included a section which asked respondents about their participation in several nature-based recreation activities and the number of days annually that were spent on private forest lands.

County Pattern Maps

Also included in this chapter are county-level maps for 2008 that depict patterns of recreation resource availability per capita across counties in the South and as well the Nation. Shown are the recreation resources per capita within a 75-mile radius of each county. The 75-mile zone includes a home county plus all surrounding counties whose centroids (geographic centers) are within a 75-mile straight-line distance from the home county centroid (roughly the equivalent of a recreation day trip). The three basic recreation resources summarized in this chapter are combined Federal and State-park land area, non-Federal forest land, and water area (from Census Tiger geographic data).

Projected Futures

The future change measure used in this chapter is the ratio of per capita acres predicted for 2060 relative to the per capita acres in 2008. This statistic indicates the proportion of the area existing in 2008 that is forecast to remain by 2060. The per capita resources forecast (Federal and State park land area, non-Federal forest land, and water) are summarized by region and for the Nation as a whole. Also reported is the percentage of total surface area in each region represented by the resource.

RESULTS

Current Population Trends for the South

Based on official Census Bureau population data, the race and ethnic composition by region, along with the percent change trend from 1990 to 2008, are summarized in table 7.1. Race and ethnicity are important determinants of what people choose as outdoor recreation activities and the settings they use for those activities (Cordell and others 2004).

The race and ethnic makeup of the U.S. population changed dramatically in the 18 years since the 1990 Census. Although all races have been growing in number, generally, Asian or Pacific Islander and Hispanic components have been growing fastest. Non-Hispanic Whites have been growing much slower than the other groups. The highest growth for the total population has been in the Rocky Mountains, and lowest has been in the North. Highest percentage growth of any group has been the Asian or Pacific Islanders in the Rocky Mountains and South. Non-Hispanic Whites experienced population losses in the North and Pacific Coast.

The population of the South grew considerably faster (32.5 percent) than the Nation as a whole (22.2 percent). The Rocky Mountains and South are the only regions that outpaced the national rate for all race/ethnic groups. The lowest percentage increase in the South by a large margin was for Non-Hispanic Whites. But the 14 percent growth rate of this group still was more than double the national rate. Although the rate of increase (35.4 percent) for African Americans in the South was slightly more than half that of the Rocky Mountains, this population of almost 19 million was nearly 20 times larger than the Rocky Mountain population and more than half of the national total (37.2 million).

The South is a close second to the Rocky Mountains in both the size and rate of increase for American Indians. Although Asian or Pacific Islander population is much smaller than it is in the North and the Pacific Coast, the growth rate of this group in the South was considerably larger than it was in either of those regions. Since 1990, the South (heavily influenced by Texas and Florida) surpassed the Pacific Coast (strongly influenced by California) in Hispanic population to lead the Nation. Just over a third of all Hispanics now live in the South. The South's 143 percent growth in Hispanic population trails only the Rocky Mountains, but the South outnumbers the other region by nearly 3-to-1 in total Hispanic population. Growth of the Hispanic population was especially high in North Carolina and Georgia.

Age distribution—Age also has a strong effect on recreation activity choices (Cordell and others 2004). Similar to other demographic aspects, the age distribution of the U.S. population has been changing over time, as table 7.2 shows. Nationally, the fastest growing age group since 1990 (in percentage terms) has been the 44-54 age bracket followed by the 55-64 bracket. Next fastest growing is age 65 or older. Age 44 to 54 is the fastest growing group in all regions. The 25-34 age group has declined nationally, led by steep declines in the North and to a lesser extent in the Pacific Coast. The 10-and-under age group has declined in the North, but has experienced its fastest growth in the Rocky Mountains.

Table 7.1—Population (thousands) in 2008 by race/ethnicity and region with percent change since the 1990 Census

Race/ ethnicity	North	Percent change	South	Percent change	Rocky Mountain	Percent change	Pacific Coast	Percent change	United States	Percent change
White	92,246.8	-0.2	63,478.5	14.0	19,479.6	25.3	24,286.6	-1.4	199,491.5	5.9
African American	14,780.5	18.7	18,866.8	35.4	952.9	69.4	2,571.6	8.9	37,171.8	26.8
American Indian	416.7	23.2	704.0	36.4	768.9	38.3	439.3	13.7	2,329.0	29.6
Asian or Pacific Islander	4,670.3	116.4	2,481.3	170.6	690.5	171.1	5,830.2	59.0	13,672.3	95.4
Two or more races[a]	1,492.0	–	1,261.5	–	426.6	–	1,271.6	–	4,451.7	–
Hispanic[b]	10,761.7	94.6	16,013.4	143.2	5,497.2	157.8	14,671.3	80.4	46,943.6	109.8
Total	**124,368.0**	**10.1**	**102,805.6**	**32.5**	**27,815.7**	**46.0**	**49,070.4**	**25.2**	**304,059.7**	**22.2**

[a]Percent change for two or more races is missing because U.S. citizens could not select more than one race until the 2000 Census.
[b]Hispanics may be of any race, but are included in the Hispanic category only.
Source: U.S. Census Bureau 1990, 2008a.

Table 7.2—Population (thousands) in 2008 by age group and region with percent change since 1990

Age group	North	Percent change	South	Percent change	Rocky Mountains	Percent change	Pacific Coast	Percent change	United States	Percent change
Under 6	9,503.9	-3.0	8,825.9	27.1	2,555.8	37.7	4,196.7	10.4	25,082.3	12.0
6 to 10	7,793.1	-1.2	6,939.6	21.7	1,941.7	24.1	3,222.9	11.4	19,897.3	10.2
11 to 15	8,206.8	10.9	6,864.0	27.6	1,897.9	34.5	3,377.4	31.9	20,346.1	21.5
16 to 24	15,645.9	3.7	12,740.3	19.2	3,544.3	41.8	6,442.8	18.6	38,373.4	13.8
25 to 34	15,928.0	-17.6	14,037.8	5.6	3,965.7	22.7	7,000.0	-4.3	40,931.6	-5.2
35 to 44	17,416.9	2.7	14,349.8	25.2	3,679.9	28.7	7,054.5	14.4	42,501.1	13.5
45 to 54	18,933.9	63.2	14,586.3	86.8	3,861.1	111.2	6,990.7	82.6	44,372.1	77.0
55 to 64	14,246.1	42.1	11,307.9	71.4	2,989.5	96.1	5,142.7	73.3	33,686.2	59.5
65+	16,693.5	12.4	13,153.9	35.2	3,379.6	48.6	5,642.7	33.6	38,869.7	25.0
Total	**124,368.0**	**10.1**	**102,805.0**	**32.5**	**27,815.7**	**46.0**	**49,070.4**	**25.2**	**304,059.0**	**22.2**

Source: U.S. Census Bureau 1990, 2008a.

Similar to the Nation, in the South, the baby boomer generation age groups (44-64) dominated all other age groups in percent growth. In fact, the nearly 87 percent growth rate for 44-54 age group was higher than any other in any region or in the Nation as a whole. As with race and ethnicity, the South and the Rocky Mountains were the only regions to outpace the national growth rate for every single age group. Two related trends stand out. The South and Rocky Mountains grew much faster than the North and Pacific Coast in the 10-and-under age group and in the 25-44 prime childbearing age group. Because these increases cannot be attributed to natural birth-over-death rate increases alone, they are likely related to the large number of younger families migrating into these regions. The South's 25-34 age group was the only group not to experience double-digit growth, but its 5.6 percent increase still outpaced overall national losses.

Population density—Figure 7.1 shows the distribution of the U.S. population density (persons per square mile) across counties. The greatest density of population is in Florida, in the Piedmont areas of North Carolina to Georgia, along the coast of the northern Atlantic States, in the Great Lakes, in eastern Texas, in the Denver-Front Range area, and in scattered areas along the Pacific Coast and into Arizona. Greatest density in Alaska (not shown) is in the Anchorage area.

The South's other high-density areas include many coastal counties, both on the Gulf of Mexico and the Atlantic Ocean, especially near the metropolitan areas in Louisiana (New Orleans), Arkansas (Little Rock), Mississippi (Jackson), Oklahoma (Oklahoma City), Alabama (Birmingham, Montgomery, and Huntsville), South Carolina (Columbia), and Tennessee (Nashville, Knoxville, and Memphis). With the exception of a handful of counties scattered throughout the Eastern United States, most of the lowest-density counties are in the Plains area of western Texas.

Figure 7.2 shows that much of the overall growth in concentration of population (growth in persons per square mile) has occurred along the northern Atlantic coast, down the Piedmont and Southern Appalachians from North Carolina to Alabama, along both Florida coasts, and around the major cities of Texas. Elsewhere in the United States, growth occurred in the Chicago and Minneapolis/St. Paul areas, in the Denver and Salt Lake City areas, in the southwest and coastal California areas, and in the Portland and Seattle areas. Growth in some areas like eastern Texas and the greater Los Angeles area is substantial—in amounts exceeding 500 persons per square mile, which is the Census Bureau definition of an urban area. Greater concentrations of people in places near public lands and bodies of water are likely to put increasing pressures on these limited resources. In the South, population density increased throughout nearly all of Florida and is notable in northern Virginia and the metropolitan areas of Tennessee, and in a band of counties that follows the I-85 corridor through the Piedmont in the States of Georgia, South Carolina, and North Carolina.

Hispanics—Figure 7.3 shows the distribution of percentage growth of the Hispanic population of the United States from 1990 to 2008. Much of the fastest growth has been in the States bordering the Atlantic Ocean and Mississippi River. High rates of growth have also occurred through the upper Midwest and through southern Nevada, Arizona, Utah, and Wyoming. Substantial percentage growth can also be seen in coastal Oregon and Washington counties. The rate of Hispanic growth throughout much of the South has been high. North Carolina stands out, with growth exceeding 376 percent in all but a handful of its 100 counties. Hispanic populations more than tripled in large portions of Georgia, South Carolina, Alabama, Arkansas, and Mississippi. Because most Texas counties already had a substantial Hispanic population base in 1990, their growth of Hispanic populations did not reach the high rates of many other southern counties. In Florida, the largest increases were concentrated in central Florida, which includes the Orlando and Tampa-St. Petersburg metropolitan areas.

Non-Hispanic Whites—The non-Hispanic White population has been growing in metropolitan areas such as Atlanta, Washington, DC, Minneapolis/St. Paul/Duluth, Phoenix, Salt Lake City, and Albuquerque (fig. 7.4). It appears to be growing fastest in areas rich in natural amenities, such as the Rocky Mountains and Florida, Arizona, Colorado, Utah, and Nevada. In the South, the State of Florida and nearly every Atlantic coastal county experienced high rates of growth. Central and eastern Tennessee, northwestern Arkansas, and the metropolitan counties of eastern and southeastern Texas also were among the fastest-growing counties.

Population Projections for Three Levels of Change (2008 to 2060)

Similar to the historic trends in population growth and composition since 1990, the RPA regions likely to lead the Nation in future projected rate of change under the moderate growth scenario are the Rocky Mountains at 79 percent and the South at 59 percent (table 7.3). The Pacific Coast follows closely, at about 56 percent. The North trails the other regions by a wide margin, with just 27 percent expected growth. The Rocky Mountains' Intermountain area far exceeds all others with projected growth of 92 percent (nearly three times the rate of its Great Plains area of this region).

The Atlantic States area in the South ranks second among its nine RPA subregion counterparts, at a 68 percent forecast increase in population, followed by the Pacific Northwest with 63 percent. Of the Atlantic coastal States, Florida leads

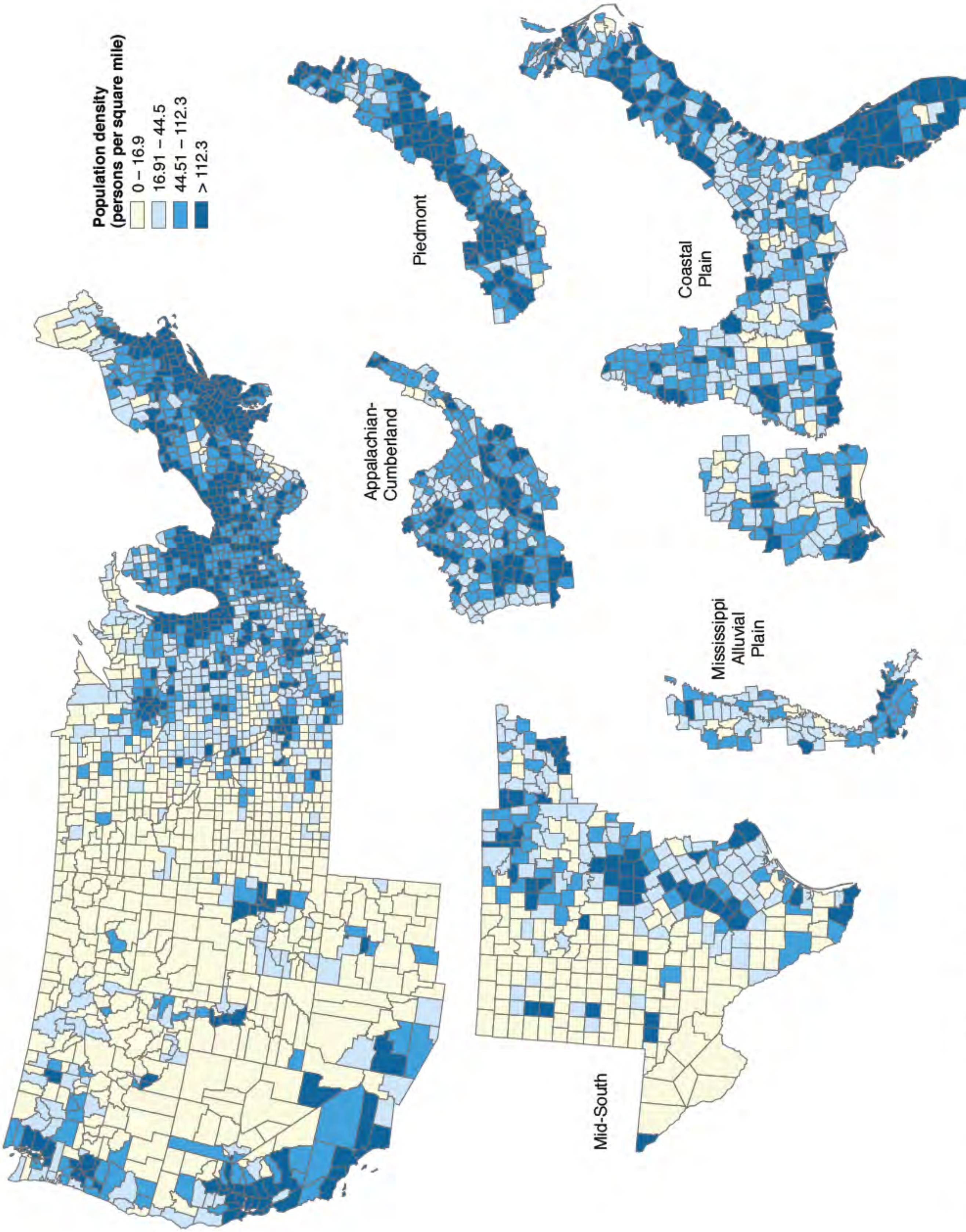


Figure 7.1—Population density by county in the contiguous United States, 2008. (Source: U.S. Census Bureau 2008b)

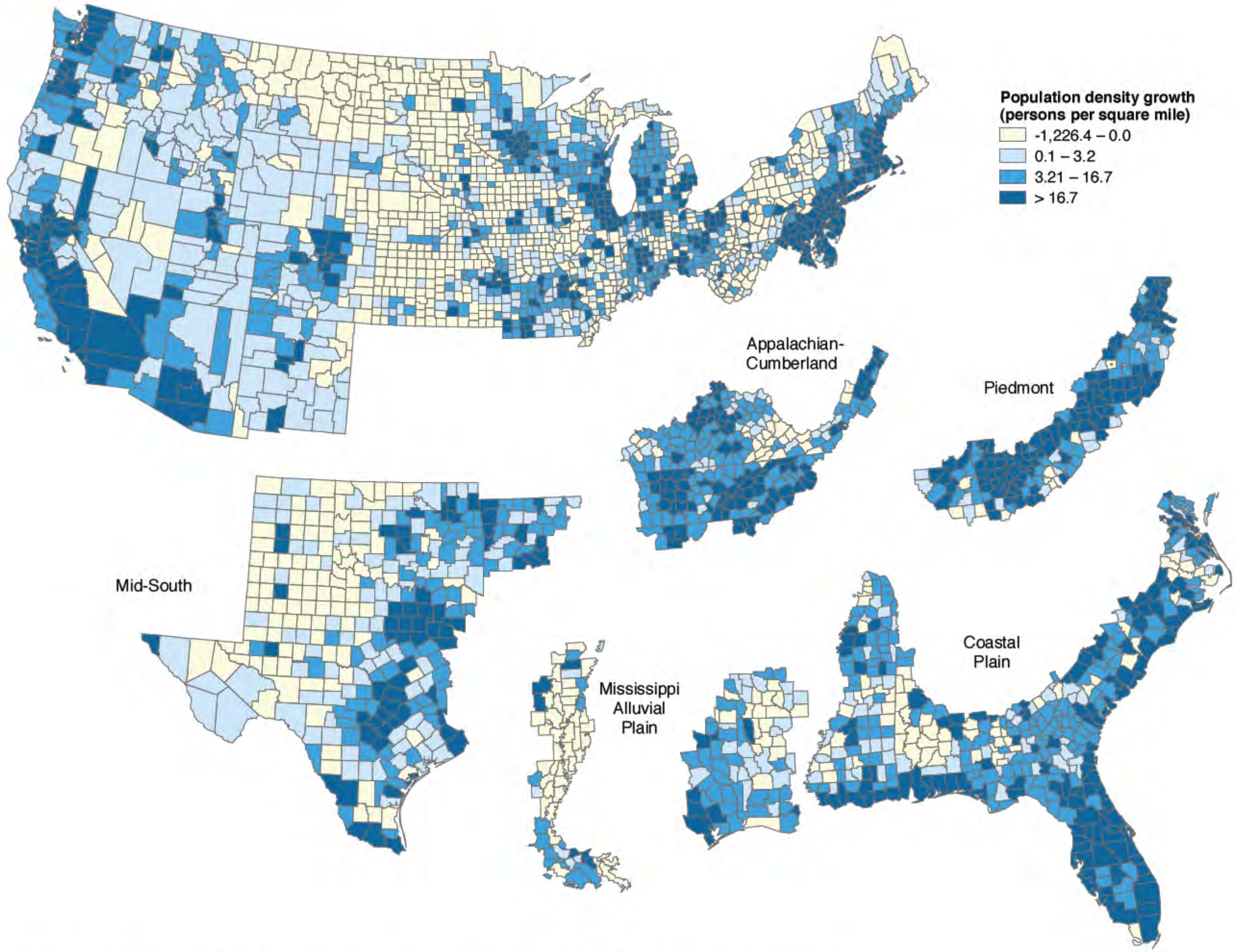


Figure 7.2—Change in population density by county in the contiguous United States, 1990 to 2008. (Source: U.S. Census Bureau 1990, 2008b)

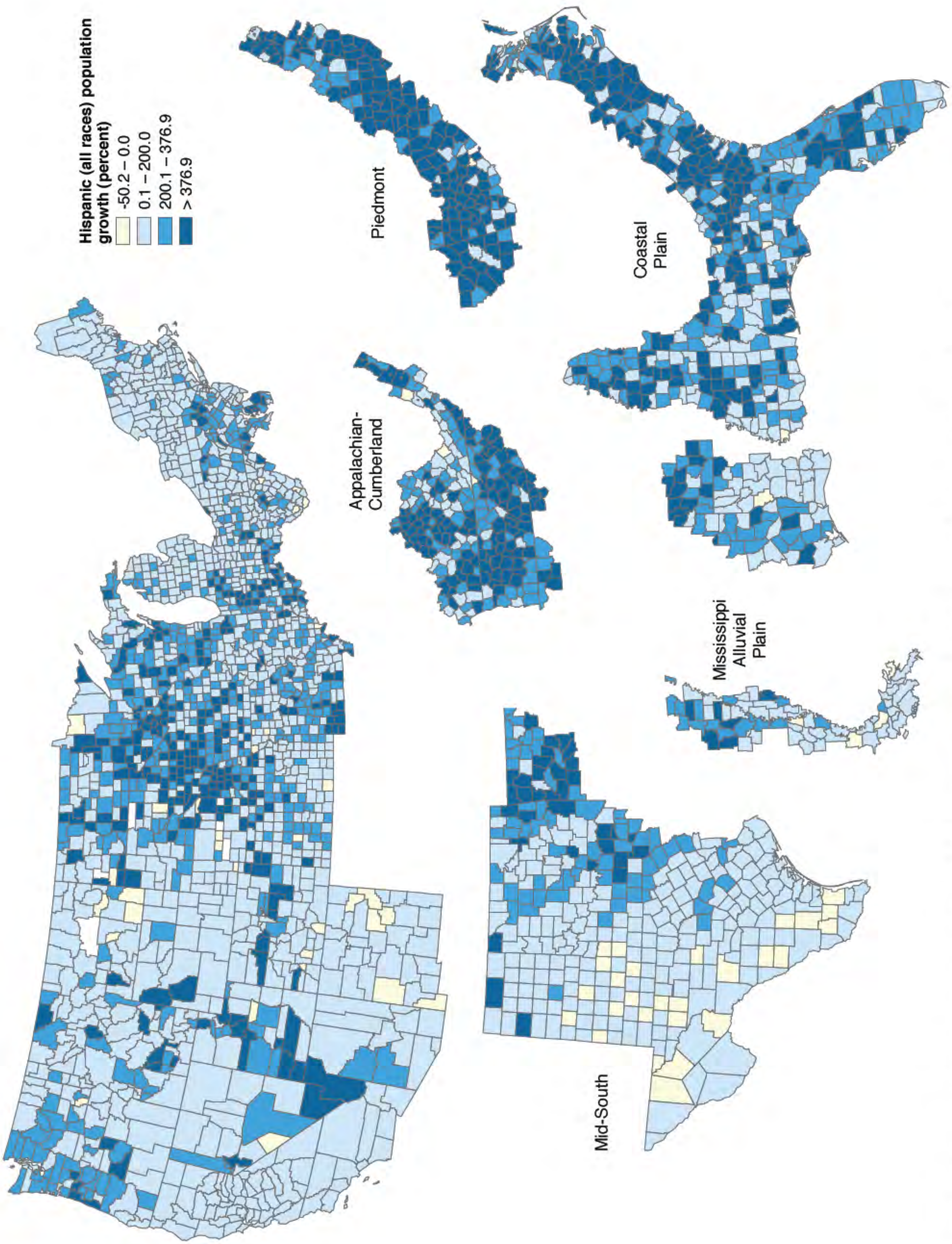


Figure 7.3—Percent change in Hispanic population by county in the contiguous United States, 1990 to 2008. (Source: U.S. Census Bureau 1990, 2008b)

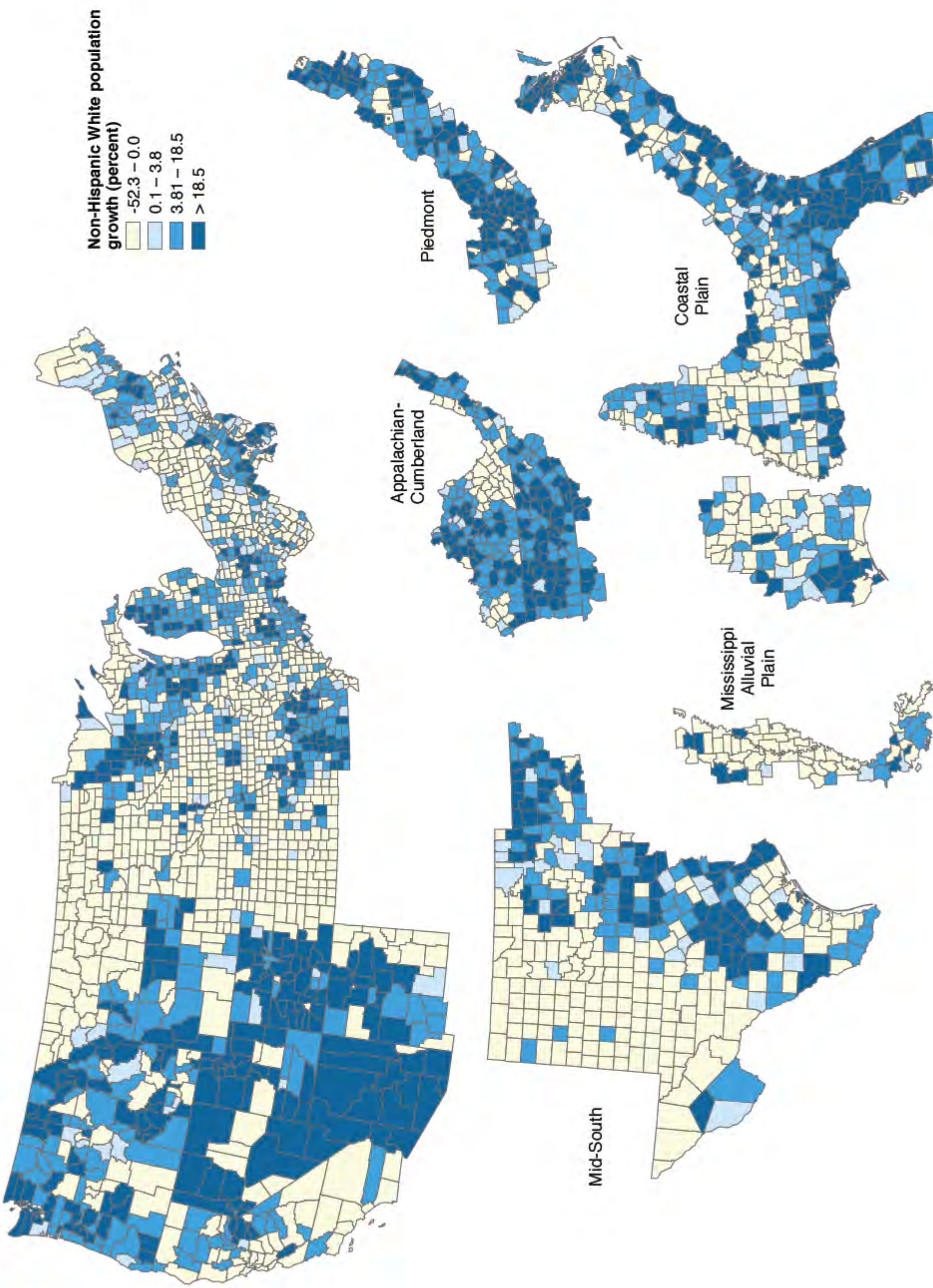


Figure 7.4—Percent change in non-Hispanic White population by county in the contiguous United States, 1990 to 2008. (Source: U.S. Census Bureau 1990, 2008b)

Table 7.3—Estimated population (thousands of people) for 2008, projections to 2060 by region and State for three levels of population growth, and percent change from 2008 to 2060 for the moderate growth projection

Region, State	Population estimate (2008)	Population growth projections (2060) Low	Moderate	High	Percent change, moderate growth level
Southern States	102,805.6	145,360.3	163,673.8	184,909.9	59.2
Alabama	4,661.9	5,988.3	6,742.8	7,617.6	44.6
Arkansas	2,855.4	3,869.2	4,356.7	4,921.9	52.6
Florida	18,328.3	30,496.7	34,338.9	38,794.3	87.4
Georgia	9,685.7	13,156.1	14,813.6	16,735.6	52.9
Kentucky	4,269.2	5,131.1	5,777.5	6,527.1	35.3
Louisiana	4,410.8	5,269.1	5,932.9	6,702.7	34.5
Mississippi	2,938.6	3,773.1	4,248.5	4,799.7	44.6
North Carolina	9,222.4	12,723.6	14,326.7	16,185.5	55.3
Oklahoma	3,642.4	4,446.7	5,006.9	5,656.5	37.5
South Carolina	4,479.8	6,257.6	7,045.9	7,960.1	57.3
Tennessee	6,214.9	8,384.0	9,440.3	10,665.1	51.9
Texas	24,327.0	34,689.9	39,060.4	44,128.4	60.6
Virginia	7,769.1	11,174.8	12,582.7	14,215.3	62.0
Northern States	124,368.0	139,964.2	157,597.9	178,045.6	26.7
Rocky Mountains States	27,760.9	44,135.2	49,695.6	56,143.5	79.0
Pacific Coast States	49,070.4	67,798.9	76,340.6	86,245.5	55.6
U.S. total	**304,004.9**	**397,258.6**	**447,308.0**	**505,344.5**	**47.1**

Source: Cordell 2012; U.S. Census Bureau 2008a.

by a wide margin with 87 percent projected growth, followed by Virginia and Texas, each at more than 60 percent. These three are the only States projected to grow faster than the South-wide rate. Louisiana, Kentucky, and Oklahoma rank lowest among the Southern States, each with less than 40 percent projected growth.

Figures 7.5 through 7.7 show the geographic patterns of projected changes in population density by 2060—ranging from lowest density (fewer than two people per square mile) to the highest density (more than 190 persons per square mile). These projected changes are shown for the low (fig. 7.5), moderate (fig. 7.6), and high (fig. 7.7) population growth projection scenarios. For the purposes of this analysis, all counties are assumed to have constant land area between 2008 and 2060.

Immediately apparent in the low growth projection scenario (fig. 7.5) is the presence of numerous lower density counties distributed throughout the South, especially in western Texas, the Mississippi Alluvial Valley, and southern portions of Arkansas, Alabama, and Georgia. Counties with the highest projected growth under this low growth scenario, with projection of more than 190 persons per square mile, are mostly limited to suburban areas, both coasts of Florida, and a few other scattered coastal counties. The moderate growth projection scenario (fig. 7.6), which closely approximates the Census Bureau State projections, has fewer low growth counties as expected, and more counties in the intermediate ranges (between 1.8 and 190.7 additional persons per square mile). The highest-growth counties under the moderate growth scenario are mostly centered around the major metropolitan areas of Atlanta, Charlotte, Nashville, Dallas-Fort Worth, San Antonio, coastal South Carolina, and the Atlantic coast of central Florida.

Under the high growth scenario (fig. 7.7), more counties in the South shift by 2060 from the lowest to the two moderate population density growth categories. Also, more of the counties that are in metropolitan areas are expected to add significant population density of more than 190 persons per square mile, especially around greater Atlanta, Charlotte, and central Florida. Smaller metropolitan regions such as the Triangle and Triad areas of North Carolina, Knoxville, New Orleans, and the Florida Panhandle are also projected to grow significantly. Only most of western Texas, the Mississippi Alluvial Valley, and portions of southern Alabama and Georgia are expected to lose population or grow very slowly, resulting in lower or about the same population density by 2060.

Trends in Outdoor Recreation

Between 2000 and 2008 (midpoint data years for two data collection periods of 1999 to 2004, and 2005 to 2009), the number of people in the Nation who participated in one or more of 60 outdoor activities grew by 7.3 percent, from an estimated 208.5 million to 223.8 million (fig. 7.8). Included in the list of 60 was a wide range of activities from visiting beaches and visiting farms to rock climbing and backpacking. Across the 60 activities, the indexed number of annual activity days of participation (measured as the product of the average number of days per activity times the number of participants and then summed across all activities) increased 31 percent from 67.1 billion to 87.8 billion. Average annual days of participation per person increased about 21 percent, from roughly 322 to about 390 total activity days per year.

For the South, the rate of growth for both total number of outdoor recreation participants and total annual activity days exceeded the national rate. Participants increased about 11 percent, from about 68 million to 75 million people age 16 and older, but this was overshadowed by a 41 percent increase in their total number of annual days (the sum of all individual activity days, which assumes that more than one activity can occur during any single day). Average activity participation days per person across the full list of activities rose from about 310 per year to 393, a 27-percent increase. Some of these faster gains can be attributed to slightly higher population growth than the national rate. The number of people age 16 and older increased 13 percent in the South (from just under 70 to around 79 million) compared to just under 10 percent (from 214 million to about 235 million) for the United States as a whole.

Results from comparison of percentages of the national number of participants by region for seven activity groups with the regional percentages of the U.S. population are shown in table 7.4. Also listed is the participation rate (percent of the region's population participating) for the four regions. Observations about regional differences in the participation rates are noted below by activity group name.

Visiting recreation and historic sites—Generally, regional differences are modest with participation in activities at recreation and historic sites slightly greater in the North and slightly lower in the South. The South is the only region where participation is less than the 81 percent national rate (not shown), though only about two percentage points less.

Viewing and photographing nature—Participation rates are a few percentage points higher in the Rocky Mountains and Pacific Coast, and a few points lower in the South. The North participation rate of 75.6 percent is identical to the national rate.

Backcountry activities—The participation rate in backcountry activities is substantially higher in the Rocky Mountains and Pacific Coast than the national rate, and is

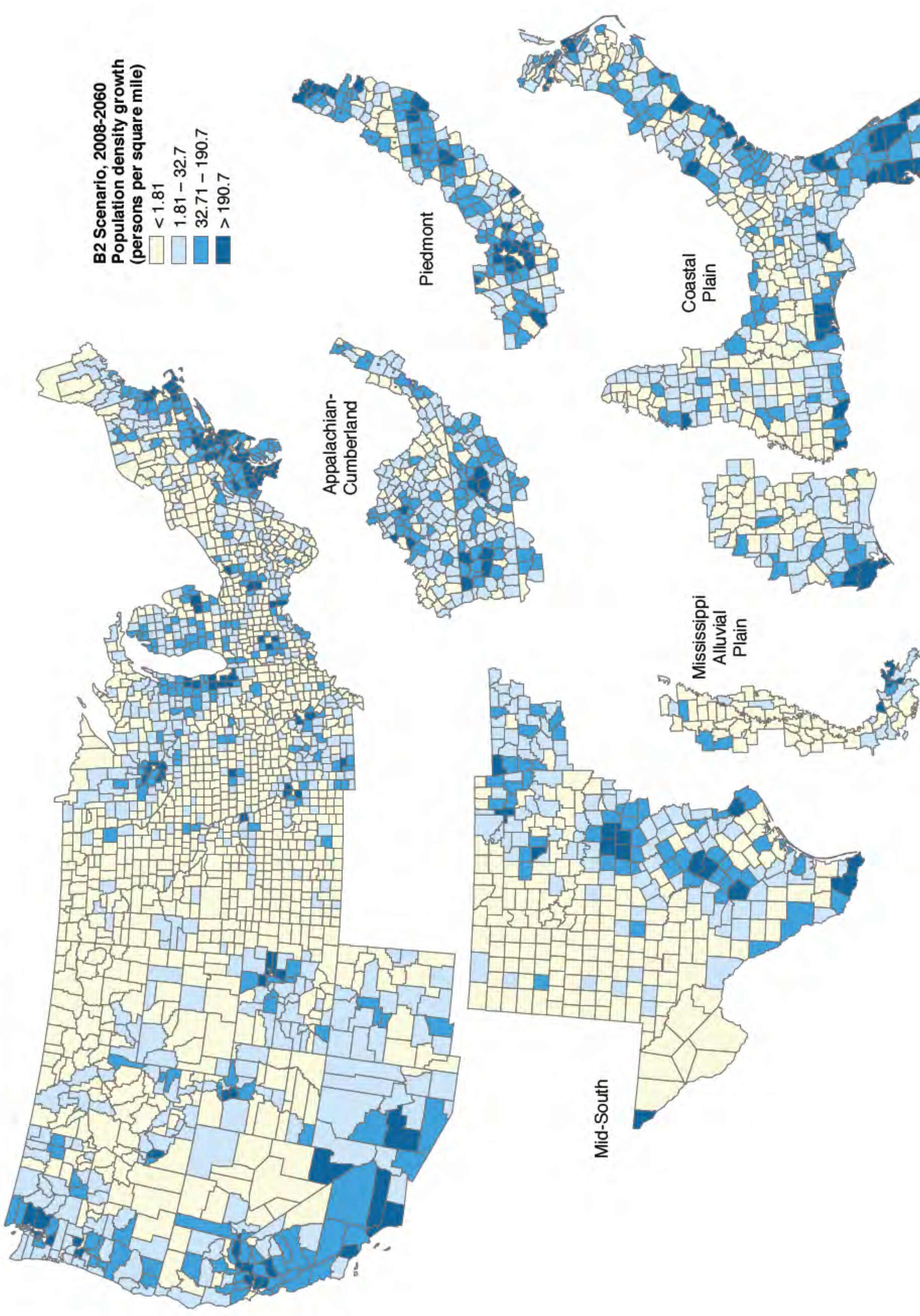


Figure 7.5—Change in persons per square mile by county in the contiguous United States, 2008 to 2060, for a low growth population projection. (Source: Cordell 2012; U.S. Census Bureau 2008b)

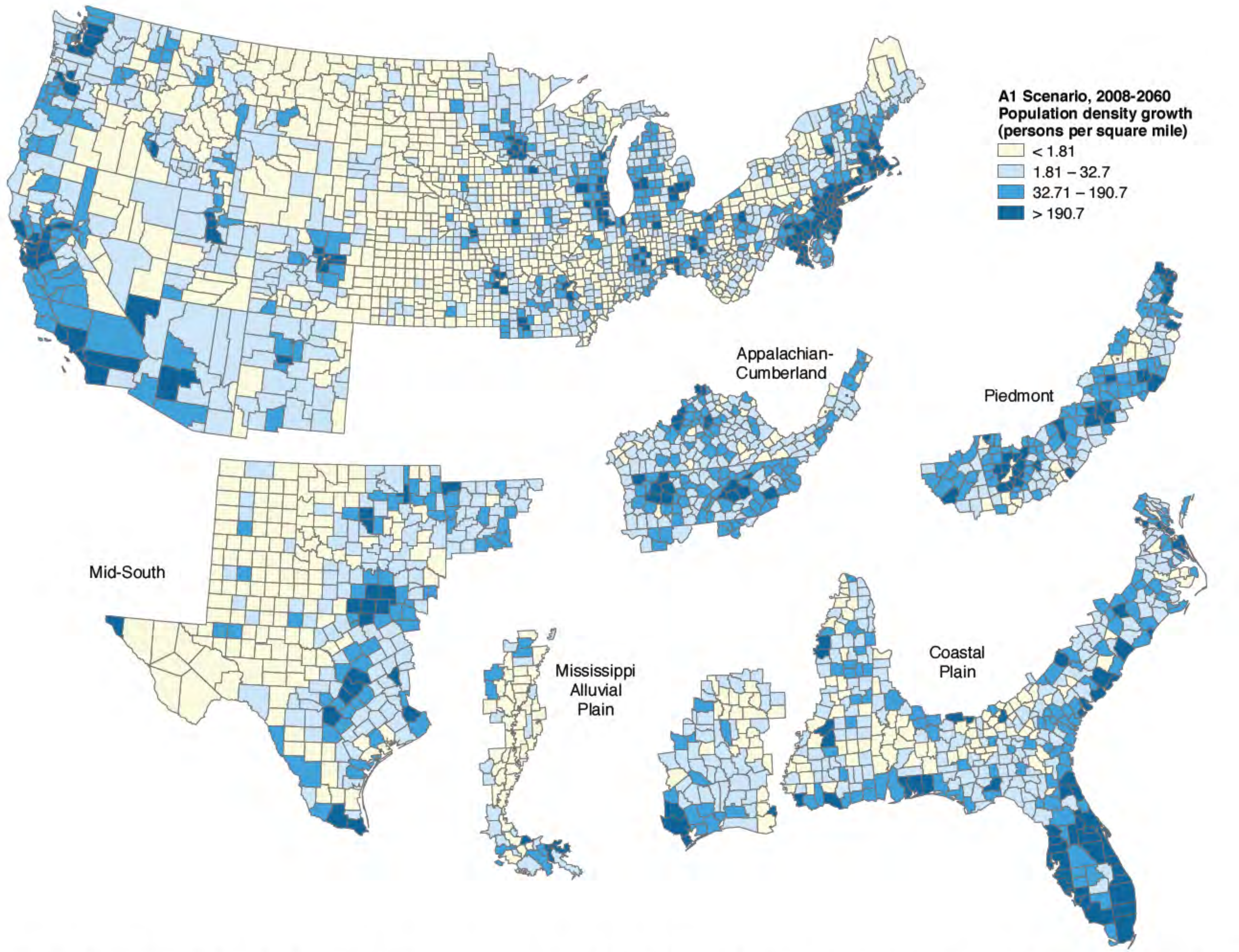


Figure 7.6—Change in persons per square mile by county in the contiguous United States, 2008 to 2060, for a moderate growth population projection. (Source: Cordell 2012; U.S. Census Bureau 2008b)

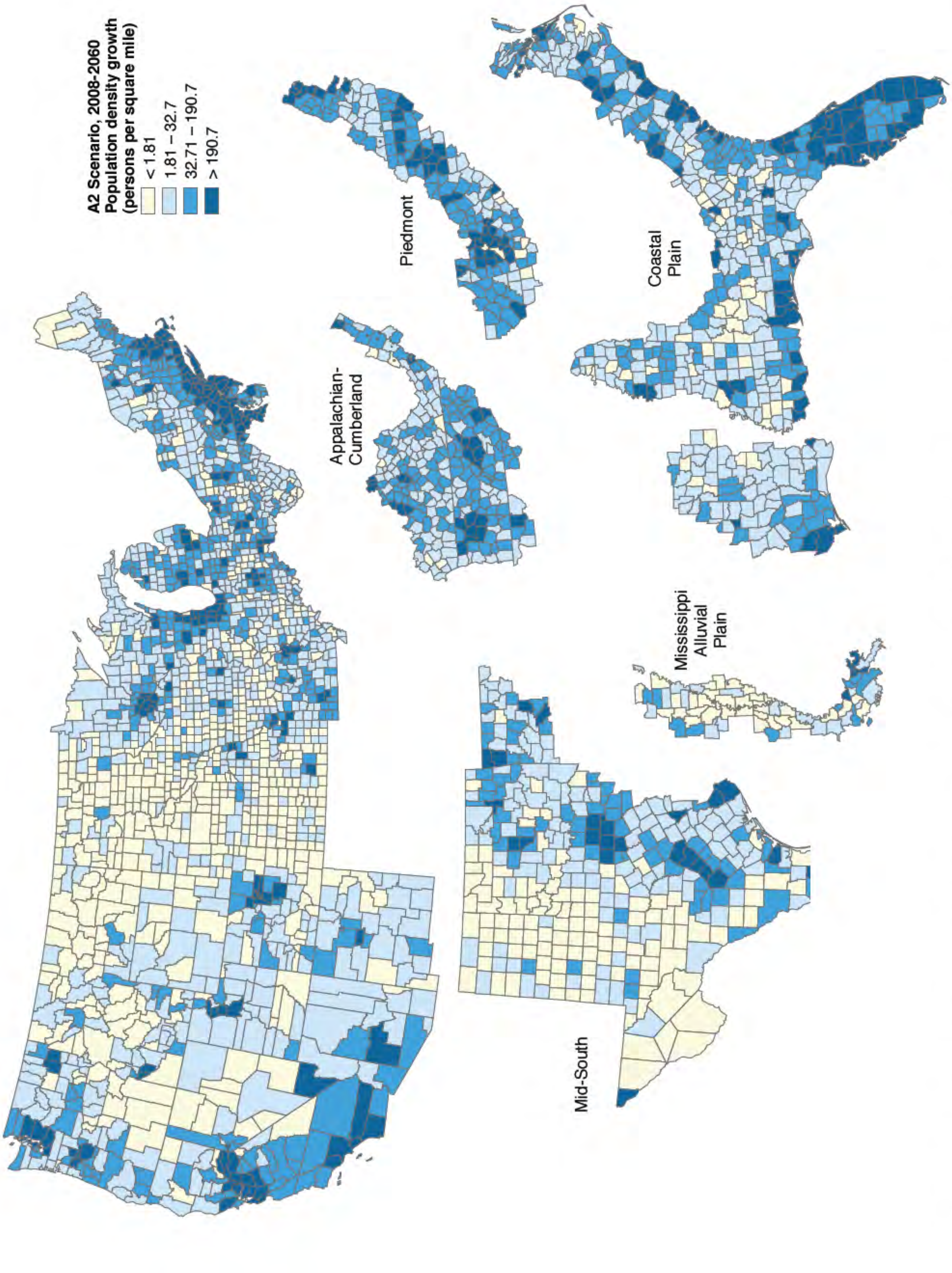


Figure 7.7—Change in persons per square mile by county in the contiguous United States, 2008 to 2060, for a high growth population projection. (Source: Cordell 2012; U.S. Census Bureau 2008b)

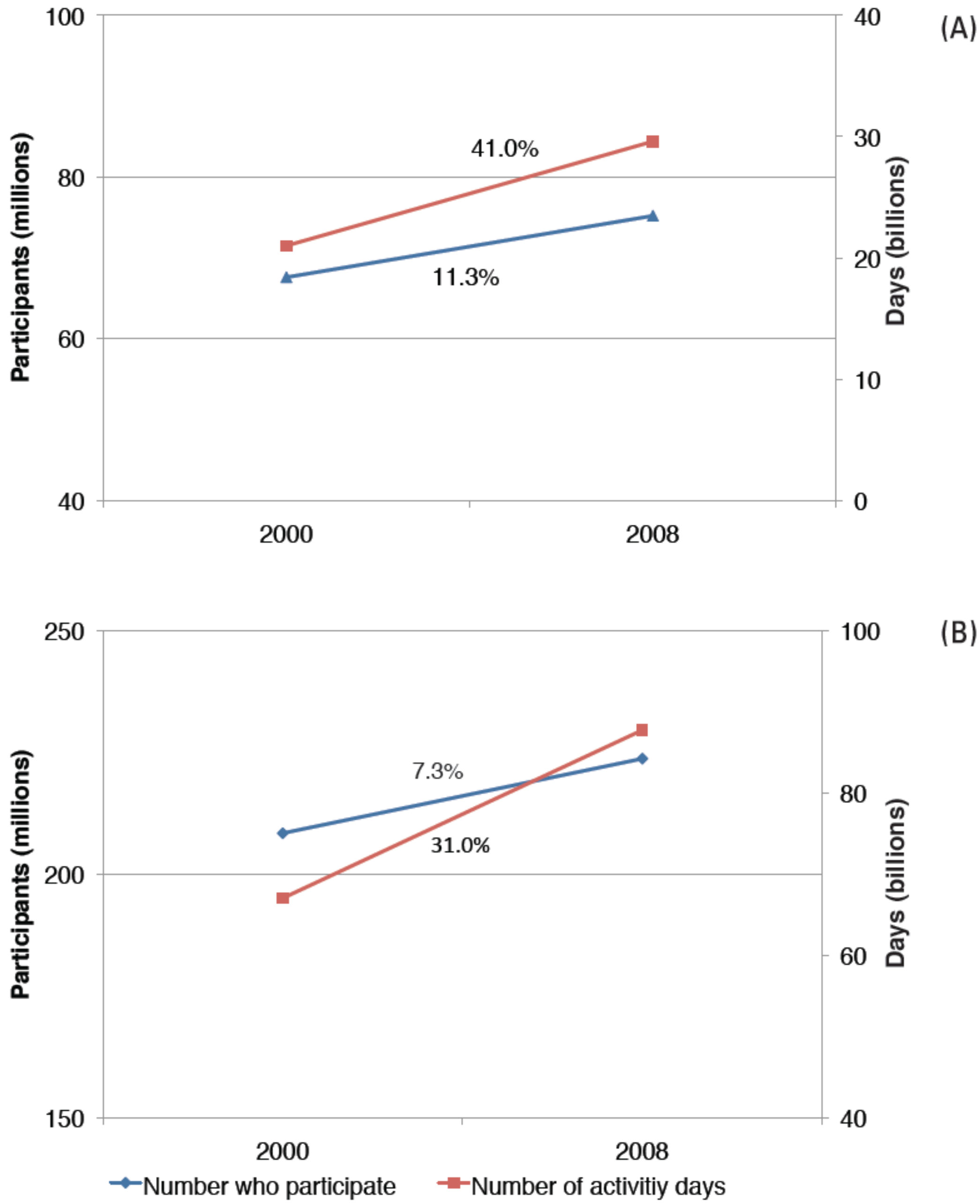


Figure 7.8—Growth in the number of people and the number of participation days in 60 outdoor recreation activities in (A) the South and (B) the United States, 2000 to 2008. (Source: U.S. Department of Agriculture Forest Service 2009a)

Table 7.4—Participants for seven activity groups in four U.S. regions

Activity group (activities that comprise the group)	Region	Percent of participants[a]	Percent of population[a]	Percent participating
Visiting recreation and historic sites (Family gatherings, picnicking, visiting the beach, visiting historic or prehistoric sites, and camping)	North	42.0	40.7	82.7
	South	29.7	31.4	78.9
	Rocky Mountains	10.1	10.1	81.9
	Pacific Coast	18.2	17.8	81.4
Viewing/photographing nature (View/photograph birds, natural scenery, other wildlife besides birds, and wildflowers, trees, and other plants)	North	40.8	40.7	75.6
	South	30.7	31.4	73.2
	Rocky Mountains	10.5	10.1	78.1
	Pacific Coast	17.9	17.8	75.8
Backcountry activities (Backpacking, day hiking, horseback riding on trails, mountain climbing, and visiting a wilderness or primitive area)	North	40.1	40.7	43.1
	South	26.0	31.4	37.4
	Rocky Mountains	13.0	10.1	57.4
	Pacific Coast	20.9	17.8	51.4
Motorized activities (Motorboating, off-highway vehicle driving, snowmobiling, using personal watercraft, and waterskiing)	North	40.8	40.7	36.4
	South	31.1	31.4	37.1
	Rocky Mountains	10.7	10.1	39.1
	Pacific Coast	17.4	17.8	35.6
Hunting and fishing (Anadromous fishing, coldwater fishing, warmwater fishing, saltwater fishing, big game hunting, small game hunting, and migratory bird hunting)	North	38.6	40.7	32.4
	South	35.5	31.4	38.8
	Rocky Mountains	10.9	10.1	37.1
	Pacific Coast	15.0	17.8	28.8
Non-motorized boating (Canoeing, kayaking, rafting, rowing, and sailing)	North	45.6	40.7	23.0
	South	27.5	31.4	18.0
	Rocky Mountains	9.2	10.1	18.7
	Pacific Coast	17.7	17.8	20.4
Snow skiing and boarding (Cross-country skiing, downhill skiing, and snowboarding)	North	49.6	40.7	14.0
	South	14.5	31.4	5.5
	Rocky Mountains	12.6	10.1	14.7
	Pacific Coast	23.3	17.8	15.1

[a]Percentages sum down to 100 within the four regions of each activity group.
Source: U.S. Department of Agriculture Forest Service 2009a.

especially higher than the South. The South's participation in backcountry activities is about 7 percent lower than the national rate of 44.3 percent. Thus, Southerners are less likely to be backcountry activity participants than are residents of any other region.

Motorized activities—The South's participation rate is just slightly above the national rate (36.9 percent), but exceeds those of the North and the Pacific Coast. Participation in motorized activities is slightly higher in the Rocky Mountains than in any other of the three regions, and the Rocky Mountains is the only region more than a few percentage points higher than the national participation rate.

Hunting and fishing—The South leads all regions in hunting and fishing participation, followed by the Rocky Mountains. Both are higher than the national rate of 34.3 percent. Thus, hunting and fishing are somewhat more likely to occur in the South than they are in the other regions. Hunting and fishing participation is lowest in the Pacific Coast.

Non-motorized boating activities—Participation in non-motor boating is highest in the North and Pacific Coast, and lowest in the South. At 18 percent participation, the South trails the national rate of 20.8 percent.

Snow skiing and boarding—It is no surprise that snow skiing and boarding participation are by far the lowest by residents of the South. Participation is highest in the Pacific Coast and Rocky Mountains, followed by the North. Every region but the South exceeds the national participation rate of 11.6 percent. Participation in the South is less than half the national rate, and whereas the South has about 31 percent of the national population, it has less than 15 percent of its skiers and snow boarders.

The South's Participation in Nature-Based Activities

Tables 7.5–7.8 summarize the trends in activity participation (number of people and percent of population age 16 and older in the South) in nature-based activities, such as bird watching or camping, from the mid-1990s to the present time.

Activities that had 30 million or more people participating at least once during a single year are shown in table 7.5. Walking for pleasure, family gatherings outdoors, gardening or landscaping, viewing/photographing natural scenery, sightseeing, and visiting outdoor nature centers occupy the top six slots, each with over 40 million participants in the South. Between 30 million and 40 million participants are shown for the activities of driving for pleasure, viewing/photographing flowers and trees, viewing/photographing wildlife (besides birds and fish), swimming in an outdoor pool, picnicking, visiting historic sites, swimming outdoors (besides pools), and visiting a beach. With the exception of picnicking, which was essentially constant, all of these activities have shown growth. Activities oriented toward viewing and photographing nature (scenery, flowers/trees, and wildlife) have been among the fastest growing.

Sixteen activities have between 10 million and 30 million participants (table 7.6). The activities of viewing or photographing birds, bicycling, gathering mushroom/berries, warmwater fishing, visiting a wilderness, visiting a farm or agricultural setting, viewing and photographing fish, and day hiking all have more than 20 million participants. All of the 16 activities, with the exception of developed camping, showed growth in numbers of participants during this decade (1999 to 2009), though a few grew modestly, under 10 percent. Fastest growing between the 1999 to 2001 and 2005 to 2009 periods were off-highway vehicle driving, gathering mushrooms and berries, and visiting farms or agricultural settings.

There are 17 activities with 3 to 10 million participants (table 7.7). Camping at primitive sites, big game hunting, waterskiing, using personal watercraft, and equestrian activities top this list for the South. All of the activities in table 7.7 have shown growth, though many at less than 10 percent. Kayaking was the fastest growing activity by a wide margin, but it began with a small base of just 1.4 million people in the late 1990s. Other relatively fast growing activities were also water-based, such as waterskiing and canoeing.

Table 7.8 shows activities with fewer than 3 million participants. At the top, with 2 or more million participants, are anadromous fishing, sailing, rowing, and rock climbing. Snowboarding and orienteering have showed significant growth since the late 1990s. (Much if not most of some activity participation, for example anadromous fishing and snowboarding, undoubtedly occurs in other regions of the country.) However, many activities with fewer than 3 million participants posted declines over the past decade. Given their low participation rates, nearly all the activities in table 7.8 represent niche activities that appeal to small market segments. Many require substantial investments in time, equipment, and skill.

The data shown in tables 7.5–7.8 may not fully describe all dimensions of activity trends, some of which may reflect the rapid rise in gasoline prices from 2007 to 2008 and the recession that began in 2007 and continues to impact incomes as of the writing of this chapter. However, viewed overall, the data presented in these four tables clearly show that what people in the South choose as activities is changing

Table 7.5—For activities with more than 30 million participants (2005–2009), trends in the number and percentage of Southerners 16 years old and older participating in nature-based activities from 1994 to 2009

Activity	1994 to 1995[a] Number of participants (millions)	1999 to 2001[b] Number of participants (millions)	2005 to 2009[c] Number of participants (millions)	2005 to 2009[c] Portion of population (percent)	1999 to 2009 Change (percent)
Walk for pleasure	42.4	55.9	66.3	83.9	18.5
Gathering of family/friends	39.2	50.7	58.4	73.9	15.2
Gardening/landscaping for pleasure	–	45.9	54.8	69.3	19.2
View/photograph natural scenery	–	38.2	47.1	59.6	23.4
Sightseeing	35.9	35.2	41.8	52.8	18.8
Visit outdoor nature center/zoo	33.3	36.8	41.5	52.5	12.8
Driving for pleasure	–	34.5	39.7	50.3	15.1
View wildflowers/trees	–	28.9	39.1	49.5	35.3
View wildlife besides birds and fish	18.3	29.4	38.9	49.2	32.2
Outdoor pool swimming	32.2	29.0	35.1	44.5	21.0
Picnicking	32.0	34.7	35.0	44.3	0.8
Visit historic sites/monuments	28.5	29.4	33.4	42.3	13.6
Swimming (other than pools)	26.7	27.0	31.2	39.4	15.3
Visit a beach	39.9	26.2	31.0	39.3	18.5

– = Missing data indicate that participation was not asked during this time period.
[a]Based on 64.01 million people age 16 and older (Woods and Poole Economics, Inc. 2009).
[b]Based on 69.88 million people age 16 and older (U.S. Census Bureau 2008a).
[c]Based on 79.02 million people age 16 and older (U.S. Census Bureau 2008a).
Source: U.S Department of Agriculture Forest Service 2009a.

Table 7.6— For activities with 10 million to 30 million participants (2005–09), trends in the number and percentage of Southerners 16 years old and older participating in nature-based activities from 1994 to 2009

Activity	1994 to 1995[a] Number of participants (millions)	1999 to 2001[b] Number of participants (millions)	2005 to 2009[c] Number of participants (millions)	2005 to 2009[c] Portion of population (percent)	1999 to 2009 Change (percent)
Viewing or photographing birds	16.9	21.0	27.0	34.2	28.7
Bicycling for fun/exercise	21.1	23.3	26.1	33.1	12.3
Gathering mushrooms/berries	–	18.1	25.1	31.8	38.7
Warmwater fishing	19.2	19.6	23.6	29.9	20.3
Visiting a wilderness	–	19.4	23.6	29.9	21.4
Visiting a farm/agricultural setting	–	17.7	23.1	29.2	30.4
Viewing salt/freshwater fish	8.8	17.9	22.9	28.9	27.9
Day hiking	13.0	17.8	20.0	25.2	12.4
Motor boating	20.1	16.8	19.1	24.2	13.4
Visiting waterside besides beach	–	17.4	18.3	23.1	5.0
Off-highway vehicle driving	11.9	11.8	16.8	21.3	42.1
Camping at developed sites	12.3	15.3	15.3	19.4	-0.2
Visiting archaeological sites	10.6	13.4	15.1	19.1	12.5
Boat touring or excursions	–	12.4	14.8	18.8	19.6
Saltwater fishing	10.3	9.7	12.1	15.3	24.3
Bicycling (mountain/hybrid bike)	–	10.9	11.6	14.7	7.3

– = Missing data indicate that participation was not asked during this time period.
[a]Based on 64.01 million people age 16 and older (Woods and Poole Economics, Inc. 2009).
[b]Based on 69.88 million people age 16 and older (U.S. Census Bureau 2008a).
[c]Based on 79.02 million people age 16 and older (U.S. Census Bureau 2008a).
Source: U.S Department of Agriculture Forest Service 2009a.

Table 7.7— For activities with 3 million to 10 million participants (2005–09), trends in the number and percentage of Southerners 16 years old and older participating in nature-based activities from 1994 to 2009

Activity	1994 to 1995[a] Number of participants (millions)	1999 to 2001[b] Number of participants (millions)	2005 to 2009[c] Number of participants (millions)	2005 to 2009[c] Portion of population (percent)	1999 to 2009 Change (percent)
Camping at primitive site	9.1	9.2	9.3	11.8	1.7
Big game hunting	6.7	6.4	8.0	10.1	25.2
Waterskiing	7.8	5.4	7.7	9.7	43.3
Using personal watercraft	4.6	6.8	7.7	9.7	13.7
Horseback riding/equestrian	6.9	6.7	7.6	9.6	12.9
Coldwater fishing	5.7	6.8	7.4	9.4	8.0
Canoeing	5.4	5.1	7.1	9.0	39.3
Small game hunting	6.7	5.9	6.8	8.6	16.0
Rafting	6.4	5.9	6.3	7.9	5.3
Backpacking on trails	4.2	5.0	6.1	7.8	22.5
Horseback riding on trails	4.7	5.4	5.6	7.1	3.7
Snorkeling[d]	5.4	4.2	4.7	5.9	10.7
Sledding	3.7	3.7	3.8	4.8	2.9
Kayaking	0.9	1.4	3.6	4.6	154.3
Mountain climbing	2.3	3.0	3.3	4.1	8.4
Caving	2.8	3.1	3.3	4.1	5.3
Downhill skiing	4.3	2.9	3.2	4.0	8.2

[a]Based on 64.01 million people age 16 and older (Woods and Poole Economics, Inc. 2009).
[b]Based on 69.88 million people age 16 and older (U.S. Census Bureau 2008a).
[c]Based on 79.02 million people age 16 and older (U.S. Census Bureau 2008a).
[d]Snorkeling in 1994-1995 included scuba diving.
Source: USDA Forest Service 2009a.

Table 7.8— For activities with fewer than 3 million participants (2005–09), trends in the number and percentage of Southerners 16 years old and older participating in nature-based activities from 1994 to 2009

Activity	1994 to 1995[ab] Number of participants (millions)	1999 to 2001[c] Number of participants (millions)	2005 to 2009[d] Number of participants (millions)	2005 to 2009[d] Portion of population (percent)	1999 to 2009 Change (percent)
Anadromous fishing	2.8	2.0	2.7	3.4	33.8
Sailing	3.0	2.6	2.6	3.2	-3.2
Rowing	2.4	1.9	2.4	3.1	24.2
Rock climbing	1.8	2.2	2.2	2.7	-0.9
Migratory bird hunting	2.2	1.8	1.9	2.5	9.7
Snowboarding	0.9	1.2	1.8	2.2	48.2
Orienteering	1.4	1.0	1.5	1.9	47.4
Ice skating	1.3	1.5	1.5	1.9	-1.9
Surfing	0.9	1.0	1.3	1.6	32.4
Snowmobiling	1.0	0.9	1.1	1.4	15.2
Scuba diving[b]	–	1.4	1.0	1.3	-25.7
Cross-country skiing	0.5	0.7	0.6	0.8	-10.6
Ice fishing	0.2	0.2	0.3	0.4	83.3
Windsurfing	0.8	0.4	0.3	0.3	-33.6
Snowshoeing	–	0.3	0.2	0.2	-36.0

– = Missing data indicate that participation was not asked during this time period.
[a]Based on 64.01 million people age 16 and older (Woods and Poole Economics, Inc. 2009).
[b]Scuba diving was included as part of snorkeling in 1994-1995.
[c]Based on 69.88 million people age 16 and older (U.S. Census Bureau 2008a).
[d]Based on 79.02 million people age 16 and older (U.S. Census Bureau 2008a).
Source: USDA Forest Service 2009a.

over time. Some of the activities that dominated in the 1960s, 1970s, and 1980s no longer dominate as generations, society, lifestyles, information, and technology are shifting (Cordell 2008).

Federal Recreation Resources

Federal land—The almost 640 million acres of Federal land provide vast areas for outdoor recreation. Such areas are as important in the South as they are throughout the country. With the exception of some national wildlife refuges, areas reserved for science and research, dams, and other administrative and operational sites, nearly all Federal land is open and available to the public. However, access is sometimes inhibited by in-holdings and ownership fragmentation.

Less than 5 percent of Federal land, about 30.5 million acres, is in the South, about 44 percent of which is managed by the Forest Service. More than 92 percent of Federal land is located in the Western United States. Even excluding Alaska—which has 36 percent of the national Federal total, Federal land is still predominantly western at 88 percent. The regional distribution of acreage in the three water resource agencies (Army Corps of Engineers, Bureau of Reclamation, and Tennessee Valley Authority), however, is much more evenly split between the West and East. Of the land and water area in the East, about 37 percent is in the South and 12 percent is in the North.

Federal acreage changes very little over time. What does change however, particularly by region, is the per capita amount of Federal land as population changes, mostly through growth. In 2008, the 2,105 acres per 1,000 U.S. residents (or about 2.1 acres per person) represented a 5.6 percent decrease from the 2002 level. Declines were largest in the Rocky Mountains (8.8 percent) and Pacific Coast (7.7 percent), reflecting greater population growth. In the South, the 296.3 Federal acres per 1,000 persons was a 4.8 percent decline since 2002.

The decline in per capita Federal acres nationally was even more pronounced when compared to 1995 levels, mirroring the 14 percent population increase (table 7.9): a decrease of 21.2 percent in the Rocky Mountains, 17.8 percent in the Pacific Coast, 15.4 percent in the South, and 8.2 percent in the North. These figures suggest that the pressure for recreation space may well grow as population grows.

Wilderness—As with Federal land in general, the Federal National Wilderness Preservation System is mostly in the western regions (96 percent), in particular in Alaska, which has more than 52 percent largely managed by the National Park Service and Fish and Wildlife Service. The South accounts for just 2.5 percent, or about 2.7 million of the 109.5 million acres. Even with Alaska's acres removed, the South's share rises to just 5.2 percent of the Nation's total. Since 1995, Wilderness area has grown about 6 percent, but with population increases, per capita acres have declined 3 percent (table 7.10) for the Nation and nearly 16 percent for the South compared to 8 percent Rocky Mountains and 10 percent for Oregon, California, and Washington on the Pacific Coast. Per capita Wilderness acres decreased across all agencies, except for Bureau of Land Management.

Protected rivers and trails—The National Wild and Scenic Rivers and National Recreation Trails were established by Congress in 1968 to designate high-value linear land areas that are important for resource protection and outdoor recreation. The more than 12,500 miles of wild and scenic rivers in the United States represent an 11 percent increase since 2000 (table 7.11); 3,000 miles are in the East and the remaining 75 percent are in the West. Classified as wild, scenic, or recreational, these rivers range from the most primitive and undeveloped (wild) to the most accessible which may have been impounded in the past (recreational). The South has only 810 miles (about 6 percent of the national total), despite an increase of more than 31 percent since 2000. Just under 100 miles were added to each of the wild and scenic classifications in the South, but no miles were added as recreational rivers.

The National Trails System consists of three categories of nationally significant, mostly long-distance trails: national scenic trails, national historic trails, and national recreation trails. Similar to the Federal designated rivers, national trails protect linear land resources that are judged to have significant value for the entire country. Scenic and historic trails are typically overland trails that are remote from population centers, but national recreation trails tend to be located near or within urban areas for the express purpose of providing accessible recreation opportunities. There were more than 20,000 miles of national recreation trails in the United States as of 2009 (table 7.12), nearly 69 percent of which are located in populous eastern areas. More than 6,500 miles are in the South, almost a third of the system. Further, the South led all regions with 84 percent growth in designated trail mileage since 2004, adding nearly 3,000 new trail miles.

Recreation facilities—The U.S. Department of the Interior coordinates the Recreation Information Database, an interagency effort to provide data to the public on Federal recreation sites and facilities through the website, www.recreation.gov. Table 7.13 shows that the Nation's estimated 9,075 Federal facilities translate into just under 30 facilities per million people (or about 1 per 33,500), with the West leading in all categories. With just 12.1 facilities per million people overall (or about 1 per 83,000), the South is fairly well represented in boating facilities, although still trailing

Table 7.9—Federal agency acres per 1,000 people (including Alaska) in 1995[a] and percent change from 1995 to 2008[b]

Federal Agency	North Acres 1995[c]	North Percent change 2008	South Acres 1995[c]	South Percent change 2008	Rocky Mountains Acres 1995[c]	Rocky Mountains Percent change 2008	Pacific Coast Acres 1995[c]	Pacific Coast Percent change 2008	United States Acres 1995[c]	United States Percent change 2008
U.S. Forest Service	101.9	-3.4	151.7	-14.6	4,600.3	-22.3	1,581.1	-12.7	719.6	-11.9
National Park Service	11.0	-1.8	58.3	-13.4	482.5	-17.5	1,447.3	-13.8	292.0	-11.2
U.S. Fish and Wildlife Service	10.3	34.0	44.8	-5.4	330.6	7.6	1,855.6	-13.7	339.7	-8.5
Bureau of Reclamation	0.0	0.0	2.3	-17.4	251.4	-21.8	20.3	-14.3	24.5	-12.7
Bureau of Land Management	3.3	-100.0	9.4	-95.7	6,629.1	-22.5	2,898.7	-22.4	1,005.1	-17.1
Tennessee Valley Authority	0.0	0.0	2.9	-17.2	0.0	0.0	0.0	0.0	0.9	-11.1
U.S. Army Corps of Engineers	24.8	-16.9	66.2	4.4	113.8	11.9	12.8	-13.3	43.4	4.1
All Federal agencies	156.4	-8.2	350.2	-15.4	12,422.9	-21.2	7,911.8	-17.8	2,448.6	-14.0

[a]1995 U.S. population estimate is 266.28 million (Woods and Poole Economics, Inc. 2009).
[b]2008 U.S. population estimate is 304.06 million (U.S. Census Bureau 2008a).
[c]Resource data years for earlier period vary by agency; expressed as 1995 because 1995 population estimates were used in per capita measures.
Sources: USDA Forest Service 1995, 2008; U.S. Department of the Interior National Park Service 1995, 2008; U.S. Department of the Interior Fish and Wildlife Service 1995, 2008; U.S. Department of the Interior Bureau of Reclamation 1993, 2008; Tennessee Valley Authority 2008; U.S. Army Corps of Engineers 2006.

Table 7.10—Federal acres in the National Wilderness Preservation System by region and Federal agency (excluding Alaska) per 1,000 people in 1995[a], and percent change from 1995 to 2009[b]

Agency	North Acres 1995	North Percent change 2009	South Acres 1995	South Percent change 2009	Rocky Mountains Acres 1995	Rocky Mountains Percent change 2009	Pacific Coast Acres 1995	Pacific Coast Percent change 2009	United States Acres 1995	United States Percent change 2009
Bureau of Land Management	0.0	0.0	0.0	0.0	74.8	121.4	89.5	-3.5	20.0	44.0
U.S. Fish and Wildlife Service	0.5	0.0	5.5	-16.4	67.3	-21.7	0.3	-33.3	7.6	-11.8
U.S. Forest Service	11.5	0.0	8.3	-12.0	823.1	-20.5	237.8	-9.1	111.5	-9.5
National Park Service	1.1	27.3	17.5	-17.1	36.0	34.2	200.9	-13.8	39.0	-6.9
U.S. total	13.2	1.5	31.3	-15.7	1,001.2	-8.0	505.2	-9.8	176.9	-3.0

[a]1995 U.S. population estimate is 265.67 million, excluding Alaska (Woods and Poole Economics, Inc. 2009).
[b]2008 U.S. population estimate is 303.37 million, excluding Alaska (U.S. Census Bureau 2008a).
Source: Wilderness.net 2009.

Table 7.11—Miles of river in the National Wild and Scenic River System by classification and region, 2000 and 2009

Region	Wild rivers 2000	Wild rivers 2009	Wild rivers Percent change	Scenic rivers 2000	Scenic rivers 2009	Scenic rivers Percent change	Recreational rivers 2000	Recreational rivers 2009	Recreational rivers Percent change	Total 2000	Total 2009	Total Percent change
North	172	174	1.5	935	1,014	8.5	964	1,007	4.4	2,070	2,195	6.0
South	187	284	51.8	318	414	30.2	112	112	0.0	617	810	31.3
Rocky Mountains	710	1,328	87.1	288	380	31.9	532	587	10.5	1,530	2,295	50.0
Pacific Coast	4,280	4,370	2.1	911	936	2.7	1,886	1,946	3.2	7,077	7,252	2.5
U.S. total	5,349	6,156	15.1	2,452	2,743	11.9	3,493	3,652	4.6	11,294	12,552	11.1

Source: Interagency Wild and Scenic Rivers Council 2009.

Table 7.12—Number and miles of National Recreation Trails in 2004 and 2009 by region and percent change in 2009

	National Recreation Trails					
	Number			Miles		
Region	2004	2009	Percent change	2004	2009	Percent change
North	226	312	38.1	4,119	7,319	77.7
South	220	264	20.0	3,578	6,577	83.8
Rocky Mountains	254	292	15.0	2,969	3,380	13.8
Pacific Coast	198	209	5.6	2,622	2,944	12.3
U.S. total	898	1,077	19.9	13,288	20,220	52.2

Source: American Trails 2010.

Table 7.13—Federal recreation facilities and activities supported per 1 million people by region in 2009

	Ratio (per 1 million people)[a]				
Activity or facility	North	South	Rocky Mountains	Pacific Coast	United States
Camping	8.3	11.2	121.3	63.8	28.6
Hiking	1.5	1.8	65.6	19.9	10.4
Fishing	1.3	2.4	64.0	18.3	10.2
Boating	1.9	4.3	22.7	10.2	5.9
Picnicking	0.1	0.1	43.6	9.3	5.6
Recreational vehicle camping	0.0	0.0	38.0	11.7	5.4
Biking	0.4	0.4	32.4	5.7	4.2
Horseback riding	0.1	0.4	27.5	4.7	3.5
Hunting	0.4	0.8	24.8	4.2	3.4
Wildlife viewing	0.1	0.1	20.1	7.5	3.1
Auto touring	0.0	0.0	13.4	2.4	1.6
Water sports	0.0	0.0	6.4	3.9	1.2
Interpretive programs	0.8	0.7	4.7	1.3	1.2
Visitor centers	0.9	0.8	4.0	1.1	1.2
Riding off highway vehicles	0.0	0.0	9.3	1.2	1.0
Wildernesses	0.0	0.0	6.0	2.3	0.9
Winter sports	0.0	0.0	6.3	0.8	0.7
Swimming sites	0.0	0.0	2.2	2.8	0.6
Historic and cultural sites	0.2	0.0	4.0	0.5	0.5
Fish hatcheries	0.1	0.2	0.7	0.3	0.2
Day use areas	0.0	0.0	1.4	0.4	0.2
Climbing	0.0	0.0	1.5	0.2	0.2
All activities and facilities	9.5	12.1	124.2	65.2	29.8

[a]Based on 2008 U.S. population estimate of 304.06 million (U.S. Census Bureau 2008a).
Source: U.S. Department of the Interior 2009.

the West in per capita availability by a wide margin due to its larger population. The Rocky Mountains has more than 10 times the number of available Federal facilities per capita than both the South and the North and nearly twice as many as the Pacific Coast. Camping facilities dominate the list; they are offered at nearly 96 percent of facilities nationwide.

Non-Federal Recreation Resources

State parks—State park systems exist in all 50 States, usually as a division or agency within a State department of natural resources or conservation. They are usually closer to population centers and more developed than their Federal counterparts, and although most manage a significant number of backcountry acres, these holdings are not nearly as extensive as those in Federal systems. State parks have been called "intermediate" resources because they represent a middle ground between the sometimes vast and distant Federal lands and the usually much smaller and more highly developed parks managed by local governments (Clawson and Knetsch 1966).

Every State system is built around flagship "State parks," but also typically consists of recreation areas and several types of other areas such as natural areas, historic sites, environmental education and science areas, State forests, and wildlife and fish areas. Although these other types of areas exist within State natural resource departments, in many States they are not managed within the State park system. This is the case for most, but not all, State forests and State wildlife and fish areas.

State park systems' accessibility is evident in their distribution across counties of the United States (fig. 7.9). The majority of U.S. counties have one or more acres of State park system lands. Although many of the largest holdings are found in western counties, representation is also substantial throughout the Eastern United States (particularly the Atlantic States and Florida for the South). With the exception of some areas in the Great Plains, and a few other scattered regions across the country, it is rare to travel across more than just a few counties without encountering State park system lands.

State parks typically provide a diversity of recreation opportunities, so many of the activities that people enjoy on Federal lands can also be enjoyed on the State park system lands. Although figure 7.9 shows Southern States having less extensive coverage as States in the Northeast and Midwest, State parks are located within less than an hour's drive regardless of where one is located in Florida and South Carolina, and throughout much of the South.

In 2009, the National Association of State Park Directors reported more than 13.9 million acres in State park systems, an increase of about 3 percent in acres per 1,000 people since 1995 (table 7.14).[2] Southern States reported about 2.2 million acres (16 percent of the national total or 21 percent if Alaska's large State parks are removed from the Pacific Coast total). State park acreage per capita grew 40 percent between 1995 and 2008 in the South. State recreation area acreage per capita dropped by nearly 29 percent during this period. The South's 8.8 percent growth in per capita acreage across all categories of areas under State park system management was more than twice that of the Nation, but was dwarfed by the North, which increased a full one-third in size. It should be noted, however, that most of the North's increase was likely due to reclassification of other State properties into the State park system jurisdictions. This was particularly prevalent in New York.

State park systems have faced difficult budgetary pressures since the onset of the 2007 recession, occasionally resulting in closure of some facilities (four in Arizona), transfer of others to other government and quasi-government entities, and/or reduced hours, services, and staffing (table 7.15). Two of the most affected States—Alabama and Georgia—are located in the South. The location and status of State park units throughout the 48 States is shown in figure 7.9. Substantial numbers are particularly evident throughout much of the Northeast, Midwest, Florida, and along the Pacific Coast. Although there are many fewer parks in the West, they tend to be larger than those in the North and South.

State facilities—Table 7.16 lists eight major types of facilities provided by State park systems and trends in these facilities since 1995. Campsites are by far the most plentiful resource per capita, although a comparison with the numbers of other facilities listed is not appropriate since each of those represents a much larger investment of resources. Nationally, improved campsites, cabins, golf courses, and marinas held steady on a per capita basis (per one million people) since 1995, but primitive campsites fell about 12 percent. The opposite was true in the South, where primitive campsites increased nearly 29 percent, accompanied by decreases in cabins, golf courses, and marinas. The drop in the number of swimming pools per capita at Southern State parks was in the same direction as the national trend. The South's large percent gain in stables per capita may represent just a handful of stables in the region, as the base number in 1995 was relatively small.

[2] Information derived from series of reports: National Association of State Park Directors. 2009. Annual Information Exchange for the Period July 1, 2007 through June 30, 2008, and National Association of State Park Directors. 1996. Annual Information Exchange for the Period July 1, 1994 through June 30, 1995. Available from North Carolina State University. Department of Parks, Recreation and Tourism Management, Jordan Hall 5107, Box 7106, Raleigh, NC 27697-7106. Yu-Fai Leung, Principal Investigator.

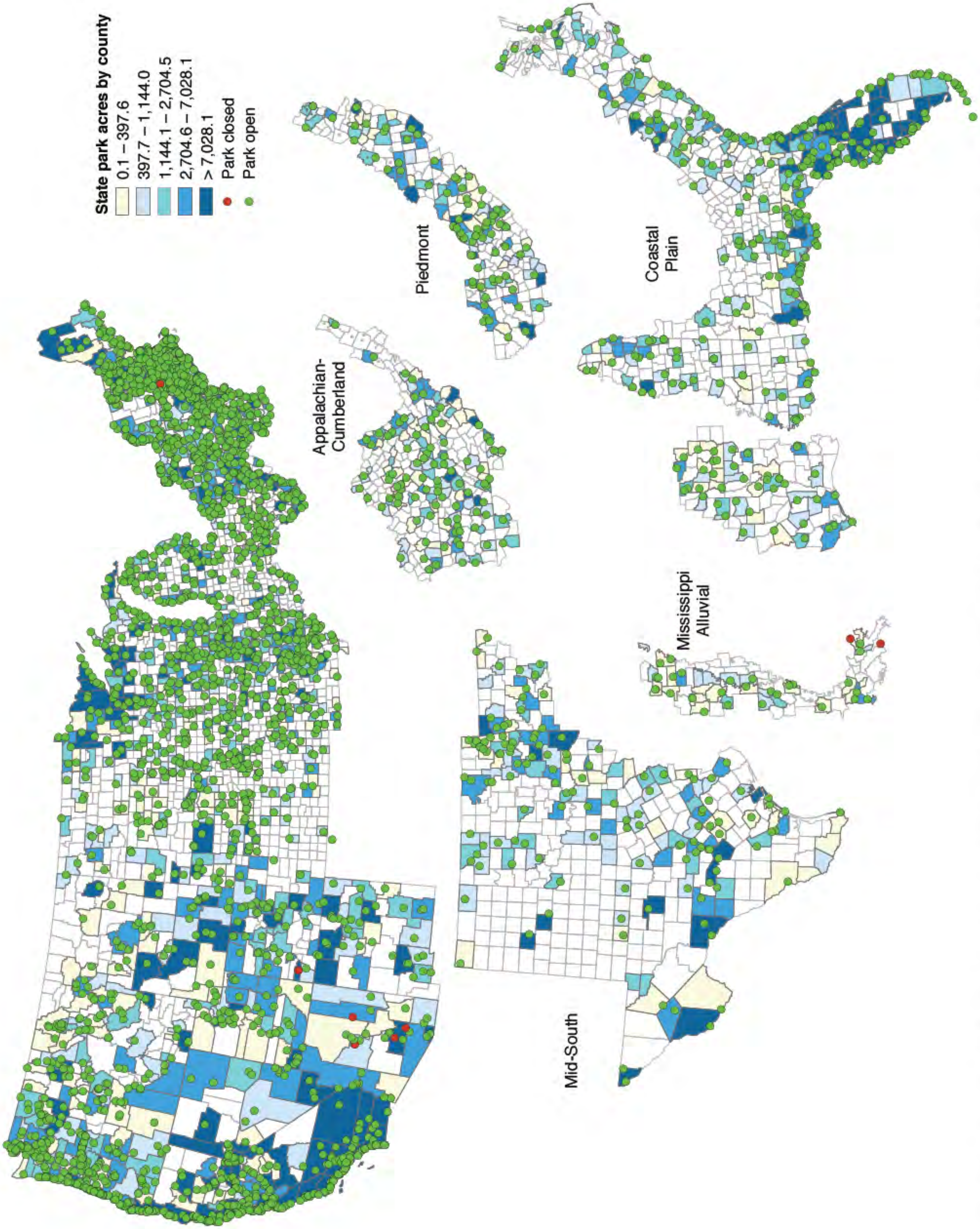


Figure 7.9—Location and status of State park system units and acres by county in the contiguous United States, 2009. (Source: U.S. Department of Agriculture Forest Service 2009b)

Table 7.14—State park system area by region and type of area per 1,000 people in 1995[a] and percent change from 1995 to 2008[b]

	North		South		Rocky Mountains		Pacific Coast		United States	
Type	Acres 1995	Percent change 2008	Acres 1995	Percent change 2008	Acres 1995	Percent change 2008	Acres 1995	Percent change 2008	Acres 1995	Percent change 2008
State parks	18.0	-2.3	10.1	40.2	37.0	-12.8	95.3	-8.1	29.4	-1.1
Recreation areas	1.5	49.7	1.3	-28.8	8.9	-22.9	18.1	-28.1	4.7	-15.0
Historic sites	0.1	123.1	0.3	-8.8	1.2	-59.8	0.4	51.2	0.3	12.1
Natural areas[c]	0.9	77.6	0.1	9066.7[d]	0.3	2907.4[d]	0.0	–	0.4	804.9
Other areas	9.4	111.6	0.6	-7.9	14.4	-87.1	1.2	7.5	5.7	52.5
All areas	31.2	33.2	19.7	8.8	70.5	-29.7	117.4	-10.1	44.4	3.2

– = unavailable.
[a]1995 U.S. population estimate is 266.28 million (Woods and Poole Economics, Inc. 2009).
[b]2008 U.S. population estimate is 304.06 million (U.S. Census Bureau 2008a).
[c]Includes environmental education sites and areas classified as scientific sites.
[d]Includes forests, fish and wildlife areas, and other miscellaneous State park system sites. Changes are likely the result of system reclassifications and not additions.
Source: National Association of State Park Directors 1996, 2009 (see footnote 2).

Table 7.15—State park systems affected by closure or reduction in services by State, 2009

State	Number of system areas	Number of closures	Reduction in services
Alabama	23	0	One park transferred to county government
Arizona	28	Two parks and two historic sites	Hours open were cut for two State parks and five historic parks
Georgia	63	0	One park changed to outdoor recreation area; six historic parks/sites have cut hours; and three historic sites are now operated by the counties within which they reside
Hawaii	50	0	One park transferred to a development corporation
Massachusetts	136	Two State forests	Two areas will not be staffed
Michigan	93	0	One site cut hours for the summer

Source: USDA Forest Service 2009b.

Table 7.16—State park system facilities per 1 million people by region and type of facility in 1995[a] and percent change from 1995 to 2008[b]

	North		South		Rocky Mountains		Pacific Coast		United States	
Facilities	Number 1995	Percent change 2008	Number 1995	Percent change 2008	Number 1995	Percent change 2008	Number 1995	Percent change 2008	Number 1995	Percent change 2008
Improved campsites	608.1	15.0	361.1	-2.4	837.2	4.7	514.8	-40.4	533.2	0.3
Primitive campsites	144.4	-31.3	60.6	28.7	855.1	-5.4	215.0	-30.5	186.9	-11.7
Cabins	23.3	11.7	30.1	-11.2	17.3	50.4	9.7	29.0	22.8	5.5
Golf courses	0.4	19.5	0.6	-3.2	0.2	38.9	0.1	-42.9	0.4	4.8
Golf holes	6.4	28.2	9.8	3.3	2.5	108.9	1.7	-46.2	6.4	15.1
Marinas	0.8	29.8	1.0	-22.9	2.5	-10.7	0.3	0.0	0.9	3.3
Swimming pools	1.4	-8.1	1.5	-19.9	0.4	8.1	0.1	100.0	1.1	-12.6
Stables	0.3	-10.0	0.3	92.6	0.6	-40.0	0.1	-77.8	0.3	14.3

[a]1995 U.S. population estimate is 266.28 million (Woods and Poole Economics, Inc. 2009).
[b]2008 U.S. population estimate is 304.06 million (U.S. Census Bureau 2008a).
Source: National Association of State Park Directors 1996, 2009 (see footnote 2).

Local government services—The 2007 Census of Governments tallied 8,852 local governments nationwide that provide recreation and park services, with just fewer than 29 percent of these (2,552 units) in the South. On a per capita basis (per million people) the South experienced almost 18 percent growth since 1997—slightly higher than the national rate of 13 percent and higher than any other single region (table 7.17). Municipal recreation departments grew much faster than county departments in the South. Fastest of all was special recreation and park districts, which grew more than 53 percent per capita. These numbers, however, were very small in 1997, with only a single special district department for every 2 million Southern residents. Further, the Trust For Public Land's LandVote database tracks ballot measures throughout the country that finance recreation and park-related protection, development, and improvements (TPL 2011). Since 2000, TPL reports 184 ballot measures passing (out of 226 or 81 percent) for municipal and county governments in the South. These initiatives summed to just over $5 billion worth of funding through bond and tax measures.

Local government resources are important for the basic fact that they provide 'close-to-home' recreation opportunities, especially in urban and urbanizing areas. Many of the most popular outdoor recreation activities (based on the proportion of people who participate in them), such as walking and bicycling for pleasure, picnicking, and outdoor family gatherings, occur most often in accessible places near where people live, hence the importance of local parks and recreation areas. Though most local parks tend to be highly developed in terms of facilities and infrastructure, a significant proportion of local resources also provide more natural environments that are suitable for dispersed forms of recreation. Nature centers, natural areas, trails, and greenways are examples of resources that offer nature-based recreation opportunities. The TPL's Center for City Park Excellence estimates that almost exactly one-half of the local government parkland in the Nation's 77 largest cities is in its natural state, as opposed to being designed or developed for human use (Harnik and others 2012).

Private businesses and land—Among the nine outdoor recreation business categories tracked, five showed a decline in the number of establishments per million people from 1998 to 2007 (table 7.18). Skiing facilities (very few of which were located in the South in 1998), amusement/theme parks, recreational/vacation camps, golf courses, and marinas all posted double-digit declines in the South. Private-sector historical sites, nature parks, and zoos/botanical gardens—all in the viewing/learning/photography group of activities—posted the greatest gains. Historical sites and zoos/gardens exceeded that national trend, and nature parks were not far from the national growth rate of 42 percent.

Table 7.17—Number of local government parks and recreation departments by governmental unit and region per million people in 1997 and 2007, and percent change from 1997[a] to 2007[b]

Type of government unit	North			South			Rocky Mountains			Pacific Coast			United States		
	1997	2007	Percent change	1997	2007	Percent change	1997	2007	Percent change	1997	2007	Percent change	1997	2007	Percent change
County	3.5	3.5	0.3	5.4	5.7	6.2	5.8	5.1	-12.6	2.3	2.2	-5.6	4.1	4.2	1.7
Municipal	15.0	18.4	22.7	15.5	18.8	20.7	21.0	29.4	40.3	12.9	14.0	8.0	15.3	18.8	22.6
Town or township	8.5	9.4	11.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	3.7	3.9	5.1
Special district	3.4	3.2	-5.6	0.5	0.7	53.2	7.6	4.8	-37.1	3.8	3.4	-11.3	2.9	2.5	-11.5
All local units	30.3	34.5	13.6	21.4	25.2	17.7	34.4	39.5	14.8	19.1	19.5	2.5	26.0	29.4	13.0

[a]1997 U.S. population estimate is 272.65 million (Woods and Poole Economics, Inc. 2009).
[b]2007 U.S. population estimate is 301.29 million (U.S. Census Bureau 2008a).
Source: U.S. Census Bureau 2007a.

Table 7.18—Number of selected private recreation business establishments by type of business and region per million people in 1998[a] and percent change from 1998 to 2007[b]

	North		South		Rocky Mountains		Pacific Coast		United States	
Recreation business	**Number 1998**	**Percent change 2007**	**Number 1998**	**Percent change 2007**	**Number 1998**	**Percent change 2007**	**Number 1998**	**Percent change 2007**	**Number 1998**	**Percent change 2007**
Golf courses and country clubs	49.8	-4.3	40.1	-11.7	47.1	-6.0	26.0	-8.8	42.6	-7.7
Recreational vehicle parks and campgrounds	13.3	4.1	11.4	0.4	26.9	-1.3	17.3	-3.1	14.5	1.4
Marinas	17.7	-3.5	16.5	-18.6	7.5	-24.9	10.6	-12.3	15.3	-11.5
Recreational and vacation camps (not campgrounds)	14.0	-18.1	8.5	-20.7	22.5	-28.4	11.3	-12.2	12.5	-19.6
Historical sites	4.5	6.1	2.3	23.9	3.8	-15.2	1.8	3.4	3.3	6.7
Nature parks and similar institutions	1.9	31.7	1.5	35.6	2.9	20.7	1.3	118.5	1.7	42.5
Amusement and theme parks	3.7	-47.8	3.6	-36.8	2.9	-16.6	2.4	-12.9	3.4	-37.7
Zoos and botanical gardens	1.4	33.8	1.3	44.8	1.7	15.5	1.5	49.3	1.4	37.8
Skiing facilities	1.7	0.6	0.4	-40.5	4.4	-7.7	1.5	-17.6	1.5	-8.3

[a] 1998 U.S. population estimate is 272.65 million (Woods and Poole Economics, Inc. 2009).
[b] 2007 U.S. population estimate is 301.29 million (U.S. Census Bureau 2008a).
Source: U.S. Census Bureau 2007b.

Privately-owned land, particularly forest, is a significant outdoor recreation resource, especially in the eastern United States. The 2006 National Woodland Owner Survey estimated that 10.4 million family forest owners hold about 264 million acres (35 percent) of all U.S. forest land and 62 percent of private forest land area (Butler 2008). Most of the private forest land is in the southern and northern regions (Butler 2008). The South has 44 percent of both the Nation's private forest land and private forest owners. Besides family forest owners, most of the other private forest land in the South is controlled by forest industry and forest management companies, including timber investment management organizations (TIMOs) and timber-oriented real estate investment trusts (REITs). More than half of family forests are owned primarily for their beauty and scenery, but also for nature protection, and other reasons. Among secondary reasons are for a vacation home or cabin and recreation, primarily for the landowner, their family, and friends. While only 15 percent of family forest land is open to the general public for recreation, all private forest land tracts may be considered available to be used by someone for recreation. Each State has a recreational use statute which limits the liability of private landowners to allow access to their land, thus ostensibly encouraging public use. However, the interpretation of what constitutes a recreational 'user' varies by State. An online copy of each State's recreational use statute appears on the University of Arkansas's National Agricultural Law Center Web site (NALC 2011).

Recreation leases on private land in the South, especially for hunting, are a popular and mutually beneficial means of allowing users access to private property while providing income to the land owner. Hunters and other recreationists who are willing to pay a fee in effect compensate the land owner for providing the necessary wildlife habitat to maintain wildlife populations. Yarrow (2009) has provided an online primer on hunting leases, including a description of four different types of lease-hunting arrangements and a copy of a sample lease. In addition to hunting, lessees may use private property for fishing, observing or photographing wildlife, and other compatible nature-based recreation activities. Timber and other forest industry companies are also in the business of offering recreation leases. Plum Creek Timber Company, Inc. is the largest private landowner in the United States with approximately 6.8 million acres of timberland in 19 States (including every Southern State except Tennessee, Virginia, and Kentucky). They are certainly one of the largest private providers of recreational opportunities (Plum Creek Timber Company, Inc. 2011). Much of Plum Creek's land in the northern and western States is open to the public, but access in the South is limited to lease arrangements. Data on industry recreation leases are not released for proprietary reasons and although some recent studies have examined economic issues regarding hunting leases in parts of the South (e.g., see Hussain and others 2007, Liu and others 2010, Zhang and others 2006), no region-wide assessment or summary statistics on recreation leases in the South exists.

The NSRE estimated the number and percent of annual recreation activity days in the United States that occur on private land (Cordell 2012). Based on a national sample of about 5,400 people age 16 and older, the estimates for seven activity groups were split into East and West regions. (Forest Service Regions Northern and Southern were combined to form the East group because of an insufficient sample for the South alone for some less popular activities.) Hunting led all activities with 47 percent of all annual days nationwide occurring on private forest lands in the East. Motorized activities ranked second with 43 percent followed by 34 percent of nature viewing and photography estimated to occur on eastern private forest lands. Backcountry activities, such as backpacking, day hiking and visiting a primitive area, were least likely to occur on eastern private forest lands.

Nearby Recreation Resources (Current)

Figure 7.10 shows the county-level pattern of four levels of Federal and State-park land acreage within the 75-mile distance zone (considered to be suitable for a day trip with no overnight stay necessary). Whereas some counties have no Federal or State land within their boundaries, all have some access to public acreage when surrounding counties are considered. Most counties in the South have from 0.07 acres to 1.46 acres of public land per person, with a high between 1.46 acres and 18.31 acres in the Ozark Highlands and the Virginia mountains and a low of less than 0.1 acres per person in central Florida and the southeastern Piedmont.

Counties in much of the drier parts of western Texas and in some parts of Nevada and California lack non-Federal forest land within their 75-mile recreation day trip zone (figure 7.11). Although much of the South has abundant forest land area, when population density is considered in calculating per capita acreage, some of the metropolitan areas are found to have relatively little. Parts of Arkansas, Louisiana, Mississippi, Alabama, and Georgia have relatively abundant per capita non-Federal forest land within 75 miles.

As with public land area, all counties have access to some water area when the 75-mile zone for each county is considered (fig. 7.12). Water as defined here is all water area with the exception of open ocean. For the South, greater water (non-ocean) area per capita is in coastland counties along the Atlantic Ocean and Gulf of Mexico. Moderate levels of water per capita are found inland throughout the South. Relatively low water per capita is found in Texas metropolitan and the Atlanta metropolitan areas (because of greater populations in these areas), as well as large portions of North Carolina, Virginia, and Kentucky. On a per capita basis, the greatest water area is the Great Lakes area, the Dakotas, and Montana (because of low population density), and in a few counties in the West.

Nearby Recreation Resources (Projected)

Federal and State park lands—Federal and State park acreage is expected to be (or almost be) constant through time. Forecasts of future areas of Federal and State park lands were not attempted for this report. Historically, the net area of federal land has changed very little in recent decades. State park systems, despite growth in per capita acreage since 1995, are not expected to continue expanding at recent historical rates. Given the recent State political and budget trends nationwide which have resulted in many closures, downsizing, and understaffing of State park units, a no-growth scenario for State park resources might be considered a reasonable future projection. For the country as a whole, about 26 percent of the total area is in Federal or State management or slightly more than 2 acres per person (table 7.19). By 2060, per capita Federal and State park acreage is predicted to decline to 1.4 acres per person or about 68 percent of the 2008 amount.

Federal or State-park land is much less in the East, with 5 percent of total area in the South or less than 0.3 acres per person. By 2060, the Federal or State park land area per person is projected to decrease to 0.17 acres, about 63 percent of the 2008 level. Percentage of total area that is Federal or State-park land is somewhat higher for the Atlantic States than for southern States further west (7.4 versus 4 percent), but higher population growth is expected to result in lower per capita acreages of the public land acres for these States.

Non-Federal forest—Non-Federal forest land area is expected to change with continuing conversions from forests and farmlands to cities and suburbs. For the country as a whole (excluding Alaska and Hawaii), about 19 percent of total land area is non-Federal forest (table 7.20), or 1.27 acres per person. By 2060, per capita non-Federal forest area is predicted to decline to 0.8 acres per person, or 63 percent of the 2010 amount.

For the South, more than 30 percent of total land area is non-Federal forest, or 1.66 acres per person. By 2060, per capita non-Federal forest is predicted to decline to 0.95 acres per person, or 57 percent of the 2010 level. The percentage of total area that is non-Federal forest is considerably higher for the Atlantic States than for States farther west (about 43 versus 26 percent), but higher projected population growth is expected to result in lower per capita non-Federal forest acreages for these States compared to those farther west.

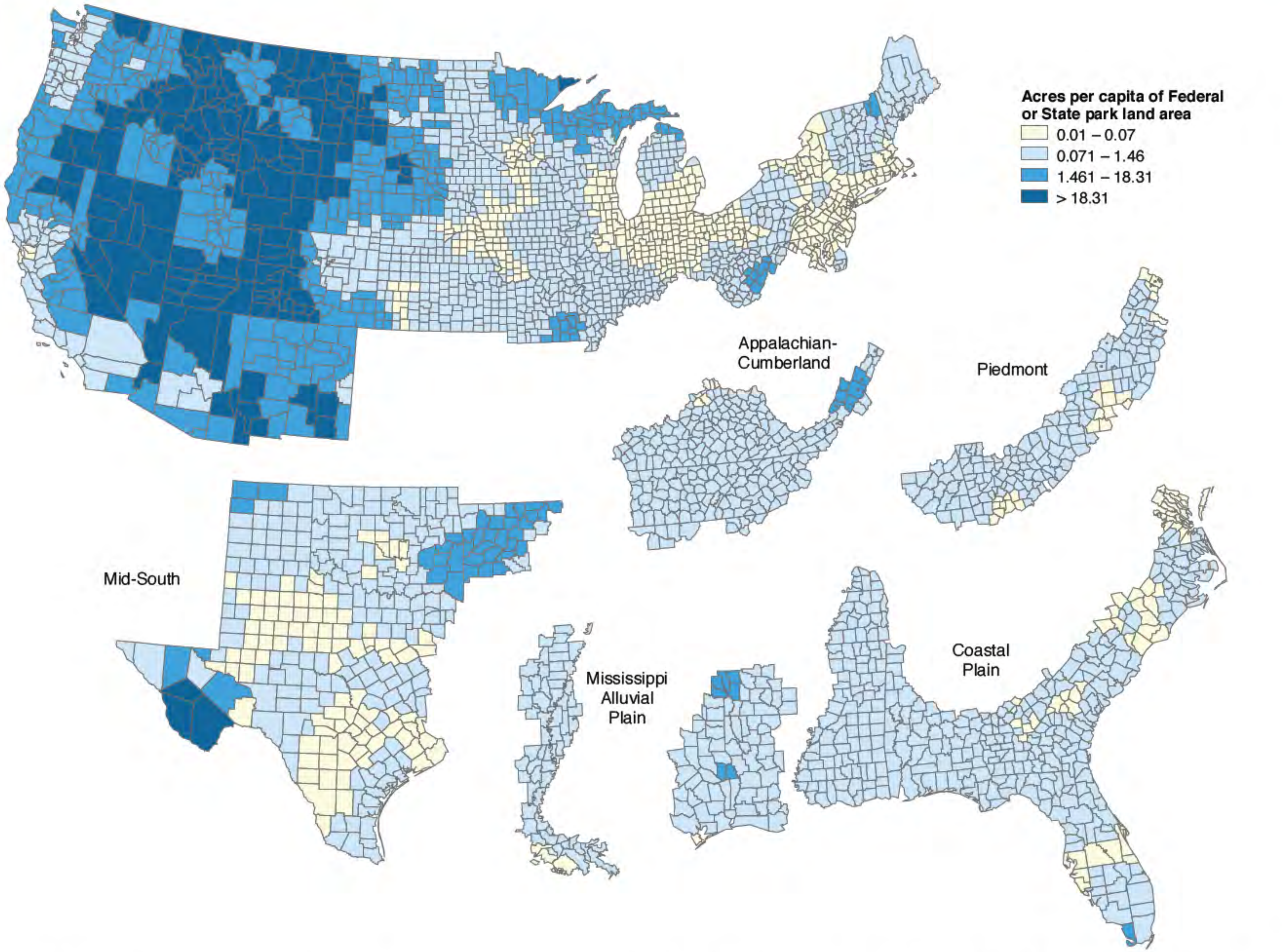


Figure 7.10—Acres per capita of Federal and State land area within a 75-mile recreation day trip of each U.S. county, 2008. [Sources: USDA Forest Service 2008; U.S. Department of the Interior National Park Service 2008; U.S. Department of the Interior Fish and Wildlife Service 2008; U.S. Department of the Interior Bureau of Land Management 2008; Tennessee Valley Authority 2008; U.S. Army Corps of Engineers 2006; National Association of State Park Directors 2009 (see footnote 2)]

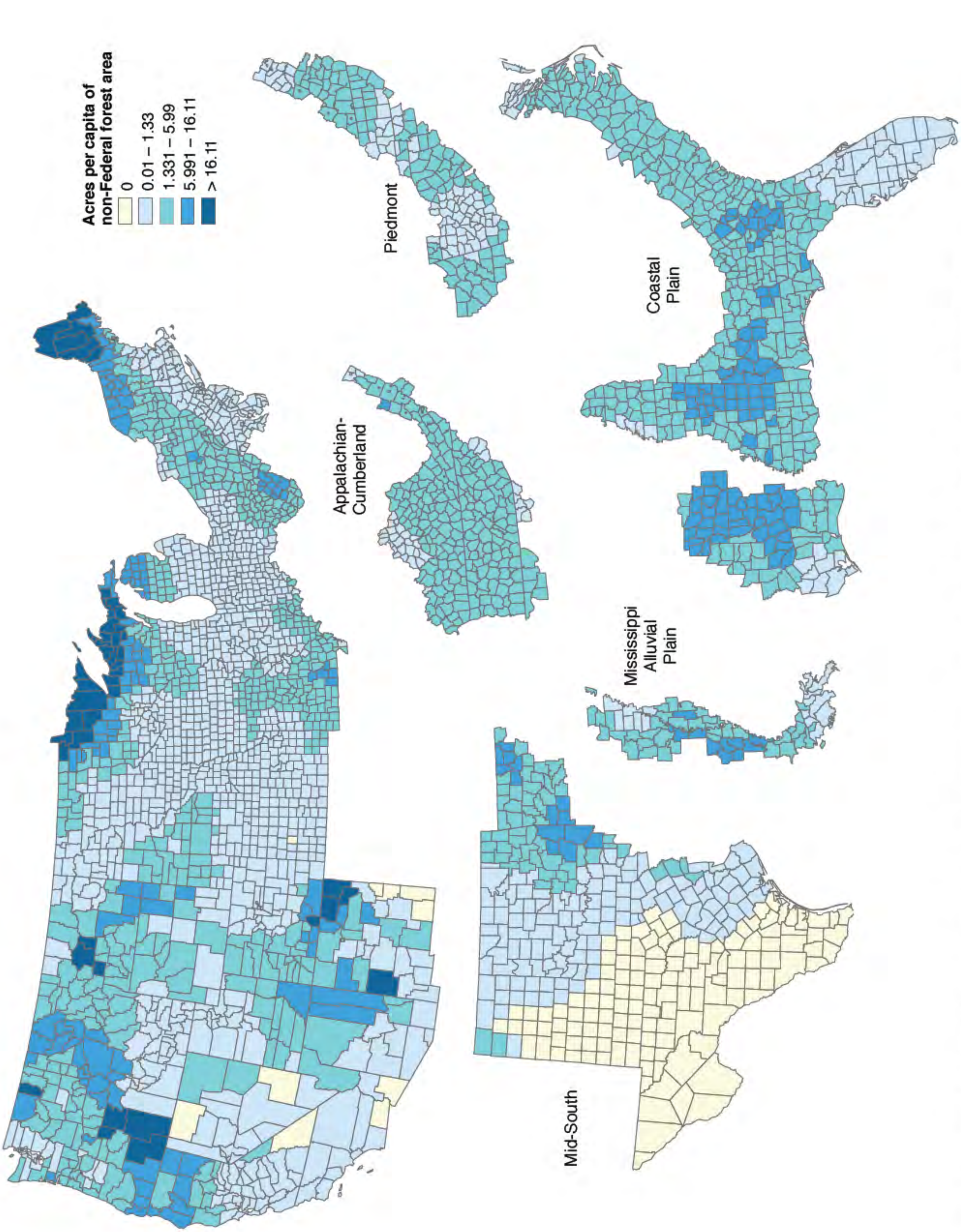


Figure 7.11—Acres of non-Federal forest area per capita within a 75-mile recreation day trip for each U.S. county, 2010. (Source: USDA Forest Service 2010)

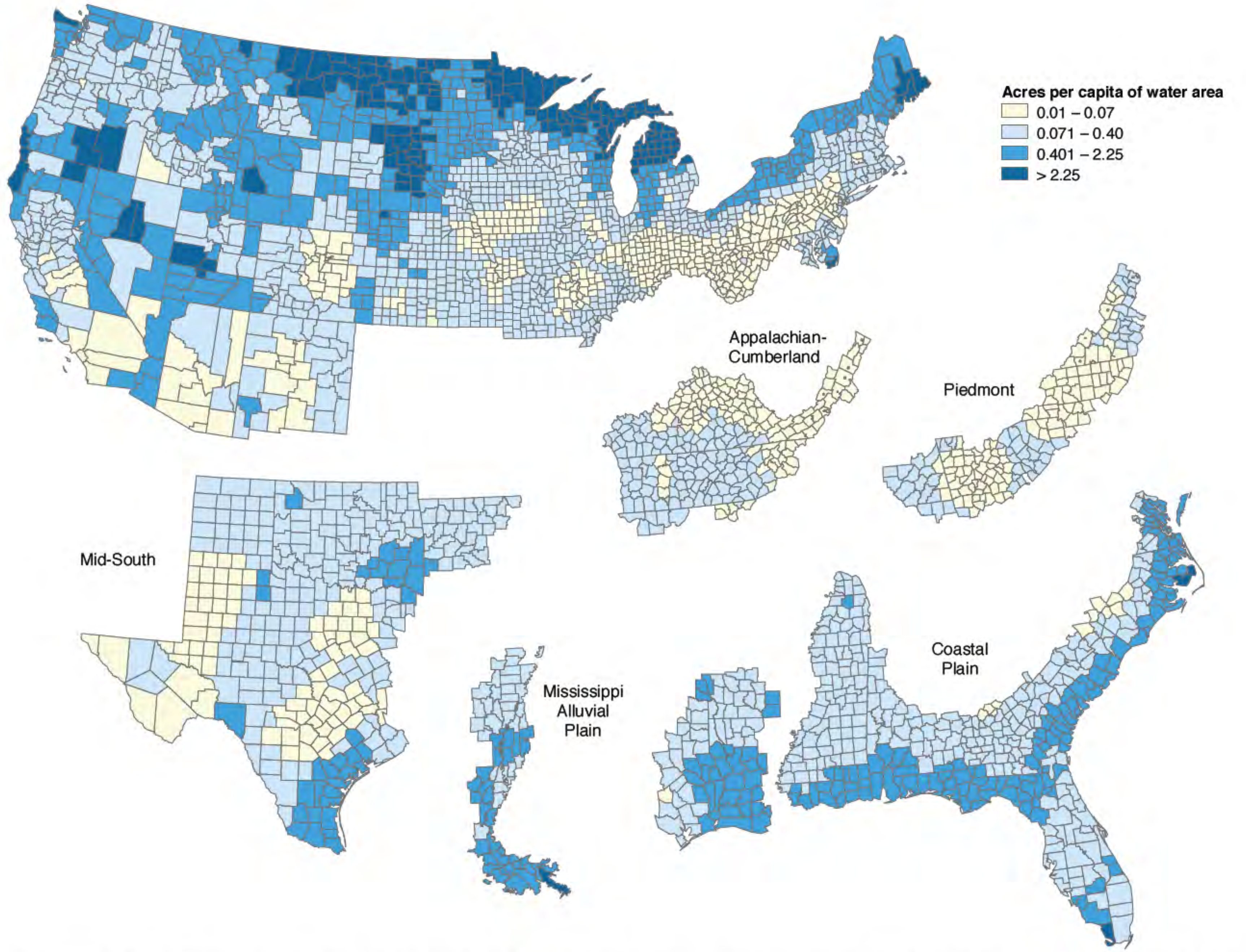


Figure 7.12—Acres per capita of water area (classified as one of four types: inland, coastal, territorial, and Great Lakes) within a 75-mile recreation day trip of each U.S. county, 2008. (Source: U.S. Census Bureau 2000)

Table 7.19—Total and per capita acres of Federal or State park land by region with percent of total surface area 2008, projected per capita acres 2060, and proportion of 2008 acres projected for 2060

	Federal or State park land[a]				
	2008			2060	
Region	Total acres (1,000s)	Percent of total area	Per capita acres	Projected per capita acres	Proportion of 2008 acres projected for 2060
South	28,274	5.0	0.28	0.17	0.63
North	19,915	4.2	0.16	0.13	0.79
Rocky Mountains	259,643	34.6	9.35	5.22	0.56
Pacific Coast	319,487	49.5	6.51	4.19	0.64
U.S. total	627,319	25.8	2.06	1.40	0.68

[a]Federal or State park land is the sum of Federal land-managing agency area and State park system areas. Federal agencies include the National Park Service, USDA Forest Service, U.S. Fish and Wildlife Service, U.S. Department of the Interior Bureau of Land Management, Tennessee Valley Authority, and U.S. Army Corps of Engineers. U.S. Department of the Interior Bureau of Reclamation is not included because most of its areas are managed by other agencies.
Sources: USDA Forest Service 2008; U.S. Department of Interior National Park Service 2008; U.S. Department of the Interior Fish and Wildlife Service 2008; U.S. Department of the Interior Bureau of Land Management 2008; Tennessee Valley Authority 2008; U.S. Army Corps of Engineers 2006; National Association of State Park Directors 2009 (see footnote 2).

Table 7.20—Total and per capita acres of non-Federal forest land by region with percent of total surface area 2010, projected per capita acres 2060, and proportion of 2010 acres projected for 2060

	Non-Federal forest land[a]				
	2010			2060	
Region	Total acres (1,000s)	Percent of total area	Per capita acres	Projected per capita acres	Proportion of 2010 acres projected for 2060
South	171,810	30.5	1.66	0.95	0.57
North	147,762	31.4	1.19	0.88	0.74
Rocky Mountains	28,486	3.8	1.02	0.55	0.54
Pacific Coast	37,736	17.1	0.79	0.47	0.59
U.S. total	385,793	19.3	1.27	0.80	0.63

[a]Non-Federal forest land projections were not done for Alaska and Hawaii.
Source: USDA Forest Service 2010.

Water—Like Federal and State park land, total water area is expected to be (or almost be) constant through time. For the country as a whole, about 7 percent of total surface area is water resources, or roughly half an acre per person (table 7.21). By 2060, per capita water area is predicted to decline to 0.37 acres per person or 68 percent of the 2008 amount.

For the South, water area is slightly more than 5 percent of the total surface area, or 0.28 acres per person. By 2060, per capita water is predicted to decline to 0.18 acres or 63 percent of the 2008 level. Water as a percent of South's total surface area is much higher for the Atlantic States than for the States farther west (9.3 versus 3.5 percent). Despite higher projected population growth, per capita water acreages for the Atlantic States and the Southern States farther west are both projected to equal the 0.18 acres of the South as a whole in 2060.

CONCLUSIONS AND DISCUSSION

The South has been and continues socially to be a very dynamic region of the country. It is characterized by rapid population growth, dramatic changes in demographics, and shifting natural cover and uses of land and water resources. In the last two decades, the South's population grew at a considerably faster rate (over 30 percent) than the Nation as a whole (just above 20 percent). The region now has over half the Nation's African American population and has surpassed the Pacific Coast Region in Hispanic population growth, which has been especially high in North Carolina and Georgia. Within this population growth dynamic, the baby boomer generation age groups (44-64 years old) have dominated all others in percentage growth since 1990. This age group is one that generally has more disposable income and wealth and often demands more housing and other goods, which in turn stimulates other development.

Greater population in this region means more people in its counties and greater density of communities, commercial areas, and industrial complexes. The greatest density of population and development in the South is in Florida, the Piedmont areas of North Carolina to Georgia, eastern Texas, and coastal counties. In some high growth areas, the increase is so substantial that it constitutes the addition of a whole new urban area at least equivalent to the U.S. Census Bureau criteria as an area with 500 or more persons per square mile. Over the next 50 years or so, projected growth for the South is expected to be nearly 60 percent over current population, which is approaching 105 million. Greater numbers of individuals, families, and households in all likelihood will translate directly into greater demand for venues for outdoor recreation, but at the same time create greater pressures on remaining natural lands.

Predicted growth and shifts in the makeup of the South's population and in what people demand for outdoor recreation is covered in the following chapter. The basic data for this chapter and the following chapter are for the most part the same. As shown by trends in this chapter, and what is forecast in the next chapter, what people now choose and likely will continue to choose for outdoor recreation represents a change from past decades and generations. The recreation activities once most popular are not necessarily what contemporary and future generations are or will be choosing. Over the past several years, we have reported growth both in number of outdoor recreation participants and in overall level of participation. Activities oriented toward viewing and photographing nature (scenery, flowers/trees, and wildlife) have been among the fastest growing in popularity. But the list of outdoor pursuits is long meaning there is and will be a variety of activities of interest that occur in forests and other natural settings.

Table 7.21—Total and per capita acres of total water area by region with percent of total surface area 2008, projected per capita acres 2060, and proportion of 2008 acres projected for 2060

	Water area[a]				
	2008			2060	
Region	Total acres (1,000s)	Percent of total area	Per capita acres	Projected per capita acres	Proportion of 2008 acres projected for 2060
South	29,282	5.2	0.28	0.18	0.63
North	56,834	12.1	0.46	0.36	0.79
Rocky Mountains	7,289	1.0	0.26	0.15	0.56
Pacific Coast	70,848	11.0	1.44	0.93	0.64
U.S. total	164,253	6.8	0.54	0.37	0.68

[a]Census Bureau water is classified as one of four types: inland, coastal, territorial, and Great Lakes.
Source: U.S. Census Bureau 2000.

Concurrent with population growth and shifting recreation demands is increasing pressure on forest and other natural lands. In the South, this can pose a challenge. For example, State and Federal lands are often the places people choose for nature-based outdoor recreation. However, less than 5 percent of Federal land, just over 30 million acres, is in the South where almost 105 million people live (about one-third of the Nation's population). Over the last decade and half, Federal acres per 1,000 persons in the South declined slightly faster than the national rate, a decrease of over 15 percent. Similar patterns can be seen for per capita State lands and for most other resources used for outdoor recreation in the South. Residents of most counties in the South have access to fewer than 1.5 acres of public land per person within 75 miles of their county of residence, with a high of up to 18.3 acres in the Ozark Highlands and Virginia mountains. In all likelihood, there will be little to no increases in Federal and State land in the South. In fact, some States have recently closed some State parks.

Water and forests will continue to be important recreation resources. Like water, across the region there is abundant forest land area. But when expressed on a per capita basis, many of the major metropolitan areas are found to have relatively little non-Federal forest land nearby. Water area per capita is abundant in coastal areas, but throughout the rest of the South there is increasing scarcity. Like public lands, total water area is fairly static over time translating to a decreasing per capita acreage over the next few years, and likely decreasing even more in future years.

In 2008, 5 percent of the South's total area was in Federal or State-park ownership, less than 0.3 acres per person. By 2060, the Federal or State-park land area per person is projected to decrease to 0.17 acres, about 63 percent of the 2008 per capita area. In 2010, more than 30 percent of total land area in the South was non-Federal forest, or 1.66 acres per person. By 2060, per capita non-Federal forest is predicted to decrease to 0.95 acres per person, or to 57 percent of the 2010 level. Not only is per capita forest area projected to decline, but also the actual total area of non-Federal forest land area is expected to decline due to conversions from forests and farmlands to cities and suburbs. In 2008, water area in the South was slightly more than 5 percent of the total surface area, or 0.28 acres per person. By 2060, water acres per capita are predicted to decline to 0.18 acres per person, or to 63 percent of the 2008 level.

Population, recreation, and resource trends and futures all are headed in directions that leave one wondering "who, where, and how?" Who will the future recreation participants be from among the South's growing population? Will participants of the future be representative of the growing diversity of our population? Or, could there be a demographic narrowing of who the participants will be as a result of shrinking per capita availability of places and resources for outdoor recreation? Where will outdoor recreation occur? As land and water resources in rural areas are increasingly pressured by expanding urban and other development, private land and water may become less available for outdoor recreation for some segments of the population. This raises the question of how future residents of the South will gain access to outdoor recreation venues. It seems that the importance of easily accessible, nearby public or publicly accessible private areas will only increase in the future. Perhaps one key to an outdoor recreation future for coming generations of Southerners would be to include recreation benefits in the calculation of the value of forest lands, especially those close to populated areas. Without inclusion of recreation and other ecosystem services in land value calculations, very often the development value outweighs all other considerations. Including recreation and other ecosystem service values could open an opportunity for local governments and other public service organizations to find concrete ways to encourage private owners to keep more land in forest and make it more accessible.

LITERATURE CITED

American Trails. 2010. National Recreation Trails Database. http://www.americantrails.org/NRTDatabase/index.php. [Date accessed: February 22, 2010].

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 72 p.

Clawson, M.; Knetsch, J.L. 1966. Economics of outdoor recreation. Baltimore, MD: Johns Hopkins Press. 328 p.

Cordell, H.K. 2008. The latest on trends in nature-based outdoor recreation. Forest History Today. Spring 2008: 4-10.

Cordell, H.K.; Betz, C.J.; Green, G.T. 2008. Nature-based outdoor recreation trends and wilderness. International Journal of Wilderness. 14(2): 7-13.

Cordell, H.K.; Betz, C.J.; Green, G.T. [and others]. 2004. Outdoor recreation for 21st Century America. State College, PA: Venture Publishing, Inc. 293 p.

Cordell, H.K. 2012. Outdoor recreation trends and futures: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-150. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 167 p.

Harnik, P.; Welle, B.; Gentles, C. 2013. Parks for city people: greenspace in the metropolis. In: Cordell, H.K.; Betz, C.J.; Zarnoch, S.J. Recreation and protected land resources in the United States: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-169. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 104-109.

Hussain, A.; Zhang, D.; Armstrong, J.B. 2004. Willingness to pay for hunting leases in Alabama. Southern Journal of Applied Forestry. 28: 21–27.

Interagency Wild and Scenic Rivers Council. 2009. Explore Designated Rivers (Map). http://www.rivers.gov/rivers/map.php. [Date accessed: February 23, 2010].

Intergovernmental Panel on Climate Change. 2007. IPCC fourth assessment report: climate change 2007 (AR4). http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm. [Date accessed: July 7, 2010].

Liu, Z.; Fleming, R.; Pagoulatos, A.; Hu, W. 2010. The supply of private acreage for public recreational use in southern and central Appalachia. Growth and Change. 41(4): 540-555.

National Agricultural Law Center (NALC). 2011. States' recreational use statutes. Springsteen, E.R.; Rumley, R.W., authors. A national aglaw center research publication. http://www.nationalaglawcenter.org/assets/recreationaluse/index.html. [Date accessed: December 14, 2011].

Plum Creek Timber Company, Inc. 2011. Hunting programs. http://www.plumcreek.com/Recreation/HuntingPrograms/tabid/142/Default.aspx. [Date accessed: December 15, 2011].

Tennessee Valley Authority. 2008. Recreation resources inventory database. Available at: Tennessee Valley Authority, 400 West Summit Hill Drive, Knoxville, TN 37902.

The Trust For Public Land (TPL). 2011. TPL Landvote database. www.landvote.org. [Date accessed: December 14, 2011].

U.S. Army Corps of Engineers. 2006. Value to the Nation: recreation fast facts. http://www.corpsresults.us/recreation/recfastfacts.cfm. [Date accessed: April 1, 2009].

U.S. Census Bureau. 1990. Census of population and housing. 1990 census summary tape file 1. http://www2.census.gov/census_1990/1990STF1.html#1A. [Date accessed: September 23, 2009].

U.S. Census Bureau. 2000. Census 2000 U.S. Gazetteer files, water area (square miles). http://www.census.gov/geo/www/gazetteer/places2k.html. [Date accessed: June 20, 2005].

U.S. Census Bureau. 2007a. Census of governments, government employment and payroll, local government, 1997 and 2007. http://www.census.gov/govs/apes/. [Date accessed: March 31, 2009].

U.S. Census Bureau. 2007b. Economic census, county business patterns, 1998 and 2007. http://www.census.gov/econ/cbp/index.html. [Date accessed: August 24, 2009].

U.S. Census Bureau. 2008a. SC-EST2008-alldata6: annual State resident population estimates for 6 race groups (5 race alone groups and one group with two or more race groups) by age, sex, and hispanic origin: April 1, 2000 to July 1, 2008. http://www.census.gov/popest/data/state/asrh/2008/SC-EST2008-03.html. [Date accessed: September 23, 2009].

U.S. Census Bureau. 2008b. CC-EST2008-ALLDATA-[ST-FIPS]: annual county resident population estimates by age, sex, race, and hispanic origin: April 1, 2000 to July 1, 2008. http://www.census.gov/popest/data/state/asrh/2008/SC-EST2008-03.html. [Date accessed: September 23, 2009].

U.S. Department of Agriculture Forest Service. 1995. Land areas report as of September 30, 1995. Unpublished report. On file with: U.S. Department of Agriculture Forest Service, Lands and Realty Management Office, 1400 Independence Ave., SW, Mailstop 1124, Washington, DC 20250-1124.

U.S. Department of Agriculture (USDA) Forest Service. 2008. Land areas report as of September 30, 2008. http://www.fs.fed.us/land/staff/lar/. [Date accessed: February 9, 2009].

U.S. Department of Agriculture (USDA) Forest Service. 2009a. National survey on recreation and the environment (NSRE dataset). Unpublished report. On file with: U.S. Department of Agriculture Forest Service, Southern Research Station, RWU-4953, 320 Green St. Athens, GA 30602. [pages unknown].

U.S. Department of Agriculture (USDA) Forest Service. 2009b. State park systems database compiled from published State literature and State park Web sites. Unpublished report. On file with: U.S. Department of Agriculture, Forest Service, Southern Research Station, RWU-4953, 320 Green St. Athens, GA 30602. [Pages unknown].

U.S. Department of the Interior. 2009. Recreation one-stop initiative: recreation information database. https://www.recdata.gov/RIDBWeb/Controller.jpf. [Date accessed: April 3, 2009].

U.S. Department of the Interior, Bureau of Land Management. 2008. Public land statistics 2008. http://www.blm.gov/public_land_statistics/pls08/pls08.pdf. [Date accessed: June 23, 2009].

U.S. Department of the Interior, Bureau of Reclamation. 1993. Recreation fast facts. Available at: Bureau of Reclamation, Land & Mineral Records System, 1849 C Street NW, Rm. 5625, Washington, DC 20240.

U.S. Department of the Interior, Bureau of Reclamation. 2009. Recreation fast facts. http://www.usbr.gov/recreation/overview.html. [Date accessed: February 19, 2009].

U.S. Department of the Interior, Fish and Wildlife Service. 1995. Annual report of lands as of September 30, 1995. Available at: U.S. Fish and Wildlife Service, 4401 N. Fairfax Dr., Arlington, VA 22203.

U.S. Department of the Interior, Fish and Wildlife Service. 2006. National survey of hunting, fishing and wildlife-associated recreation. http://library.fws.gov/pubs/nat_survey2006_final.pdf. [Date accessed: July 7, 2010].

U.S. Department of the Interior, Fish and Wildlife Service. 2008. Annual report of lands as of September 30, 2008. http://www.fws.gov/refuges/land/LandReport.html. [Date accessed: June 18, 2009].

U.S. Department of the Interior, National Park Service. 1995. Listing of acreage by State and county as of October 31, 1995. Available at: U.S. Department of the Interior, National Park Service Land Resources Division, 1849 C Street NW, Washington, DC 20240.

U.S. Department of the Interior, National Park Service. 2008. Listing of acreage by State and county as of December 31, 2008. https://irma.nps.gov/Stats/Reports/ReportList. [Date accessed: February 26, 2009].

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

Wear, D.N.; Greis, J.G.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS-115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Wilderness.net. 2009. The Wilderness Institute, University of Montana. http://www.wilderness.net/index.cfm?fuse=NWPS&sec=advSearch. [Date accessed: July 6, 2009].

Woods and Poole Econometrics, Inc. 2009. 2010 complete economic and demographic data source (CEDDS). [CD-ROM]. Washington, DC: Woods and Poole Econometrics, Inc. www.woodsandpoole.com. [Date accessed: December 4, 2012].

Yarrow, G. 2009. Hunting leases (Fact Sheet 2). Clemson University, Extension Forestry & Natural Resources. http://www.clemson.edu/extension/natural_resources/wildlife/publications/fs2_huntingleases.html. [Date accessed: December 15, 2011].

Zarnoch, S.J.; Cordell, H.K.; Betz, C.J. [and others]. 2010. Multiple imputation: an application to income nonresponse in the national survey on recreation and the environment. Res. Pap. SRS–49. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 15 p.

Zhang, D.; Hussain, A.; Armstrong, J.B. 2006. Supply of hunting leases from nonindustrial private forest lands in Alabama. Human Dimensions of Wildlife. 11: 1–14.

CHAPTER 8.
Outdoor Recreation

J. M. Bowker, Ashley Askew, H. Ken Cordell, and John C. Bergstrom[1]

KEY FINDINGS

- By 2060, the number of southern adults participating in each of 10 different popular outdoor recreation activities is projected to increase. Depending on future demographic, economic, land use, and population changes, the activity demonstrating the least growth in participants is hunting (8–25 percent). The activity projected to demonstrate the most growth is day hiking (70–113 percent).
- For many activities, participation will grow similarly to the population growth rate. However, the number of participants in fishing, hunting, and motorized off-roading will grow slower than the regional population, as a smaller proportion of adults are projected to engage in these activities. Conversely, the growth in the number of participants in birding and day-hiking is projected to exceed that of the population.
- By 2060, the number of days that southern adults will participate annually in each of 10 different outdoor recreation activities is projected to increase. The smallest increase in days of participation will be for hunting (8–24 percent), while the largest increase in days of participation will be for day hiking (77–116 percent).
- Days of annual participation for each of the 10 activities are projected to increase at rates similar to the growth in participant numbers.
- Acres of southern forest and rangeland per recreation participant will decline by up to 50 percent across the various activities by 2060. Acres per participant in hiking will shrink the most, while acres per participant for hunting will shrink the least.
- Annual user days per acre of forest and rangeland for recreation activities will increase most by 2060 for horseback riding on trails (up to 151 percent) and hiking (up to 118 percent) and least for motorized off-road use (up to 59 percent) and hunting (up to 34 percent).
- Depending on social and economic factors, southern national forest recreation visits are projected by 2060 to increase across all site types: Wilderness (38–72 percent), day use developed sites (35–70 percent), overnight use developed sites (30–64 percent), and general forest area (22–55 percent).
- Because southern national forest acreage is expected to stay approximately constant to 2060, visits per acre across the various site types will grow at same rate as visits.

INTRODUCTION

In this chapter, we address a small component of the question posed by Wear and others (2009) in defining the Southern Forest Futures Project, namely, "How will changing demographics influence associated demand for esthetic settings, recreation, and second homes?" We focus our analysis on projecting natural resource-based outdoor recreation demand at a broad regional scale, as well as at the regional national forest scale. In doing so, we hope to provide relevant information to "[e]valuate how population growth and changing demographics will affect changes in demands for different types of recreation activities, and explore implications for forest land uses" and "[e]xamine the potential for increased congestion and conflict among recreational users of forests as a result of changing supply and demand factors" (Wear and others 2009). Specifically, for the southern region through 2060, we develop and present projections of (a) the number of adult participants in 10 traditional outdoor recreation activities, (b) the number of days of adult participation in the same 10 outdoor recreation activities, and (c) the number of recreation visits to national forests in the southern region by national forest setting.

An individual is said to have participated in an outdoor recreation activity if the individual reported engaging in that activity at least once in the preceding 12 months. Participation is a general indicator of the size of a given market and can also be indicative of relative public interest. For example, if over 80 percent of the population goes day hiking, whereas only 4 percent participate in snowmobiling, public resource management agencies and private land managers may be more concerned with providing hiking trails rather than snowmobiling opportunities. It is important, therefore, for

[1]J.M. Bowker is a Research Social Scientist, U.S. Department of Agriculture, Forest Service, Forest Sciences Laboratory, Athens, GA 30602; Ashley E. Askew is a Doctoral Candidate, University of Georgia, Department of Statistics, Athens, GA 30602; H. Ken Cordell is a Pioneering Research Scientist, U.S. Department of Agriculture, Forest Service, Forest Sciences Laboratory, Athens, GA 30602; John C. Bergstrom is a Professor, Department of Agricultural and Applied Economics, University of Georgia, Athens, GA 30602.

land managers and legislators to know how many people participate in a given recreation activity, and how this measure could change over time. Measures of participation, either per capita or absolute numbers of participants, provide the broadest measure of a recreation market.

A second measure of recreation use or demand is consumption. Consumption can be measured in such units as number of times, days, or trips in a given year. The Forest Service, U.S. Department of Agriculture, has used such consumption measures as recreation visitor days and national forest visits. A consumption measure is important because it adds another dimension to participation. Although resource managers providing recreation opportunities need to know how many people participate, many of their decisions depend even more upon knowing how often and for how long people engage in an activity. Such information can be critical to the allocation of existing resources, such as campsites, and is also useful in planning the development of new venues. Participation and consumption at the regional level together provide the broadest measures of a recreation market. The regional consumption measure used in this study [item (b) above] is the number of days in the previous year that an individual, residing in the South, reported engaging in a specific activity. A day in this case follows the definition given by the National Survey on Recreation and the Environment (NSRE) definition of an activity day, i.e., any amount of time spent on an activity on a given day, whether less than an hour or for several hours, whether that activity was the primary reason for recreating outdoors or not (USDA Forest Service 2009).

The preceding two metrics are origin based, i.e., resulting from household-level surveying. There is no additional information as to where the respondent engaged in the participation for any activity. Research has shown, however, that the vast majority of outdoor recreation takes place within a few hours' drive of one's residence. Another metric, based on the destination rather than origin, is the on-site visit. In addressing item (c) above, southern national forest recreation visits by each of four different site types, Wilderness, day use developed sites, overnight use developed sites, and general forest area sites are used.

Past outdoor recreation trends, as well as recent ones, are important indicators of what may happen with outdoor recreation in the near future (chapter 7, Hall and others 2009). However, simple descriptive statistics or trends do not formally explore underlying factors and associations which may be driving these trends. Thus a trend may be of limited value if the time horizon is long and factors driving the trend are expected to deviate substantially from their historic levels. Trend analysis can therefore be supplemented by development of projection models which attempt to relate recreation participation directly to factors known to influence this behavior. The projection models can then be used to simulate future participation by combining external projections of relevant factors, including population growth, with estimated model parameters. Such modeling allows changes in recreation participation and consumption behavior over time to be assessed in light of previously unseen changes in factors driving this behavior, e.g., large changes in demographic, economic, and land use factors.

Previous research (Bowker and others 1999, Bowker and others 2006, Cicchetti 1973, Hof and Kaiser 1983b, Leeworthy and others 2005) has established that factors including race, ethnicity, gender, age, income, and supply or proximity to settings affect outdoor recreation participation as well as the participation intensity or consumption. Similarly, these factors along with others, including distance and quality descriptors, have been used to explain visitation to specific sites (Bowker and others 2009, Bowker and others 2007, Englin and Shonkwiler 1995). Reliable information about these factors is often available from external sources, like the U.S. Census or parallel research efforts aimed at modeling and simulating influential variables into the future. Such information can thus be available long before recreation survey results can be obtained.

A two-step approach was used to develop projections for participation and consumption of 10 traditional outdoor recreation activities (see table 8.1). The first step, or model estimation step, focused on the development of statistical models of southern adult per capita participation and days of participation (conditional on being a participant) for each of the activities. The statistical models first represent the probability that one participated in an activity. Then, if one participated, the number of days is modeled. These models can be used to estimate the total number of participants and the total number of days of participation for each activity by regional residents. This information is important as it allows a better understanding of the factors that influence individual recreation choices or behavior. In addition, it allows one to examine how, under the assumption of static tastes and preferences, individual behavior changes over time as underlying factors change. Statistical models were also developed explaining the demand for visits to national forests in the South across the four different types of settings listed above.

The second step, or simulation step, combines the estimated models with external projections of relevant explanatory variables to generate estimated per capita participation probabilities and conditional expected days of participation for each activity at 10-year intervals to 2060. Per capita estimates are in turn combined with population projections to derive regional estimates of adult participants and days of participation for each activity. These estimates are then used to create indices by which 2008 baseline estimates of participants for the various activities, found in table 8.1,

Table 8.1—Outdoor recreation activities in the South, 2008, by participation rate, number of participants, and number of days

Activity	Participation Rate	Participants (thousands)	Days (millions)
Land-based			
Developed Site Use—Family gathering, picnicking, developed camping	.799	63,157.5	672.2
Horseback riding on trails	.071	5,649.2	99.0
Hiking–Day hiking	.252	20,283.2	462.7
Motorized Off-road–Off-road driving	.213	16,907.4	561.6
Primitive–Visiting a Wilderness, primitive camping, backpacking	.353	28,158	412.3
Water-based			
Motorized Water–Motor boating, water skiing, personal water craft	.270	21,268.7	384.2
Non-motorized–Canoeing, kayaking, rafting	.154	12,201.6	80.0
Wildlife			
Birding–Viewing or photographing birds	.342	26,975.5	2,862.4
Fishing	.357	28,038.5	572.5
Hunting	.137	10,785.9	230.3

Source: NSRE 2005-2009 (n=30,394), U.S. Department of Agriculture Forest Service 2009.

can be scaled. Indices of estimated adult participants for each of the 10 activities and days of annual participation are presented across the three 2010 Resources Planning Act (RPA) Assessment scenarios described below. For discussion, the activities are grouped into the broader categories as follows: land-based activities, water-based activities, and wildlife (see table 8.1).

For southern national forest visits, the simulation step consists of combining estimated visitation models for each site type with relevant projected explanatory variables to derive estimates of conditional expected visits at 10-year intervals to 2060. These estimates are combined with projected population changes to derive indices by which 2008 baseline estimates of visits per site type can be scaled. Indices of estimated visits for each forest site type across each of the RPA Assessment scenarios are presented below.

The remainder of the chapter proceeds as follows. First, we present a brief discussion of the statistical methods and previous research upon which our per capita participation, consumption models, and national forest visitation models are based. Next, we describe the data used in the estimation step including projections of covariates for the three assessment scenarios and relevant assumptions. We then present the results of our estimation and simulation steps for regional participation and days projections by activity and assessment scenario to 2060. Similarly, we present projections for visits by each of the national forest site types and assessment scenarios to 2060. Finally, we discuss some of the key findings within and across categories as well as with respect to demographics.

METHODS AND DATA

Models used to assess recreation demand decisions can be grouped into three basic categories: site-specific user models, site-specific aggregate models, and population-level models (Cicchetti 1973). Population-level modeling is used to address items (a) and (b) above, while site-specific user models are developed to address item (c).

Cicchetti (1973) pioneered the use of cross-sectional population-level models with the household-based 1965 National Survey on Recreation and the Environment to estimate annual participation and use nationally for many outdoor recreation activities. Estimated models and Census Bureau projections of socio-demographic variables and population were then used to forecast participation and use to 2000. The cross-sectional population-level approach has subsequently been used to estimate and project participation and use for recreation activities at national and regional levels (Bowker 2001, Bowker and others 1999, Hof and Kaiser 1983a, 1983b, Leeworthy and others 2005, Walsh and others 1992). Alternative approaches, wherein population data were combined with individual site-level data to project participation or consumption have also been used (Bowker and others 2006, Cordell and Bergstrom 1991, Cordell and others 1990, Englin and Shonkwiler 1995, English and others 1993).

A major drawback of cross-sectional models, imposed by the nature of the data, is that the structure of the estimated models remains constant over the forecast period. For example, the factors that influence participation or use are assumed to have the same effects throughout the projection period. Hence, barring major shifts in demographics, the results are primarily driven by population growth. This assumption can be tenuous. For example, new sports brought about by technological changes or shifts in tastes and preferences, such as mountain biking, jet skiing, snowboarding, flat-water kayaking, and orienteering are unlikely to be correctly represented in the models. Moreover, if data are collected while activities are in a new or rapid growth phase, recent trends can be potentially very misleading. For example, Cordell and others (chapter 7) report a recent increase in kayaking of 154 percent, something unlikely to be sustained into the future. Nevertheless, without appropriate time-series data, researchers are left with the use of cross-sectional models and their inherent limitations, as a second-best alternative to estimate and forecast participation and use. A further drawback of these models is that it is difficult to account for the dampening effects of future congestion, supply limitations, and price changes on growth in participation and use.

Regional cross-sectional population-level logistic models are used to describe the probability of adult participation in each of the 10 activities as:

$$P_{ij} = \frac{1}{[1 + \exp(-X_{ij} B)]} \qquad (1)$$

where, P_{ij} is the probability that the j^{th} individual participated in the i^{th} recreation activity in the preceding year. The vector X_{ij} contains socio-demographic characteristics unique to activity i for individual j and relevant supply variables for activity i pertaining to individual j's location (table 8.2), and B represents a vector of parameters which are estimated using NLOGIT 3.0 (Greene 2003).

Logistic models for each activity, based on NSRE data from 1999–2008, were combined with 2008 baseline population-weighted sample means for the explanatory variables to create an initial predicted per capita participation rate for each activity. The per capita participation rates were recalculated at 10-year intervals using projected external data. Indices were then created for the participation rates by which the NSRE 2005-09 average population-weighted participation frequencies (baselines) were scaled, leading to indexed per capita participation rates for each of the 10 activities. Indexing the 2005-2009 averages by changes in model-predicted rates was judged to be superior in terms of mitigating potential non-linearity biases associated with complete reliance on logistic predicted values (Souter and Bowker 1996). The indexed participation rate estimates were then combined with projected changes in population, according to each of the three 2010 RPA Assessment scenarios, to yield indexed values for total adult participants across the 10 activities.

Participation intensity or consumption models are similar to the participation models listed above except that an integer metric represents use, e.g., times, days, trips, modeled rather than the binary (yes/no) choice to participate. The general specification for the population-level consumption model is,

$$Y_{ij} = f(X_j, Q_j) + u_j \qquad (2)$$

where, Y_{ij} represents the annual number of times or days that individual j participates in activity i, X_j is a vector of socio-demographic characteristics associated with individual j, Q_j is a vector of supply relevant variables, and u_j is a random disturbance term. These integer or count data models are often estimated using negative binomial specifications with a link function of semi-logarithmic form (Bowker 2001, Bowker and others 1999, Zawacki and others 2000).

Alternatively, if one thinks that observed zeros for the dependent variable are excessive or not entirely caused by the same data generating process as the positive values, a hurdle model structure can be employed (Cameron and Trivedi 1998, p. 124). The hurdle model combines the probability of participation (threshold) with the estimated number of days for those participating, i.e.,

$$Y_{ij} = P_{ij} * Y_{ij,\ y>0} \qquad (3)$$

The hurdle model allows different vectors of explanatory variables for the respective probability and conditional days portions of the model, here estimated as a truncated negative binomial, and thus leads to two unique sets of estimated parameters. Model parameters for each of the 10 models for regional activity days were estimated with NLOGIT 3.0 (Greene 2003) using NSRE data for southern households from 1999 to 2008. Similar to the procedure with the participation models and indices, hurdle model parameter estimates are combined with 2008 NSRE baseline participation and days estimates, projected explanatory variables, and projected population changes under each of the RPA Assessment scenarios (A1B, A2, B2) to provide indices of projected growth of annual days of participation for the 10 activities listed in table 8.1.

Site specific user models were developed to describe the demand for recreation visits to southern national forests by each of four forest settings: Wilderness, day use developed sites, overnight use developed sites, and general forest area

Table 8.2—Socioeconomic and supply variables for participation and days projections for outdoor recreation activities in the South

Variable	Description
Gender	1=male
American Indian	1=American Indian, non-Hispanic, 0=otherwise
Asian/Pacific Islander	1=Asian/Pac Islander, 0=otherwise
Hispanic	1=Hispanic, 0=otherwise
Black	1=Black, non-Hispanic, 0=otherwise
Bachelor's	1=Bachelor's degree, 0=otherwise
Below High School	1=Less than high school, 0=otherwise
Post Graduate	1=Post-graduate degree, 0=otherwise
Some College	1=Some college or technical school, 0=otherwise
Age	Respondent age in years
Age Squared	Respondent age squared
Income	Respondent household income (2007 dollars)
Population Density	County area divided by population. Base 1997.
Coastal	1=County on coast, 0 otherwise
for_ran_pcap	Sum of forest land acres and rangeland acres divided by population at county level and at 50, 100, 200-mile radii. Base 1997.
water_pcap	Water acres divided by population at county level and at 50, 100, 200-mile radii. Base 1997.
mtns_pcap	Acres in mountainous divided by population. Base 1997.
pct_mtns_pcap	Percentage of county acres in mountains divided by population (x100000). Base 1997.
natpark_pcap	Number of nature parks and similar institutions divided by population (x100000). Base 1997
fed_land_pcap	Sum USFS, NPS, USFWS, BLM, USBR, TVA, and USACE acreage divided by population. Base 1997.
avg_elev	Average elevation in meters at county level and 50, 100, 200-mile radii. Base 1997.

sites. These settings correspond to the sampling strata used to collect all visitor use information in the national forest system (English and others 2002, USDA Forest Service 2010). The data used for the on-site visitation models were obtained from the Forest Service's National Visitor Use Monitoring Program database for round one and pooled across all national forests in the South.

Pooled, on-site, individual travel cost models are commonly used to examine forest recreation visitation (Bowker and others 2007, Englin and Shonkwiler 1995, Ovaskainen and others 2001). The modeling approach follows Englin and Shonkwiler (1995) wherein a truncated negative binomial specification, adjusted to account for endogenous stratification, is used with a semi-logarithmic link function. For each of the site types, the models can be generally specified as:

$$\text{Ln } Y_{ik} = f\,(TC_{ik}, SE_i, QS_k) \qquad (4)$$

where, Ln Y_{ik} is the natural log of annual visits by the i^{th} group to the k^{th} forest, TC_{ik} is the travel cost for the i^{th} group to the k^{th} forest, SE_i is a vector of characteristics of the i^{th} group, and QS_k is a vector of characteristics related to the k^{th} forest. For a more complete discussion of the modeling approach and procedures see Sardana (2010).

Similar to the simulation step in the participation and days projections, model parameter estimates were first combined with projected values for relevant explanatory variables to obtain projections of per-group visits to each of the four site types at 10-year intervals to 2060. These estimates were in turn adjusted for average group size (number in travel party) by setting type to obtain projections of conditional site visits per group. Englin and Shonkwiler (1995) applied such conditional site visit means across a general population to forecast Wilderness visits in the State of Washington. However, this approach is misguided if the unknown population of potential visitors is not identical to the overall State or regional population. To address this problem, and to create appropriate growth indices, we assume that the proportion of the population who would be in the market to visit southern national forests is an unknown constant, K, of some magnitude less than one. Therefore, the total change in visits for a given site type between any two time periods can be represented as:

$$dTV_{t,t+1} = [K_{t+1}*E(Y)_{t+1}*POP_{t+1} - K_t*E(Y)_t*POP_t] \qquad (5)$$

where, d represents the total differential operator, TV_t is the total annual visits in time t, $E(Y)_t$ is mean visits per group from the truncated negative binomial model, and POP_t is the overall population in time t. As the K's in (5) are assumed constant, an index of change can be created dividing the first term by the second term in (5) and using the model parameters along with projections of explanatory variables and population for the given time period. Estimates of southern national forest visits by site type for 2008 derived from the National Visitor Use Monitoring Program database can then be scaled by the estimated growth index to derive projections of visits to 2060.

RESULTS

The results reported in this section combine the models and indexing procedures discussed above with projections of population change, economic growth, and land use change common to three future scenarios from the Forest Service's 2010 RPA Assessment. The goal of the Assessment is to characterize the common demographic, socioeconomic, and technological driving forces underlying changes in resource conditions in order to evaluate the sensitivity of resource trends to a feasible future range of these driving forces. The use of scenarios links underlying assumptions of the individual analyses and frames the future uncertainty in these driving forces within the integrated modeling and analysis framework of the 2010 RPA Assessment.

Three scenarios, considered equally likely, were chosen that are linked to globally consistent and well-documented scenarios used in the Fourth Assessment by the Intergovernmental Panel on Climate Change (IPCC 2007). The scenarios include a range of future global and U.S. socioeconomic and climate conditions that are likely to have different effects on future U.S. resource conditions and trends (USDA Forest Service 2012). The IPCC scenario "names" have been maintained in both the RPA Assessment and in this chapter of the Southern Forest Futures Project documentation for continuity: A1B, A2, and B2. The IPCC global data were scaled to the U.S. national and sub-national levels, here the South, to facilitate the resource analyses for the 2010 RPA Assessment. U.S. gross domestic product (GDP) and population projections used in IPCC analyses were updated, and the updated U.S. population and disposable personal income data were then downscaled to the southern county level (USDA Forest Service 2010, Zarnoch and others 2010).

As shown in figures 8.1 and 8.2, A1B corresponds to mid-range population growth and the highest household income level of the three IPCC scenarios. Under this scenario, the South can expect to see about 164 million people (135 million adults) and an average household income of $129,000 by 2060. Scenario A2 projects the highest population growth, reaching about 185 million people (152 million adults) by 2060, and the lowest projected household income, around $91,000. Scenario B2 projects the lowest population growth and mid-level personal income, predicting a population of 145 million people (120 million adults) with average household income about $96,000.

In accordance with the assessment scenarios A1B, A2, and B2, projected land use changes are incorporated from Wear (2011) to develop supply variables listed in table 8.2. Nationally, Wear's projections indicate an increase in urban area of 1-1.4 million acres per year between 1997 and 2060, with a decline in forest area of 24-37 million acres, and decline in cropland of 19-28 million acres by 2060. Wear also projects that about 90 percent of forecasted forest land losses are found in the Eastern United States with more than half in the South. For the South, Wear (chapter 4) forecasts forest acreage losses of 11-23 million acres or about 7-13 percent for Cornerstones based on scenarios A1B and B2. Based on the forecasts of land use change from Wear (chapter 4) across the three scenarios adopted in this chapter, forest and rangeland per capita across the South between 2008 and 2060 is expected to decline about 45 percent under A1B, 50 percent under A2, and about 37 percent under B2. Federal lands and areas covered by water are assumed static throughout the projection period. Further details regarding explanatory variables can be found in chapter 8-appendix A (retrievable at http://www.srs.fs.usda.gov/trends/research/sffpa2010.html).

Participants and Days of Recreation Participation

Estimation results for the participation and days models and related projections for A1B, A2, and B2 are reported in chapter 8-appendix A (retrievable at http://www.srs.fs.usda.gov/trends/research/sffpa2010.html). Reported results include model estimates for each activity, values and definitions for explanatory variables by scenario and year, odds ratios which indicate the odds of participation occurring in one group to the odds of it occurring in another group, and graphics of overall participant growth by activity and assessment scenario. Throughout the remainder of this sub-section, we present the results for per capita and overall changes in participation and days of participation by activity and scenario at 10-year intervals from 2010 to 2060.

Land-based activities—Land-based activities include developed site use, hiking, horseback riding on trails, motorized off-roading, and visiting primitive areas (table

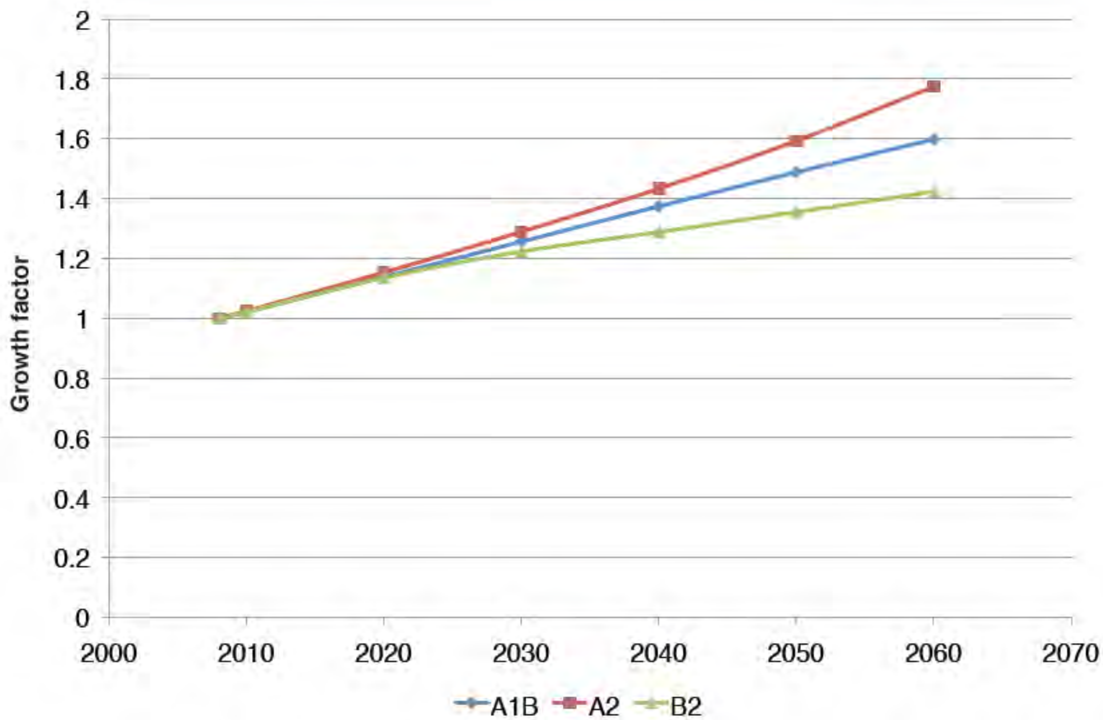


Figure 8.1—Population growth from 2008 to 2060 in the South.

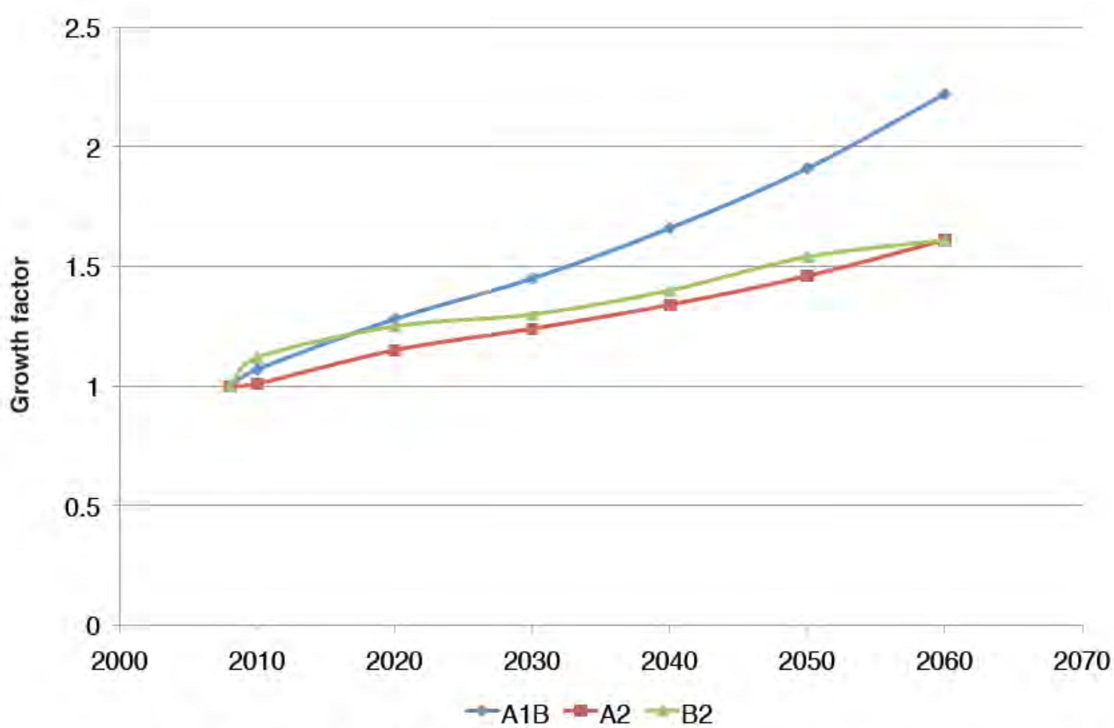


Figure 8.2—National Survey on Recreation and the Environment average real household income growth, 2008 to 2060, in the South.

8.1). Developed site use is the most popular of the land-based outdoor recreation activities, both nationally and in the South. This composite activity includes family gatherings, picnicking, and developed camping. On average, between 2005 and 2009, this activity was practiced by about 80 percent of southern adults, or more than 63 million people, accounting for 672 million days of participation in 2008. Moreover, because our projections only relate to adults and many kids participate in these activities, participation including all age groups should be much higher. As table 8.3 indicates, per capita participation growth in this activity is expected to be static over the next 50 years across each of the assessment scenarios with A1B showing the most change at less than a 3-percent change from 2008. However, as this composite activity is highly popular to begin with, the static participation rate means that overall participants in this activity will grow by the rate at which the population increases for each scenario (see table 8.3). Thus A2, which has the greatest expected population growth, demonstrated an increase in participants of nearly 90 percent to approximately 121 million adults per year. Days per participant in developed site use is projected to remain constant across each of the three scenarios. Hence, total days of developed site use will follow growth in participant numbers and range from 53 to 90 percent over the next 5 decades.

Hiking is perhaps the most popular single land-based backcountry activity. In 2008 about 33 percent of adults nationally participated in hiking. In the South, 25 percent of adults participated in hiking totaling about 20 million participants and 463 million days of hiking annually (table 8.4). Among the three assessment scenarios, hiking participation per capita is expected to increase by 12 to 15 percent by 2060, increasing the most under A1B (table 8.4). As the participation rates are similar across scenarios, A2's higher population growth leads to the greatest increase in hiking participants over the time span, nearly 113 percent, resulting in about 44 million hikers by 2060. Scenarios B2 and A1B led to hiking participant increases from 2008 of about 70 percent and 96 percent, respectively. A notable model result for hiking is that it is the only activity in this chapter for which Hispanic ethnicity is associated with a higher participation rate and higher days per participant than whites (see chapter 8-appendix A retrievable at http://www.srs.fs.usda.gov/trends/research/sffpa2010.html).

Horseback riding on trails, while the least popular of the land-based activities in this chapter, is nevertheless engaged in by seven percent of southern adults annually (table 8.5). Unlike developed use and hiking, per capita participation in horseback riding on trails is projected to decrease by five to nine percent in two of the three scenarios (B2, A2). In scenario A1B, however, per capita participation is expected to increase by about nine percent over the next 50 years. The number of participants in this activity increases under scenarios A1B and A2 from about 5.6 million in 2008 to about 10 million by 2060. Despite A1B's lower population growth, greater income growth under this scenario yields more participants. Annual riding days per participant is static under A2, but increases by 8 to 26 percent under B2 and A1B, respectively. Combined with the participation rate changes and population growth, horseback riding on trails by Southerners is projected to increase from a total of about 100 million days in 2008 to 150-230 million days annually by 2060 (table 8.5).

Motorized off-road driving increased in popularity among Southerners by 42 percent from 1999 to 2009 (chapter 7, table 8.6). In 2008, approximately 21 percent or 17 million adults took part in off-road driving, accounting for more than 560 million days region-wide. This total makes motorized off-roading second only to visiting developed sites for days of use among the land-based activities. However, participation rates are projected to decline by about eight percent across scenarios A1B, A2, and B2 over the next five decades resulting in participant numbers growing less than the population growth rate (table 8.6). By 2060, the number of participants in motorized off-roading is projected to increase 26-50 percent, depending on the scenario. Annual days per participant is expected to decline by up to three percent; therefore the total number of days for this activity will grow slightly less than participant numbers, or from 24 to 48 percent during the same time frame, which is less than population growth.

Visiting primitive areas is the final land-based activity examined in this chapter. It is an aggregate, which consists of participating in NSRE activities such as backpacking, primitive camping, and visiting a wilderness, either designated or undesignated. This composite accounted for 28 million participants in 2008, or about 35 percent of all adults in the South (table 8.1). These participants visited primitive areas on 412 million days in 2008. Annual per capita participation in this category is expected to decline by up to 7 percent over the next 50 years (table 8.7). Increased population density and declines in forest and rangeland per capita appear to be factors influencing the participation rate decline (see chapter 8-appendix A retrievable at http://www.srs.fs.usda.gov/trends/research/sffpa2010.html). However, overall participation is expected to increase by 43 to 76 percent across the three scenarios by 2060 because population growth offsets the small decline in participation rates. Annual days of visiting primitive areas per participant is projected to remain nearly constant throughout the simulation period, therefore the growth in total days per year will closely follow adult population growth and range from 44 to 79 percent across the three future alternatives used in this chapter.

Table 8.3—Developed site use (family gatherings, picnicking, or developed camping) as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.799	A1B	1.00128	1.004375	1.006045	1.0103	1.016267	1.02331
0.799	A2	0.99992	1.000946	1.000462	1.001864	1.004499	1.007731
0.799	B2	1.00276	1.003951	1.002652	1.004684	1.008491	1.010542
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
63157.5	A1B	1.02711	1.172944	1.33204	1.474788	1.607101	1.738229
64252.81	A2	1.02846	1.184915	1.359355	1.525197	1.70001	1.900895
62992.86	B2	1.02821	1.169015	1.292198	1.374478	1.452541	1.528463
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
10.61488	A1B	1.00016	1.000722	1.001326	1.001467	1.001553	1.001659
10.61488	A2	1.00016	1.000699	1.001287	1.001411	1.001479	1.001569
10.61488	B2	1.00017	1.000712	1.00131	1.001452	1.001525	1.00159
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
672.2	A1B	1.02728	1.173791	1.333806	1.476952	1.609596	1.741113
683.8577	A2	1.02863	1.185743	1.361105	1.527348	1.702524	1.903877
670.4477	B2	1.02838	1.169847	1.293891	1.376473	1.454756	1.530894

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.4—Hiking as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.252	A1B	1.00605	1.031514	1.055053	1.084983	1.119007	1.15579
0.252	A2	1.00371	1.025849	1.046013	1.071215	1.099834	1.130571
0.252	B2	1.00879	1.030516	1.046885	1.069836	1.097007	1.120834
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
20283.2	A1B	1.03201	1.204638	1.396929	1.583806	1.769571	1.963266
20634.96	A2	1.03236	1.214396	1.421246	1.630774	1.861355	2.13261
20230.33	B2	1.03439	1.199947	1.349204	1.463611	1.580032	1.695281
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
22.93241	A1B	1.00131	1.005806	1.011284	1.016951	1.023362	1.030894
22.93241	A2	1.00104	1.004255	1.008036	1.011268	1.013613	1.014911
22.93241	B2	1.00135	1.006119	1.014205	1.024453	1.034866	1.045992
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
462.7	A1B	1.03336	1.211632	1.412692	1.610654	1.810911	2.023918
470.7244	A2	1.03344	1.219563	1.432668	1.649149	1.886693	2.16441
461.4938	B2	1.03579	1.20729	1.368369	1.4994	1.635121	1.77325

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.5—Horseback riding on trails as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.071	A1B	1.00612	1.003754	0.985406	0.999309	1.035266	1.087135
0.071	A2	0.99265	0.969614	0.931027	0.915953	0.914336	0.918211
0.071	B2	1.02113	0.999758	0.953196	0.945632	0.957732	0.952997
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
5649.2	A1B	1.03208	1.172219	1.304713	1.458744	1.637146	1.846645
5747.172	A2	1.02099	1.147825	1.265012	1.39441	1.547419	1.732034
5634.474	B2	1.02113	0.999758	0.953196	0.945632	0.957732	0.952997
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
17.67102	A1B	1.01537	1.051192	1.075871	1.114747	1.175211	1.264171
17.67102	A2	0.99742	1.002701	0.99473	0.987054	0.984611	0.987825
17.67102	B2	1.03525	1.046258	1.034731	1.048706	1.079023	1.085742
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
99	A1B	1.04795	1.232227	1.403703	1.626131	1.923993	2.334475
100.7169	A2	1.01835	1.150925	1.258345	1.376358	1.523606	1.710946
98.74192	B2	1.08396	1.217983	1.271125	1.356701	1.48844	1.565016

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.6—Motorized off-road driving as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.213	A1B	0.99766	0.957862	0.906493	0.884038	0.879865	0.886648
0.213	A2	0.98756	0.930879	0.863019	0.818057	0.784222	0.75284
0.213	B2	1.0082	0.955955	0.891692	0.865497	0.855411	0.835686
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
16907.4	A1B	1.0234	1.118624	1.20023	1.290476	1.391398	1.506091
17200.62	A2	1.01575	1.10197	1.172607	1.245377	1.327214	1.420091
16863.33	B2	1.03379	1.113128	1.149195	1.18406	1.232058	1.26399
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
33.29748	A1B	0.99909	0.994347	0.987165	0.983684	0.981891	0.980326
33.29748	A2	0.99905	0.993779	0.985774	0.980973	0.976998	0.971912
33.29748	B2	0.99912	0.99424	0.987199	0.984712	0.984311	0.984114
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
561.6	A1B	1.02247	1.1123	1.184825	1.269421	1.366202	1.47646
571.3396	A2	1.01478	1.095115	1.155925	1.221681	1.296686	1.380204
560.136	B2	1.03287	1.106717	1.134484	1.165959	1.212728	1.24391

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.7—Primitive activities (visiting a wilderness, primitive camping, backpacking) as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.353	A1B	1.00011	0.990617	0.975478	0.972364	0.97673	0.985278
0.353	A2	0.99614	0.980348	0.95872	0.9467	0.939954	0.934888
0.353	B2	1.00443	0.989538	0.966515	0.957866	0.956245	0.949698
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
28158.1	A1B	1.02592	1.156877	1.291568	1.41941	1.544578	1.673628
28646.43	A2	1.02458	1.160532	1.302639	1.441217	1.590774	1.763491
28084.7	B2	1.02992	1.152233	1.245625	1.310427	1.37729	1.436435
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
14.5468	A1B	1.00011	1.001487	1.00081	1.003275	1.006743	1.009793
14.5468	A2	1.00025	1.002073	1.001824	1.004803	1.009072	1.013173
14.5468	B2	1.00009	1.001351	0.999549	1.000399	1.002826	1.005186
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
412.3	A1B	1.02603	1.158598	1.292615	1.424059	1.554994	1.690018
419.4503	A2	1.02483	1.162938	1.305015	1.448139	1.605205	1.786722
411.2252	B2	1.03001	1.153789	1.245064	1.310951	1.381182	1.443884

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Water-based activities—Two water-based activity aggregates are examined in this chapter, motorized and non-motorized (table 8.1). Motorized water use includes motor boating, waterskiing, and personal watercraft use. Twenty-seven percent of southern adults, or about 21 million participants, accounted for approximately 384 million days of motorized water use in 2008. Taken separately, these activities all experienced relatively strong growth in participants from 1999 to 2009 (chapter 7). The participation rate for motorized water use is projected to increase by 10 percent to 2060 under scenario A1B, while decreasing by up to five percent under scenarios A2 and B2 (table 8.8). The difference can be attributed to A1B's higher growth rate for household income which is an important driver of this activity (see chapter 8- appendix A retrievable at http://www.fs.usda.gov/trends/research/sffpa2010.html). Combining the participation rate change with population growth yields projected increases in total participants by 2060 of 48 to 87 percent. Annual days per participant is expected to be stable at 18 days per year under A1B, but decline slightly under A2 and B2. Total days of motorized water use will therefore grow faster than adult population under A1B, but somewhat less than the population under scenarios A2 and B2. By 2060, annual days of motorized water use are expected to grow from 2008 levels by 38 to 86 percent, totaling 528-714 million days annually.

Non-motorized water use is an aggregate which includes canoeing, kayaking, and rafting. In 2008 approximately 15 percent or 12 million adults in the South participated in this activity resulting in 80 million days of use (table 8.1). Although rafting grew by just 5 percent between 1999 and 2009, canoeing (39 percent) and kayaking (154 percent) grew dramatically during the same period (chapter 7, table 8.7). Despite rapid growth over the past decade, per capita adult participation in non-motorized water activities is projected to be stable out to 2060, resulting in participant numbers growing at the same rate as the population, or 5-81 percent (table 8.9). This activity is less affected by income than its motorized counterpart. Hence, A2 with greater population growth yields the biggest increase in participants. Days per participant is expected to remain about constant over time at about seven, meaning that the current 80 million days for this activity will increase to 115-141 million days by 2060.

Wildlife-based activities—Three wildlife activities are assessed in this chapter: birding, fishing, and hunting. Birding, a non-consumptive activity, consists of viewing

Table 8.8—Motorized water activities (motor boating, waterskiing, or using personal watercraft) as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.27	A1B	1.00734	1.014868	1.010267	1.026023	1.057717	1.102462
0.27	A2	0.99533	0.984415	0.960997	0.950488	0.949452	0.953869
0.27	B2	1.0207	1.011029	0.979127	0.973127	0.982065	0.975312
Adult participants (thousands)		Participants index					
2008	Scenario	2010	2020	2030	2040	2050	2060
21268.7	A1B	1.03333	1.185198	1.337631	1.497739	1.672649	1.87268
21637.55	A2	1.02374	1.165345	1.305732	1.446985	1.606848	1.799296
21213.26	B2	1.0466	1.177257	1.26188	1.331306	1.41448	1.475177
Days per participant		Per capita days index					
2008	Scenario	2010	2020	2030	2040	2050	2060
18.20546	A1B	1.00211	0.995464	0.983224	0.979496	0.983172	0.993332
18.20546	A2	0.99588	0.979454	0.957283	0.939857	0.926315	0.914961
18.20546	B2	1.009	0.993569	0.968414	0.955711	0.950136	0.937173
Total days (millions)		Total days index					
2008	Scenario	2010	2020	2030	2040	2050	2060
384.2	A1B	1.03551	1.179822	1.31519	1.467029	1.644502	1.860192
390.863	A2	1.01952	1.141402	1.249956	1.359958	1.488447	1.646286
383.1985	B2	1.05602	1.169686	1.222022	1.272343	1.343948	1.382495

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.9—Participation in whitewater activities (canoeing, kayaking, or rafting) as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.154	A1B	1.00312	0.999375	0.982134	0.993721	1.022044	1.0596
0.154	A2	0.99461	0.978312	0.948653	0.942407	0.948409	0.958434
0.154	B2	1.01282	0.996408	0.958152	0.951875	0.961969	0.960829
Adult participants (thousands)		Participants index					
2008	Scenario	2010	2020	2030	2040	2050	2060
12201.6	A1B	1.029	1.167105	1.300382	1.450587	1.616236	1.799874
12413.21	A2	1.02301	1.158121	1.28896	1.434682	1.605084	1.807906
12169.79	B2	1.03853	1.160231	1.234847	1.302232	1.385535	1.453271
Days per participant		Per capita days index					
2008	Scenario	2010	2020	2030	2040	2050	2060
6.576664	A1B	0.99965	0.996812	0.994198	0.989302	0.983887	0.978904
6.576664	A2	0.99956	0.996113	0.992653	0.986506	0.979073	0.970976
6.576664	B2	0.99968	0.996803	0.994834	0.991485	0.987636	0.984023
Total days (millions)		Total days index					
2008	Scenario	2010	2020	2030	2040	2050	2060
80	A1B	1.02865	1.163385	1.292836	1.435069	1.590194	1.761904
81.38741	A2	1.02256	1.15362	1.27949	1.415322	1.571494	1.755434
79.79145	B2	1.0382	1.156522	1.228468	1.291143	1.368404	1.430052

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

or photographing birds. This activity is very popular in the South, involving 34 percent of the adult population or 27 million people. Among all the activities in this chapter, birding, at 106, has the highest annual days per participant (table 8.1) accounting for about 2,900 million days annually. This extremely high value is likely reflective of the many levels or intensities of birding, from watching feeders to pursuing sightings in remote forests or along the coast. Cordell and others (chapter 7) report that birding participation increased by nearly 30 percent from 1999 to 2009. Per capita participation in birding is projected to increase 7 to 10 percent over the next five decades meaning that birders will increase faster than the adult population at large across each of the future scenarios used herein (table 8.10). By 2060 birding participants are projected to number 44-56 million in the South. Days per participant are expected to decline by 9-13 percent over the same time period. This decline will mean that the total number of days per year of birding by Southerners will increase marginally less than the population, or 47-75 percent by 2060.

Fishing, as defined here, is a composite including various types of saltwater and freshwater pursuits. Fishing has the second highest participation rate (36 percent) for Southerners among the activities examined in this chapter. In 2008, approximately 28 million anglers accounted for 572 million days of participation (table 8.1). Fishing participants increased in the South by over 20 percent in the past decade (chapter 7, table 8.7). Across each of the futures scenarios used in this chapter, the fishing participation rate is projected to decline by 10 to 18 percent over the next five decades (table 8.11). Thus, the number of Southern anglers will grow slower than the regional population. Projected growth rates for participants of 32-54 are expected. Days per participant will remain at about 20 per year across A1B, A2, and B2. Therefore, the number of days of fishing is expected to grow considerably slower than the population, or 30-51 percent. Nevertheless, fishing will remain among the top recreation activities in the South accounting for 742-859 million days in 2060.

Hunting is the final activity examined in this section. Here, hunting consists of an aggregate including all types of legal hunting, including big game, small game, waterfowl, and varmint. Approximately 10 to 11 million adults in the South, or over 13 percent, reported hunting in 2008 on a total of 230 million days (table 8.1). Cordell and others (chapter 7) report that small game hunting participants increased by 16 percent, and big game hunters increased by 25 percent from 1999 to 2009. Findings from our models, suggest that per capita participation by southerners in hunting has peaked and will decline by 26-42 percent over the next five decades (table 8.12). A number of factors appear to be driving the participation rate decline including: increasing population density, growth in Asian and Hispanic population proportions, increasing levels of education, and declining forest and rangeland per capita (chapter 8-appendix A retrievable at http://www.fs.usda.gov/trends/research/sffpa2010.html). Despite the declining participation rate, the number of southern hunters is expected to increase out to 2060 by 8 to 25 percent for scenarios B2 and A1B, respectively (table 8.12). Days of participation per hunter, currently around 22, is projected to remain relatively constant regardless of the selected future scenario. Total days of hunting are forecast to grow at about the same rate as hunter numbers, by 8-24 percent. By 2060 the southern adults will account for 248-286 million days of hunting annually.

Visits to Southern National Forests

Estimation results for visits to southern national forests and related projections for A1B, A2, and B2 are reported in appendix B (retrievable at http://www.srs.fs.usda.gov/trends/research/sffpb2010.html). Reported results include on-site visitation model estimates for each of the four site types, values for explanatory variables by scenario and year, population projections and site visit indexes. Beginning with over 30 million site visits annually in 2008 (table 8.13), we present the results for annual visits per group and overall changes in total Southern national forest visitation by site type and scenario at 10-year intervals, from 2010 to 2060.

Developed use day sites—Visitation to developed use day sites is the second most popular of site types encountered in Southern national forests accounting for 6.5 million recreation visits in 2008. Depending on the specific national forest, these sites include some combination of built structures including picnic areas, playgrounds, shelters, boat ramps, toilets, parking lots, and the like. Groups visiting developed use day sites averaged more than 12 person-trips per year (e.g., a family of four traveling to the site 3 times per year). Annual visits per group are projected to decline 5-8 percent by 2060 across the three scenarios used in this chapter (table 8.14). However, as population is forecast to increase with each scenario, visits to developed use day sites are projected to rise by 35 percent under the lower population growth of B2, 47 percent under mid-population growth A1B, and by approximately 70 percent under scenario A2 wherein population is expected to increase by 77 percent.

Overnight use developed sites—As the name implies, overnight use developed sites have facilities which accommodate overnight stays such as cottages, recreation vehicle hook-ups, camp sites, electricity, and running water. Southern national forests experienced about 2.3 million visits to these sites in 2008 (table 8.13). Annual visits per group averaged around 10, and are projected to decline by 7 percent under A2 and by 14 percent under scenario A1B. However, because of forecasted population growth, an increase of

Table 8.10—Participation in birding (viewing or photographing birds) as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.342	A1B	1.00618	1.032559	1.061017	1.076363	1.087937	1.101538
0.342	A2	1.00422	1.02759	1.052804	1.063612	1.069752	1.076769
0.342	B2	1.00846	1.031673	1.054197	1.06431	1.071119	1.075097
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
26974.5	A1B	1.03214	1.205858	1.404826	1.571223	1.720438	1.871112
27442.31	A2	1.03289	1.216456	1.430473	1.6192	1.810444	2.031123
26904.18	B2	1.03406	1.201295	1.358629	1.45605	1.542745	1.626103
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
106.6459	A1B	0.9974	0.981444	0.968683	0.942633	0.913481	0.886459
106.6459	A2	0.99705	0.979323	0.964218	0.934968	0.900713	0.866154
106.6459	B2	0.99745	0.981866	0.972521	0.952338	0.92803	0.905072
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
2862.4	A1B	1.02946	1.183483	1.36083	1.481086	1.571588	1.658663
2862.4	A2	1.02984	1.191303	1.379288	1.5139	1.63069	1.759266
2854.938	B2	1.02708	1.174842	1.319549	1.385743	1.429886	1.47403

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.11—Fishing (cold water, warm water, Saltwater, or anadromous fishing) as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.357	A1B	0.99853	0.973791	0.942967	0.921708	0.90907	0.903249
0.357	A2	0.99265	0.957615	0.915961	0.88001	0.848306	0.818184
0.357	B2	1.00464	0.972593	0.933503	0.909384	0.892704	0.86999
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
28038.5	A1B	1.0243	1.137227	1.248522	1.345465	1.437583	1.53429
28524.76	A2	1.02099	1.13362	1.24454	1.339691	1.43567	1.543351
27965.41	B2	1.03013	1.132501	1.203081	1.2441	1.285772	1.315875
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
20.58497	A1B	0.99983	0.996436	0.99389	0.989476	0.98509	0.981589
20.58497	A2	0.9996	0.99517	0.991378	0.985243	0.978098	0.970506
20.58497	B2	0.99988	0.996576	0.995829	0.994575	0.992771	0.991327
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
572.5	A1B	1.02412	1.133173	1.240893	1.331306	1.416148	1.506043
582.4286	A2	1.02057	1.128145	1.23381	1.319922	1.404226	1.497831
571.0076	B2	1.03001	1.128624	1.198063	1.237351	1.276477	1.304462

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.12—Hunting as part of outdoor recreation activities in the South for 2010 and projected to 2060 by participation rate, number of participants, and days per participant for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Participation rate		Per capita participation index					
2008	Scenario	2010	2020	2030	2040	2050	2060
0.137	A1B	0.99305	0.922444	0.843038	0.790214	0.757181	0.737596
0.137	A2	0.98094	0.88952	0.790927	0.713447	0.648339	0.588152
0.137	B2	1.00519	0.921013	0.832986	0.785025	0.753318	0.714254
Adult participants (thousands)		**Participants index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
10785.9	A1B	1.01867	1.077262	1.116213	1.153516	1.197389	1.252906
10972.96	A2	1.00894	1.053009	1.074654	1.086123	1.097246	1.109438
10757.78	B2	1.0307	1.07244	1.073536	1.073968	1.085012	1.080322
Days per participant		**Per capita days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
21.68489	A1B	0.99986	0.998123	0.996155	0.994609	0.993631	0.993092
21.68489	A2	0.99973	0.997374	0.994599	0.9919	0.989004	0.985531
21.68489	B2	0.99988	0.998275	0.997554	0.998172	0.999059	1.000172
Total days (millions)		**Total days index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
230.3	A1B	1.01853	1.07524	1.111921	1.147297	1.189763	1.24425
234.294	A2	1.00867	1.050244	1.068849	1.077326	1.085181	1.093386
229.6996	B2	1.03057	1.07059	1.07091	1.072005	1.083992	1.080508

Source: http://www.srs.fs.usda.gov/trends/research/sffpa2010.html

Table 8.13—National forest visits in the South by site type as counted in 2008 and as projected for 2060 (averages per Resources Planning Act scenarios A1B, A2, and B2).

Site type	2008 visits	2060 visits (avg. A1B, A2, B2)
Developed use day sites	6,522,780	9,828,167
Overnight use developed sites	2,297,810	3,305,599
Wilderness	826,883	1,217,358
General forest areas	22,858,446	30,390,127

Source: U.S. Department of Agriculture Forest Service 2010.

Table 8.14—Developed day use site visits to national forests in the South in 2008 and 2010 and projected to 2060 for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Annual person visits per group		Person visit index					
2008	Scenario	2010	2020	2030	2040	2050	2060
12.87	A1B	0.99	0.98	0.96	0.95	0.94	0.92
12.87	A2	1.00	0.99	0.98	0.98	0.97	0.96
12.87	B2	0.99	0.98	0.97	0.96	0.95	0.95
Annual site visits (thousands)		**Total site visit index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
6,523	A1B	1.01	1.11	1.21	1.31	1.39	1.47
6,523	A2	1.02	1.14	1.27	1.40	1.54	1.70
6,523	B2	1.01	1.11	1.19	1.24	1.29	1.35

Table 8.15—Overnight use developed site visits to national forests in the South in 2008 and 2010 and projected to 2060 for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Annual person visits per group		Person visit index					
2008	Scenario	2010	2020	2030	2040	2050	2060
10.28	A1B	0.99	0.96	0.94	0.91	0.89	0.86
10.28	A2	1.00	0.98	0.97	0.96	0.94	0.93
10.28	B2	0.97	0.96	0.95	0.94	0.92	0.91
Annual site visits (thousands)		**Total site visit index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
2,298	A1B	1.01	1.09	1.18	1.26	1.32	1.37
2,298	A2	1.02	1.13	1.25	1.37	1.50	1.64
2,298	B2	1.00	1.09	1.16	1.21	1.25	1.30

Table 8.16—Wilderness site visits to national forests in the South in 2008 and 2010 and projected to 2060 for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Annual person visits per group		Person visit index					
2008	Scenario	2010	2020	2030	2040	2050	2060
14.52	A1B	0.99	0.98	0.98	0.97	0.96	0.95
14.52	A2	1.00	0.99	0.99	0.98	0.98	0.97
14.52	B2	0.99	0.98	0.98	0.98	0.97	0.97
Annual site visits (thousands)		**Total site visit index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
827	A1B	1.02	1.12	1.23	1.33	1.42	1.51
827	A2	1.02	1.15	1.27	1.41	1.56	1.72
827	B2	1.01	1.12	1.20	1.26	1.31	1.38

30 percent (B2) to 64 percent (A2) in visitors to these sites is projected (table 8.15).

Wilderness—Recreation visits to designated Wilderness sites in southern national forests totaled 826,883 in 2008 (table 8.13). Annual visits per group averages over 14 and is expected to decline slightly 3 to 5 percent over the next five decades (table 8.16). This relatively stable per group annual visitation rate, when combined with population growth, suggests that Wilderness visits to southern national forests will grow the most among the four site types, between 38 percent (B2) and 72 percent (A2). Despite faster relative growth in visits, Wilderness visits will remain the smallest in absolute terms, totaling 1.1-1.4 million visits annually by 2060.

General forest areas—Visits to general forest areas in southern national forests, at almost 23 million in 2008, greatly exceed recreation visits to the other three site types combined. General forest areas are probably the most like private forest lands in that while they often have trails and forest roads, they generally lack maintained facilities of any type. Like Wilderness, the average annual visits per group to general forest areas is approximately 14. Unlike Wilderness, though, this average per group is projected to decline by 12-24 percent by 2060 (table 8.17). The biggest decline comes with scenario A1B and this is primarily driven by the effect of increased household income. Like the other national forest settings, the increase in population over the next five decades offsets the drop in average visits per group yielding increases in annual visits by 2060 of 22 percent for A1B and B2, and 55 percent for A2. By scenario, the relative increases are less than for each of the other site types. However, in total, the average visits across the various site types in 2060 is still substantially more than the combination of the other three (table 8.13, figure 8.3).

DISCUSSION AND CONCLUSIONS

This chapter developed models to explain outdoor recreation participation and days of participation for residents of the Southern United States. Models were also developed to examine visits to national forests in the South. These models, combined with population, socioeconomic, and land use projections from alternative futures were employed to project the number of outdoor recreation participants and days of participation regionally to 2060, and to project the number of southern national forest recreation visits by site type to 2060. The objectives were to first, evaluate how population growth and changing demographics will affect changes in demand for different types of recreation activities, and second, to examine the potential for increased congestion and conflict among recreational users of forests as a result of changing supply and demand factors.

Regarding the first objective, the preceding results section indicates that in general, despite continued losses in forest and rangeland across the region and changing demographics, outdoor recreation activity will continue to grow in both numbers of participants and days of participation. Generally, speaking, the number of projected participants and days of participation will increase at a rate near or somewhat below the rate of growth of the regional population.

For a few activities, such as developed site use, hiking, and birding, participant numbers as well as days of participation are projected to grow faster than the rate at which the regional population grows. Other activities typically associated with higher income, like horseback riding on trails, motorized water use, and non-motorized water use, will grow faster than the population if the higher income conditions of scenario A1B eventuate. Otherwise, they will grow at rates slightly less than the population.

A few activities, such as fishing, hunting, and motorized off-road use are projected to experience substantial declines in participation rates and thus, while increasing, will grow much slower than the growth rate of the regional population. Hunting and motorized off-road use, being relatively land intensive, are adversely affected by the expected decline in available forest and rangeland. Moreover, these activities are essentially counter-cultural to the growing numbers of ethnic minorities in the region.

Annual visits per group to southern national forests will decline across all site type and scenario combinations. For day use developed sites, overnight use developed sites, and Wilderness sites, these declines are virtually all less than 10 percent. Thus, when visits per group are combined with an increasing number of groups due to population growth, overall national forest visits will grow, slightly lagging regional population growth. However, visits to general forest areas, which comprise about 70 percent of all national forest visits in the South will grow noticeably slower than the regional population, albeit still increasing by 22-55 percent.

The second objective was to examine the potential for increased congestion and conflict among recreational users of forests as a result of changing supply and demand factors. While modeling use for specific activity and site combinations was beyond the scope of this chapter, tables 8.18 and 8.19 can be used to broadly assess the potential for congestion and conflict facing forest recreationists as demand and supply factors change over the next five decades. Two measures of density and change are reported in table 8.18—forest and range acres per participant, and days of participation per forest and range acre. With the exception of hunting, forest and range acres per participant are projected to decline over the next decade by 33-50 percent. For hunting

Table 8.17—General forest area site visits to national forests in the South in 2008 and 2010 and projected to 2060 for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

Annual person visits per group		Person visit index					
2008	Scenario	2010	2020	2030	2040	2050	2060
14.23	A1B	0.98	0.93	0.90	0.86	0.81	0.76
14.23	A2	1.00	0.97	0.95	0.93	0.90	0.88
14.23	B2	0.96	0.93	0.92	0.90	0.87	0.86
Annual site visits (thousands)		**Total site visit index**					
2008	**Scenario**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
22,858	A1B	1.00	1.06	1.13	1.18	1.21	1.22
22,858	A2	1.02	1.12	1.22	1.33	1.44	1.55
22,858	B2	0.98	1.05	1.12	1.16	1.18	1.22

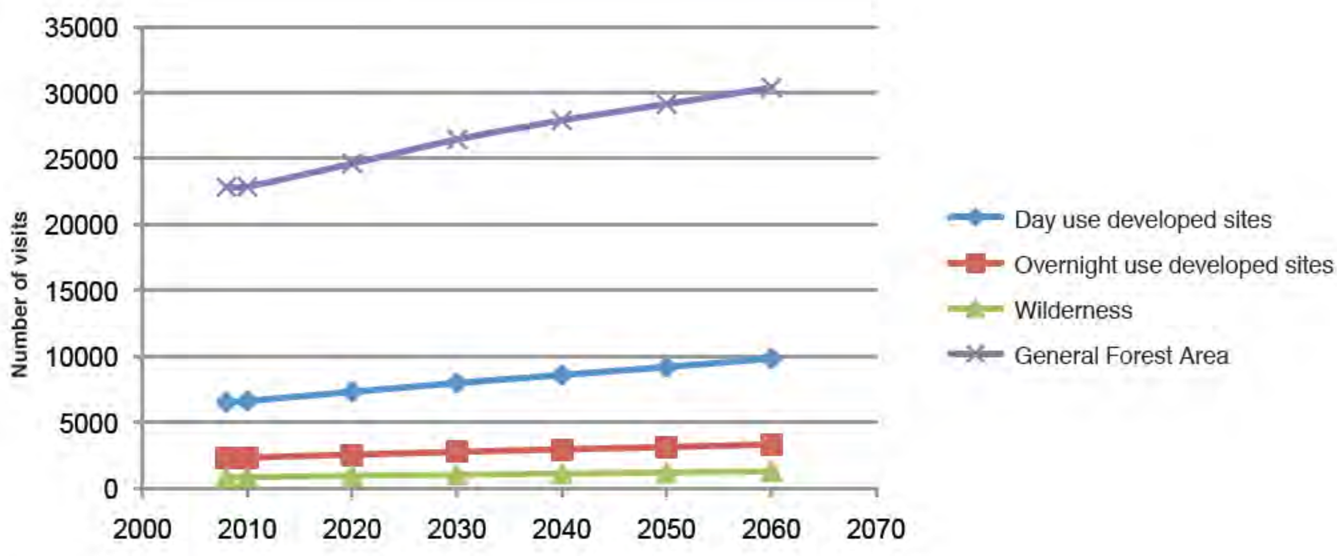


Figure 8.3—Southern national forest visits (thousands) by site-type, 2008 to 2060.

Table 8.18—Forest-based recreation use densities in the South in 2008 and projected for 2060 for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

		Forest and range acres per participant			Days per forest/range acre		
Activity	Scenario	2008	2060	Percent change	2008	2060	Percent change
Birding	A1B	10.5	5.2	-50	10.1	18.0	79
	A2	10.4	4.8	-54	10.3	19.2	87
	B2	10.5	6.2	-41	10.1	15.5	54
Developed site use	A1B	4.5	2.4	-47	2.4	4.4	88
	A2	4.4	2.2	-51	2.4	4.9	102
	B2	4.5	2.8	-37	2.4	3.8	60
Hiking	A1B	14.0	6.6	-53	1.6	3.6	118
	A2	13.8	6.1	-51	1.7	3.8	130
	B2	14.0	7.9	-43	1.6	3.0	85
Horseback on trails	A1B	50.2	25.2	-50	0.3	0.9	151
	A2	49.4	26.8	-46	0.4	0.6	82
	B2	50.2	33.4	-33	0.3	0.6	63
Hunting	A1B	26.3	19.5	-26	0.8	1.1	34
	A2	25.9	21.9	-15	0.8	1.0	16
	B2	26.3	23.3	-11	0.8	0.9	13
Motorized off-road	A1B	16.8	10.3	-38	2.0	3.1	59
	A2	16.5	10.9	-34	2.0	3.0	47
	B2	16.8	12.7	-24	2.0	2.6	30
Primitive area use	A1B	10.1	5.6	-45	1.5	2.6	82
	A2	9.9	5.3	-47	1.5	2.8	90
	B2	10.1	6.7	-33	1.5	2.2	51

Table 8.19—National forest site type use densities in the South in 2008 and projected for 2060 for Resources Planning Act (RPA) scenarios. (RPA scenario A1B corresponds to Cornerstone Futures A, B, and E. RPA scenario B2 corresponds to Cornerstone Futures C, D, and F.)

		Visits per national forest acre		
Site type	**Scenario**	**2008**	**2060**	**Percent change**
Developed day use	A1B	0.49	0.72	47
	A2	0.49	0.88	70
	B2	0.49	0.66	35
Overnight developed use	A1B	0.17	0.24	37
	A2	0.17	0.28	64
	B2	0.17	0.22	30
General forest area	A1B	1.72	2.10	22
	A2	1.72	2.66	55
	B2	1.72	2.10	22
		Visits per national forest wilderness acre		
Site type	**Scenario**	**2008**	**2060**	**Percent change**
Wilderness	A1B	1.26	1.91	51
	A2	1.26	2.17	72
	B2	1.26	1.74	38

the decline will be from 11 to 26 percent. For developed site use and hiking, this could begin to strain existing infrastructure necessary for such activities. For birding and hiking, as defined in the NSRE, these may or may not require expansive areas for quality experiences. The activities currently taking place on the largest amount of space, e.g., horseback riding on trails, hunting, and motorized off-road use, while experiencing somewhat smaller changes in acres per participant, may actually "feel" more congested given the nature of the activity, particularly hunting. It should also be noted that across the three futures scenarios (A1B, A2, and B2), A1B which has the highest income growth, middle land conversion, and middle population growth led to the most "congestion" by the loss in forest and range land per participant measure.

An alternative measure of congestion or land impact—annual days of use per forest and range land acre—is also presented in table 8.18. This measure is perhaps better to assess the impact of activities on nature as it combines participant number and participant intensity per unit of land area. Congestion per unit of land is will rise most over the next five decades for horseback riding on trails (151 percent) and hiking (118 percent). Hunting will see the smallest increase (13-34 percent). These measures are not intended to be comparable across activities, and some may actually have a social component, and thus increase user utility with increased congestion—up to a point. Nevertheless, for those activities which may be near biological carrying capacity or infrastructure carrying capacity, the large increases in use per acre could be a concern, both for the land and for the user.

A final measure of congestion—visits per acre to southern national forests by site type—is reported in table 8.19. Wilderness visits per acre appear to be facing the biggest increases in potential congestion with visits per acre increasing from 38 to 72 percent. Increases across the various scenarios suggest that the density of Wilderness visits in 2060 will exceed that of general forest area visits today. This increase could present difficult challenges to Wilderness and protected area land managers. For example, it is generally understood that an important motivation for visiting Wilderness is to "get away from civilization" or experience nature "untrammeled by man." Having this type of experience will be challenging if Wilderness visitor density continues to increase. In order to accommodate visitor satisfaction, and to comply with Wilderness legislation, managers may be faced with the potentially unappealing prospect of regulating access in the future.

General forest area use density is expected to rise by 22 percent (A1B, B2) to 55 percent (A2) as national forests likely become even more of a substitute destination as private forest and range land is reduced by further development. Because general forest area recreation use including hunting, motorized off-road use, and horseback riding on trails generally require more space between users for high-quality (and safe) experiences, this increase in use density should also be of concern to national forest managers. For example, conflicts due to congestion may increase not just within activities (e.g., motorized off-road users running into each other figuratively and literally), but across activities (e.g., motorized off-road users scaring away game sought by hunters and spooking horses). As in the case of Wilderness, managers could be faced with choosing among potentially unpopular access regulation schemes to mitigate congestion conflicts. Managers may also need to consider sectioning general forest areas into special use areas for specific activities such as motorized off-road use, horseback riding on trails and hunting in order to reduce cross-activity congestion conflicts. Regardless, the increased congestion can only increase the impacts of recreation on the forest environment.

Across all activities and venues, private and public, this chapter provides strong evidence to suggest that the number of southern outdoor recreation participants and their annual days of use will continue to grow over the next five decades putting increasing pressure on existing infrastructure, both built and natural, thus stressing the recreation carrying capacity of the forest and range land resources. In some cases, it may be possible to relieve congestion problems by investing in and building more infrastructure, e.g., constructing more hiking trails on public lands. Private land owners may also help to meet increased demand by increasing built recreation infrastructure on private lands. In the South, there has historically been a fairly large market for consumptive recreational activities (e.g., hunting) provided on private lands. In the future, owners of remaining private land may also be able to "cash in" on increased demand for non-consumptive recreational activities by investing in recreation infrastructure traditionally provided by public lands (e.g., hiking trails, bird-watching facilities).

Because of increasing visitors per acre resulting from increasing population and decreasing private forest and range land, remaining private land will likely become more valuable for other recreation uses including overnight developed site use and developed site day use. A portion of private land in the South is already devoted to private developed campgrounds which have sprung up over the past several decades in response to increased demand for camping opportunities and limited public campgrounds, particularly public campgrounds with RV hook-ups. Increasing congestion on public lands in the future may provide increased demand for private campgrounds and incentives for private land owners to invest in private, overnight developed site infrastructure.

NSRE data suggest that some ethnic minority populations in the South participate in activities occurring at public day use developed sites such as family gatherings and picnicking in greater proportions than traditional visitors. Thus, as the ethnic minority populations in the South increase to 2060, public day use developed sites and hiking venues are likely to become even more congested leading to visitor competition and conflict over limited facilities (e.g., limited picnic pavilions). Public land managers can respond by devoting more public land and management budgets to day use developed sites. Because increasing scarcity of public day use developed sites will increase the value of private land for day use developed sites, private land owners may have incentives in the future to invest in day use developed site infrastructure such as picnic area pavilions to rent out for profit.

KNOWLEDGE AND INFORMATION GAPS

It is impossible to see exactly how changes in income, socioeconomic factors, and economic development will affect the supply and demand for forest-based outdoor recreation. The models, results, and conclusions presented in this chapter are predicated on a number of assumptions and relationships that are likely to change with time. People's preferences change over time. New technology will bring changes to how people enjoy the outdoors—and how they avoid the outdoors. Activities like snowboarding, mountain biking, flat water kayaking, and orienteering did not appear on the radar when Cicchetti's seminal forecasting work on national recreation use was published in 1973, nor did activities like video gaming and DVD renting. Despite differences in outdoor recreation and consumption across ethnic lines today, acculturation factors may mask such differences over the course of the next five decades. Regardless, as the population grows, it is likely that outdoor recreation pressure on the natural environment will become more prevalent and management will need to find ways of creatively mitigating this pressure.

ACKNOWLEDGMENTS

We are grateful to Carter Betz, Don English, Shela Mou, Meghan Starbuck, Kavita Sardana, and Stan Zarnoch for various helpful insights and technical assistance.

LITERATURE CITED

Bowker, J.M. 2001. Outdoor recreation participation and use by Alaskans: projections 2000-2020. Gen. Tech. Rep. PNW-GTR-527. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 28 p.

Bowker, J.M.; Bergstrom, J.C.; Gill, J. 2007. Estimating the economic value and impacts of recreational trails: a case study of the Virginia Creeper Rail Trail. Tourism Economics. 13: 241-260.

Bowker, J.M.; English, D.B.K.; Cordell, H.K. 1999. Outdoor recreation participation and consumption: projections 2000 to 2050. In: Cordell, H.K.; Betz, C.J.; Bowker, J.M. [and others]. Outdoor recreation in American life: a national assessment of demand and supply trends. Champagne, IL: Sagamore Press, Inc.: 323-350.

Bowker, J.M.; Starbuck, C.M.; English, D.B.K. [and others]. 2009. Estimating the net economic value of national forest recreation: an application of the National Visitor Use Monitoring database. Faculty Series Working Paper, FS 09-02. Athens, GA: The University of Georgia, Department of Agricultural and Applied Economics. 222 p. http://ideas.repec.org/p/ags/ugeofs/59603.html. [Date accessed: December 4, 2012].

Bowker, J.M.; Murphy, D.; Cordell, H.K. 2006. Wilderness and primitive area recreation participation and consumption: an examination of demographic and spatial factors. Journal of Agricultural and Applied Economics. 38(2): 317-326.

Cameron, C.A.; Trivedi, P.K. 1998. Econometric society monographs: regression analysis of count data. New York: Cambridge University Press. 412 p.

Cicchetti, C.J. 1973. Forecasting recreation in the United States. Lexington, MA: D.C. Heath and Company. 200 p.

Cordell, H.K.; Bergstrom, J.C.; Hartmann, L.A.; English, D.B.K. 1990. An analysis of the outdoor recreation and wilderness situation in the United States: 1989–2040. Gen. Tech. Rep. RM-189. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station. 112 p.

Cordell, H.K.; Bergstrom, J.C. 1991. A methodology for assessing national outdoor recreation demand and supply trends. Leisure Sciences. 13(1): 1-20.

Englin, J.E.; Shonkwiler, J.S. 1995. Estimating social welfare using count data models: an application to long-run recreation demand under conditions of endogenous stratification and truncation. Review of Economics and Statistics. 77(1): 104-112.

English, D.B.K.; Betz, C.J.; Young, J.M. 1993. Regional demand and supply projections for outdoor recreation. Gen. Tech. Rep. RM-230. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 39 p.

English, D.B.K.; Kocis, S.M.; Zarnoch, S.J.; Arnold, J.R. 2002. Forest Service national visitor use monitoring process: research method documentation. Gen. Tech. Rep. SRS-57. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 14 p.

Greene, W.H. 2003. NLOGIT. Version 3.0. Plainview, NY: Econometric Software, Inc.

Hall, T.E.; Heaton, H.; Kruger, L.E. 2009. Outdoor recreation in the Pacific Northwest and Alaska: trends in activity participation. Gen. Tech. Rep. PNW-GTR-778. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 108 p.

Hof, J.G.; Kaiser, H.F. 1983a. Long term outdoor recreation participation projections for public land management agencies. Journal of Leisure Research. 15(1): 1-14.

Hof, J.G.; Kaiser, H.F. 1983b. Projections of future forest recreation use. Resour. Bull. WO-2. Washington, DC: U.S. Department of Agriculture Forest Service. 12 p.

Intergovernmental Panel on Climate Change [IPCC]. 2007. Climate change 2007, the fourth IPCC assessment report. http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html. [Date accessed: December 10, 2008].

Leeworthy, V.R.; Bowker, J.M.; Hospital, J.D.; Stone, E.A. 2005. Projected participation in marine recreation: 2005 and 2010. http://www.srs.fs.usda.gov/pubs/ja/ja_leeworthy002.pdf. [Date accessed: August 31, 2010].

Ovaskainen, V.; Mikkola, J.; Pouta, E. 2001. Estimating recreation demand with on-site data: an application of truncated and endogenously stratified count data models. Journal of Forest Economics. 7(2): 125-144.

Sardana, K. 2010. Modeling demand for outdoor recreation settings with choice-based samples. Athens, GA: University of Georgia. 61 p. Ph.D. dissertation.

Souter, R.A.; Bowker, J.M. 1996. A note on nonlinearity bias and dichotomous choice CVM: implications for aggregate benefits estimation. Agricultural and Resource Economics Review. 25(1): 54-59.

U.S. Department of Agriculture (USDA) Forest Service. 2012. Future scenarios: a technical document supporting the forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-272. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 34 p.

U.S. Department of Agriculture (USDA) Forest Service. 2010. National Visitor Use Monitoring Program: FY 2009 NVUM national summary report. www.fs.fed.us/recreation/programs/nvum/. [Date accessed: August 21, 2010].

U.S. Department of Agriculture (USDA) Forest Service. 2009. National Survey on Recreation and the Environment (NSRE dataset, various years). Athens, GA: U.S. Department of Agriculture Forest Service, Southern Research Station, RWU-4953. http://www.srs.fs.usda.gov/trends/nsre-directory/index.html. [Date accessed: December 4, 2012].

Walsh, R.G.; Jon, K.H.; McKean, J.R.; Hof, J. 1992. Effect of price on forecasts of participation in fish and wildlife recreation: an aggregate demand model. Journal of Leisure Research. 21: 140-156.

Wear, D.N.; Greis, J.G.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS-115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Wear, D.N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

Zarnoch, S.J.; Cordell, H.K.; Betz, C.J.; Langner, L. 2010. Projecting county-level populations under three future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. e-Gen. Tech. Rep. SRS-128. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 8 p.

Zawacki, W.T.; Marsinko, A.; Bowker, J.M. 2000. A travel cost analysis of economic use value of nonconsumptive wildlife recreation in the United States. Forest Science. 46(4): 496-505.

CHAPTER 9. Markets

David N. Wear, Jeffrey Prestemon, Robert Huggett, and Douglas Carter[1]

KEY FINDINGS

- Although timber production in the South more than doubled from the 1960s to the late 1990s, output levels have declined over the last 10 years, signaling structural changes in timber markets.
- For softwood products, production declines are most clearly related to demand issues. Demand for softwood solid wood products is strongly linked to housing markets, and a sharp decline in construction beginning in 2007 reduced timber demand, a short run adjustment. Demand for pulpwood in paper manufacturing has declined as the production capacity has dropped in the South, a long run adjustment.
- As demand declined, investments in softwood production continued to expand, leading to supply growth for all softwoods, but especially for softwood pulpwood. The net result was a substantial reduction in softwood pulpwood prices.
- In contrast to softwood products, hardwood pulpwood output declined and its price increased in the 2000s, indicating a contraction of supply, especially in the Coastal Plain where paper production is concentrated.
- Several forecasts of timber markets show expanding supplies of softwood timber, especially softwood pulpwood, as new plantations mature and additional plantations accumulate across the South. Across all forecasts, softwood pulpwood supply expands through the next 40 years, while softwood sawtimber supply grows over the next decade and then stabilizes.
- Forecasts of hardwood supplies indicate a gradual contraction as urbanization shrinks inventories.
- If timber product demand returns to and stays at the 2006 levels, total timber production is forecasted to expand by about 25 percent over the next 50 years, with little impact on the price of softwood sawtimber and hardwood pulpwood. Softwood pulpwood prices would decline by about 50 percent.
- If demand growth returns to 1980s and 1990s levels, total timber production could expand by about 40 percent over the next 50 years, with the greatest gains in softwood pulpwood output. Softwood pulpwood prices stabilize at 2006 levels while softwood sawtimber and hardwood pulpwood prices would increase at an average annual rate of slightly less than 1 percent.
- Growth in demand, coupled with gains in the productivity of planted pine forests, would likely expand total timber production by about 70 percent, with the production of softwood pulpwood more than tripling. The price of softwood sawtimber would stabilize, the price of softwood pulpwood would fall at less than 1 percent per year, and the price of hardwood pulpwood would increase by less than 1 percent per year.
- Forecasts indicate that the South's timber supply could expand if moderate rates of future forest investments are added to investments in forests made over the past 20 years. Forecasts for 2055 show that annual production of softwood pulpwood could increase beyond 2006 levels by an additional 2.4 billion to 3.7 billion cubic feet (36.6 million to 57.9 million green tons) without substantial price effects.
- Timber production has the potential to expand substantially in the South, but future markets are likely to be limited by demand levels. Bioenergy is a potential but highly uncertain source of demand. Recovery of housing-related demand for wood products remains a key uncertainty in the short run.
- Without an expansion in timber demand, private forest owners would be expected to eventually experience a strong shift away from forest management as investment returns diminish to the point where continued investments cannot be justified.

INTRODUCTION

Timber production from the South grew substantially and steadily from 1950 to the late 1990s. Although production has declined from 1997/1998 peak levels, the region still provides a majority of the timber products produced in the United States (Smith and others 2009). Rapid growth in production from 1970 to 1998 did not, however, deplete standing inventories of biomass because high growth rates and investments in agricultural-style forestry increased

[1]David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695; Jeffrey Prestemon is a Research Forester at the Forest Economics and Policy Research Work Unit, Southern Research Station, U.S. Department of Agriculture Forest Service, Research Triangle Park, NC 27709; Robert Huggett is a Research Assistant Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695; Douglas Carter is a Professor, School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611.

forest productivity—planted pine forests now represent 19 percent of southern forest land. Recent harvest declines raise questions about the future of timber markets, and recent policy discourse about the use of wood to produce energy on large scales suggests potential for uncertainty and structural changes in these markets.

The objectives of this chapter are to examine the history of change in forest products markets and to consider potential futures. We use historical records of harvest quantities and timber prices to test general hypotheses about changes in supply and demand. Supply forecasts and trends in product demand are then used to analyze market potential and to construct alternative forecasts of harvests and timber prices. Throughout these analyses, the chapter addresses the following specific questions:

- How have markets for forest products changed, especially in the past decade?
- What are the implications of these changes for the future of timber markets?
- How is timber supply projected to change?
- What factors influence the future of forest product demand and what are the implications for timber markets?
- How might markets develop in response to alternative scenarios for future supply and demand?

Influences on Timber Supply

Timber supply defines how landowners deliver timber to market in response to timber prices and, in the longer run, to a variety of other signals. Several factors make it difficult to analyze the timber supply situation, including the long production period involved in growing trees, the multiple benefits that landowners can derive from standing forests, and constant changes in the land base from which timber is produced. It is common to think of supply as simply the relationship between harvests and prices but these other factors need to be accounted for, especially when considering long run supply dynamics.

Supplies of timber are ultimately determined by the intersection of the biological production capacity of forests and the preferences of forest land owners. This chapter describes alternative production possibilities by evaluating alternative assumptions about productivity. It also considers a range of producer behavior by considering alternative projections of forest investments (plantation replacement and establishment), based on the historical behavior of private forest landowners.

Influences on Timber Demand

Demand is an economic concept that relates the consumption of a commodity to its price. Economic theory indicates that less of a commodity is consumed at a higher price and that charting all the possible price-consumption combinations defines a demand curve. This curve, however, can be repositioned based on many factors other than the commodity's price—such as income, prices of substitutes for the commodity, and changing tastes. In this chapter, we examine demand for timber products by analyzing the various factors that could alter demand relationships. We look closely at substitution possibilities, production capacity, and international trade as indicators of changes in domestic demand for timber products.

Perhaps the most important uncertainty about the future of timber demand is the development of new markets for fiber in the production of bioenergy. As a renewable resource, forest biomass may play an important role in meeting goals established through renewable portfolio standards, and cellulosic feedstocks for liquid fuels have been targeted in 2008 Farm Bill and other policies aimed at increasing the use of renewable energy. Demands for wood for co-firing in coal fired electricity plants and for production of fuel pellets have already emerged, although biofuel production on a large scale would require technological advances. Chapter 10 addresses potential bioenergy futures in detail.

Scope of Analysis

Chapter 10 examines how demand for wood in the production of bioenergy could develop in the future, and we refer to that chapter in examining a full range of market futures. While evaluating market futures, we do not attempt to forecast the business cycle, in particular, the recovery from the 2007 recession and the return to historical trends in product demand. Rather, our focus is on long run trends and, ultimately, the implications for forest sustainability and the capacity to adapt to changing demand for fiber in the coming years and decades.

METHODS

The analysis of historical changes in timber markets presented here starts by updating the data from a report (Wear and others 2007) that examined basic price- and harvest-quantity indicators and interpreted patterns of change to provide general insights into market direction and trends in demand and supply. A set of explanatory factors that have affected the demand for timber products—including domestic conditions, technology changes, and international trade—places demand trends in context. An analysis of timber supply fundamentals focuses on land use, forest investment, and timberland ownership and their effects on the future provision of timber from private lands.

We use empirical models of timber supply and demand to explore alternative futures for timber markets. Future timber supply relationships are derived from simulation runs of the U.S. Forest Assessment System's Forest Dynamics Model described in chapters 4 and 5. The model simulates change in the South on all plots of the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture, including harvest choices made in response to the future market conditions described by the price projections of the six Cornerstone Futures (chapter 2):

- Cornerstone A describes a future of very rapid economic and technological growth, combined with increasing timber prices.
- Cornerstone B is also based on rapid economic and technological growth but combined with decreasing timber prices.
- Cornerstone C is based on moderate levels of economic development and less rapid but more diverse technological change, combined with increasing timber prices.
- Cornerstone D is also based on moderate levels of economic development and less rapid technological change, but combined with decreasing timber prices.
- Cornerstone E is based on Cornerstone A but allows for an increased rate of planting following the harvest of naturally regenerated forests.
- Cornerstone F is based on Cornerstone D but with a decreased rate of forest planting following harvests.

Harvest choice models are based on empirical models of historical harvesting linked to FIA plots in the South. The models are sensitive to changing forest productivity and prices that affect net revenues from harvest/no harvest alternatives. Using the Cornerstone Futures, simulations of harvests for a range of prices are summed across all plots to define the timber supply function (defined as the relationship between aggregate timber harvest quantities and their respective timber prices within a forecast period). Prices for softwood sawtimber, other softwoods, hardwood sawtimber, and other hardwoods enter the calculations (Polyakov and others 2010), and a set of empirical supply functions are derived for these four product classes.

Supply Scenarios

We used a modified version of the method outlined by Polyakov and others (2010) to construct aggregate supplies. For a set of related Cornerstone Futures—for example, Cornerstones A, B, and E, that share the same population and economic growth futures but apply different price projections—we use the simulations to generate multiple supply realizations, specifically, a bootstrapping approach (employing random sampling with replacement) of simulations for each State in each time period that generates 1000 observations of supply. These realizations provide the data for regression equations where the harvest quantity for each product is modeled as the function of its price, and cumulative results for all products provide estimates of supply models in each period. We set up the equations so that the coefficient on price is the own-price elasticity of supply (the ratio of proportional change in harvest to the proportional change in price), and so that supply for each period reflects forecasts of land use change and responses to climate, disturbances, and forest succession.

The U.S. Forest Assessment System models the supply of total removals from inventory, but our questions target specific product markets. Estimated quantities of products obtained from numbers of removals derive from utilization coefficients that translate sawtimber-sized removals and other removals into what we label sawlogs and pulpwood. Sawlogs are used in the production of lumber and veneer for panels. Pulpwood is defined as material delivered for use in the paper manufacturing and in other industrial processes—especially for fuelwood and for the manufacture of oriented strand board. The timber product output database (Johnson and others 2010) provides estimates of these conversion factors, which we adjusted to reflect the difference between chip-and-saw sawlogs from plantations and sawtimber products from naturally regenerated forests.

Basic supply scenarios—We constructed two supply scenarios from the Cornerstone Futures, one labeled "High GDP" to reflect the strong economic and moderate population growth projections of Cornerstones A, B, and E; and the other labeled "Low GDP" to reflect the weak economic and low population growth projections of Cornerstones C, D, and F.

These forecasts of changes in forests are contingent on projections of timber harvests across private and public forested plots in the FIA inventory using market-driven harvest probability models (Polyakov and others 2010). Harvest predictions are driven by the price projections that are part of the assumptions that structure each of the Cornerstone Futures. We use these projections of harvests to estimate supply functions for the two fundamental economic storylines they embody. Associated forest condition forecasts and land use forecasts are described in chapters 5 and 4, respectively.

Effects of productivity increases—The imputation approach adopted for the U.S. Forest Assessment System that undergirds our supply projections uses current observed forest productivity to construct forecasts. This is appropriate for short run supply forecasts, but recent research indicates that the productivity of pine plantations could expand over the next several years (McKeand and others 2003). Tree improvement programs have yielded genotypes with large gains in productivity and newly planted forests are expected to have even larger productivity gains (with additional crossing of superior parents). Tissue culture propagation along with other advanced genetic techniques may increase output per acre by even greater amounts. The rate of deployment of improved planting stock and the proportion of established plantations receiving intensive management throughout their rotation is unclear and compounds the uncertainty of any attempt to forecast productivity growth.

To examine the potential contributions of this enhanced productivity, we adopted a straightforward simulation approach using an additive formula that increases productivity by 10 percent each decade, so that by the 2050s average productivity of planted pine forests is 50 percent higher than the current level. Although we expect increased productivity to eventually alter planting decisions, and therefore skew some of the decision models that undergird our analysis, we believe that this simulation approach provides a first approximation of long run production potential.

Demand Scenarios

We examine two different demand scenarios. The first—labeled Constant Demand—holds the demand relationships for timber products in 2006 constant over the 50-year projection period. This is consistent with demand stability for both paper and solid-wood products and would be consistent with some substitution within product lines. In effect, it is consistent with moderate (long run average) housing demand and the stability observed in pulp and paper markets in the late 2000s. Demand was modeled using a constant elasticity equation by intersecting the harvest-price observation for 2006 and applying exogenously determined own-price elasticity, always -0.5, as was consistent with the literature. Note that constant demand does not imply constant harvests. Rather it holds the demand relationship between price and harvest constant, so prices and harvests can vary over time in response to supply shifts.

The second demand scenario—labeled Expanding Demand—examines a return to demand growth in the South. Under this scenario, product demand is assumed to return to 1996 levels by 2015 and then expand 10 percent per decade through the end of the projection period. This is roughly consistent with demand growth in the 1980s and 1990s.

We did not construct these demand scenarios to address changes in world trade of forest products explicitly, but instead assumed that they capture range of market realizations that is useful for our projections, i.e., they should provide useful insights into the potential range of market responses over the next 50 years.

Market Forecasts

For market forecasts defined by permutations of the supply and demand scenarios, we report forecasted harvests and prices for every decade. Inventory and removals are constructed on a decadal basis, with inventory reflecting the conditions at the end of the period and removals reflecting the average removals over the previous decade—for example, the 2030 inventory reflects removals occurring over the years 2021–30. All prices are in real 2009 dollars and harvest forecasts are, after applying conversion factors, comparable to the historical timber product output data and reported in summary reports (Johnson and others 2010) for the 2010 Resources Planning Act (RPA) Assessment.

Data Sources

Historical harvest quantity data are derived from the timber product output system of the Forest Service, U.S. Department of Agriculture. Reports of roundwood output by region have been developed for the RPA National Inventory Database for the years 1952, 1962, 1977, 1981, 1996, 2001, and 2006 (Smith and others 2001, 2004, 2009). Comparable annual data for softwood and hardwood pulpwood harvests have been compiled for the South (Johnson and Steppleton 2005). We also constructed an annual series of softwood sawlog production by interpolating between the RPA reporting years based on the production of softwood lumber in the South as reported by the Southern Forest Products Association.

To examine price trends we constructed regional price indices based on prices reported by Timber-Mart South for all subregions of the South. We constructed price indices by product class based on prices reported for intra-State areas by Timber Mart-South, with each index representing an average weighted by the inventory volumes of its associated geographic area. Throughout this paper we report prices in real terms, adjusted for inflation using the Consumer Price Index price deflator, with 2009 as the value basis. Indices of timber prices were also used to allow easier comparisons among product types. When indices were used, we defined 1977 as the base year (the index is set equal to 1 in 1977) and applied the indexing to the real prices described above.

Trade data were taken largely from the database compiled by Daniels (2008), which summarizes extensive records on imports and exports from the U.S. Department of Commerce through 2005. Other secondary sources were tapped to provide data on exports/imports of selected products beyond 2005, wood products capacity, and various price indices.

RESULTS

We start this section by examining how timber markets have changed in the South since detailed records have been kept (with emphasis on the most recent changes) using timber harvests and prices as summary indicators of development over time. We begin by examining how harvest quantities and prices have changed, and where possible, deconstructing those changes into implied shifts in supply and demand to add context.

Historical Timber Markets

Southern forests yield a wide variety of hardwood and softwood timber products. Softwood products constituted 71 percent of harvest output in 2006, the latest year for which comprehensive timber product output data are available (fig. 9.1). Forty-two percent of total harvest was for sawlogs and 38 percent was for pulpwood products. Softwood sawlogs comprised the largest product class (31 percent), followed by softwood pulpwood (26 percent) and hardwood pulpwood (12 percent); the three represented roughly 69 percent of harvests, continuing a trend that began in the 1970s (fig. 9.1).

Timber harvests from southern forests trended strongly upward during the last half of the 20th century (fig. 9.1). From 1962 to 1996, annual harvesting more than doubled from about 4 to almost 10 billion cubic feet, with a relatively constant product mix. Production ranged from 39 to 44 percent from pulpwood and 64 to 71 percent from all softwoods, with no consistent trends.

Growth in harvests for all products was steady from one year to the next with only a few exceptions (fig. 9.2), the most notable being a dip in output during a brief recession in the mid-1970s. Growth in harvests was at its strongest from 1982 through 1998, with output expanding at a compound rate of 3.3 percent per year. After this long period of strong growth, total harvest quantity fell by approximately 23 percent from 1997 to 2008, returning total harvest quantity to 1987 levels. This represents the largest and longest downturn in harvesting over the historical period (1952 to 2008).

Trends in the three largest product classes (fig. 9.3) show that the harvest decline was led by reductions in hardwood pulpwood (a loss of 42 percent), followed by 27 percent for softwood sawtimber and 7 percent for pulpwood. Most of the decline in softwood sawtimber production occurred since 2005 (fig. 9.3). We were unable to construct an annual time series of hardwood sawlog production (the fourth largest product class) using a comparable technique, but the periodic data (fig. 9.1) suggest that hardwood sawtimber harvests were relatively stable at least through 2006, with incomplete data suggesting substantial declines beginning in 2007 in association with the housing-related recession that began that year.

Timber prices are an indicator of the scarcity of timber as an input to production, and they reflect the interaction of supply and demand: if stumpage prices increase, then timber becomes relatively scarcer. Conversely, falling stumpage prices indicate that timber is becoming more abundant relative to demand for its use. Prices for various wood products demonstrated a variety of trends from 1977 to 2009, the period for which we have comprehensive data, indicating that scarcity or abundance of these resources is a complex and evolving story.

From 1977 to the late 1980s, timber prices were flat-to-declining for all hardwood and softwood products (fig. 9.4). Compared to 1977, softwood sawtimber prices declined very slightly through 1991, softwood pulpwood prices were essentially flat through 1989, and hardwood pulpwood prices were flat through 1988. Harvesting grew at moderate rates (fig. 9.3), with no indications of increasing scarcity through the late 1980s.

Price patterns began changing between 1989 and 1992 (fig. 9.4). Real-dollar prices turned upward for all four products and increased through 1997 or 1998, when production peaked. From 1988 to 1998, hardwood pulpwood prices increased at an average annual rate of 12 percent, followed by softwood pulpwood at 5 percent and softwood sawtimber at 8 percent. Hardwood sawtimber prices increased by 6 percent from 1992 to 1998. These price data indicate increasing scarcity for all timber products over the decade.

From 1998 to 2009, hardwood pulpwood and sawtimber prices stabilized, and softwood sawtimber prices declined from their near-peak 1998 level (only exceeded in 1979) and from 2005 to 2009 reached their lowest level of the historical period. Softwood pulpwood prices have, however, followed a decidedly different pattern. From 1998 to 2001, prices for this product fell to about half of their 1998 value, their lowest level of the historical period, and have remained at this level through 2009.

Changes in harvest quantities and timber prices since 1998 suggest that timber markets have been and continue to be dynamic. Softwood product prices have declined from their peak levels, but hardwood product prices have remained relatively constant. These price changes, combined with harvest patterns, suggest that returns available to most timberland owners are now substantially lower than they were in the peak years of the 1990s. For softwood pulpwood, these patterns suggest a contraction in pulpwood demand coupled with stable-to-expanding supply of standing pulpwood-sized timber. In contrast, hardwood pulpwood

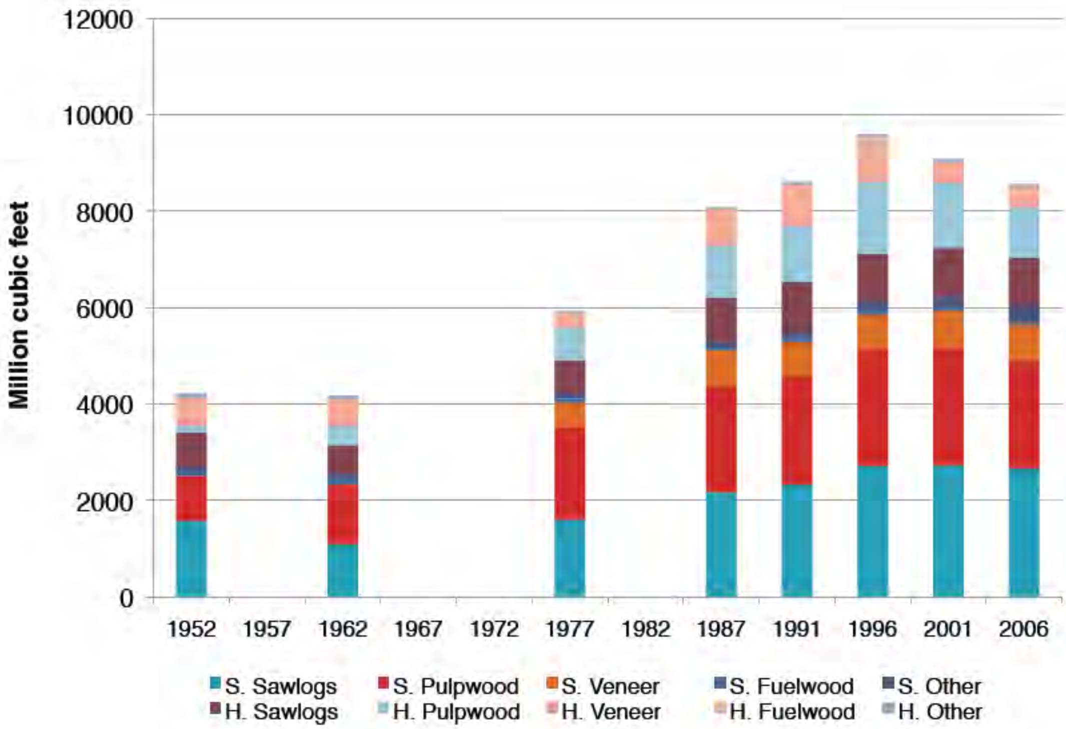


Figure 9.1—Roundwood harvests in the South by product, various years from 1952 to 2006. (Source: Smith and others 2009)

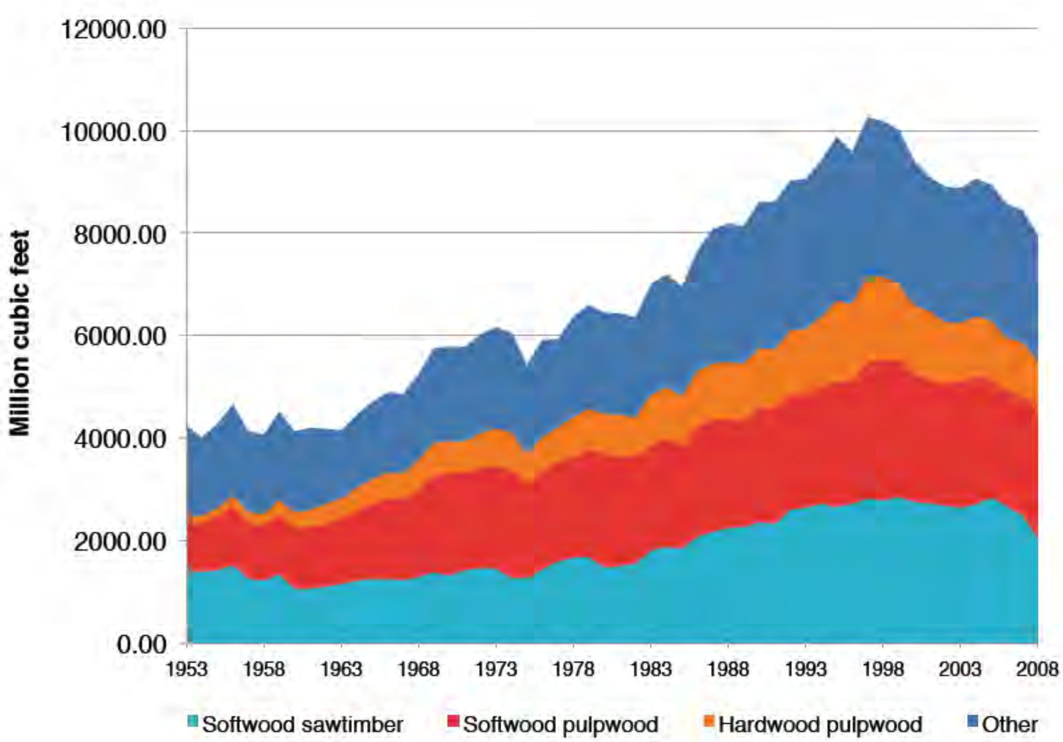


Figure 9.2—Roundwood production in the South, all products, 1953 to 2008. (Source: Smith and others 2009)

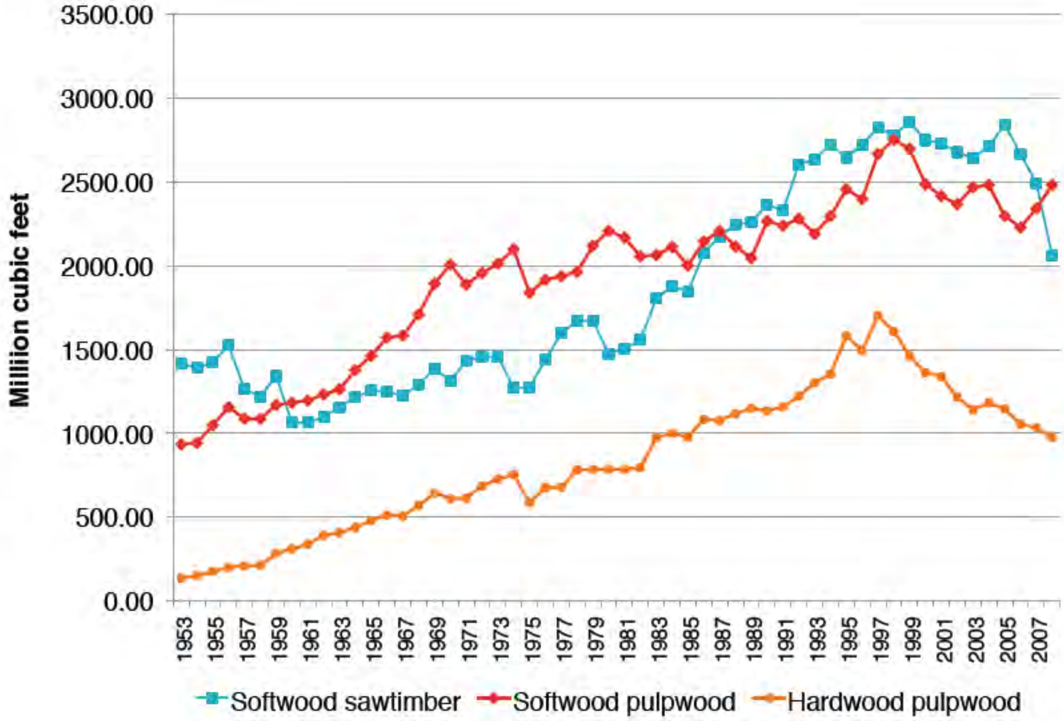


Figure 9.3—Roundwood production in the South for selected products, 1953 to 2008. (Source: Smith and others 2009)

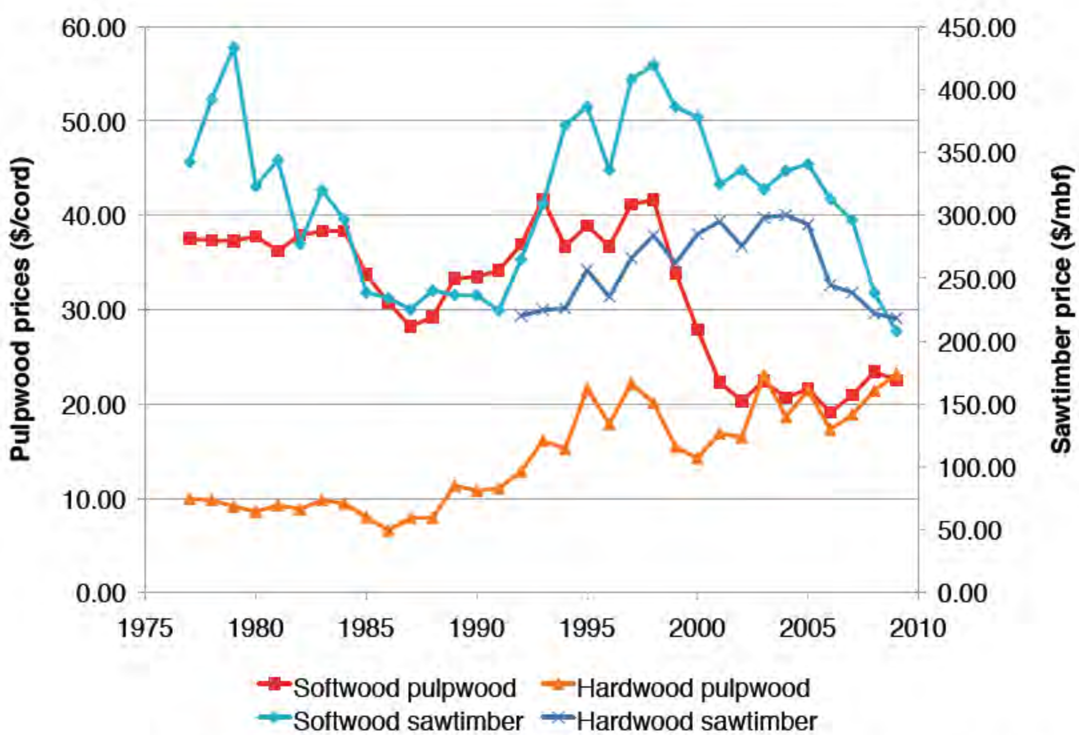


Figure 9.4—Real stumpage prices in the South by product, 1977 to 2008. (Source: Timber Mart-South adjusted using the CPI inflator; Norris Foundation, various issues)

seems to have become somewhat scarcer; softwood pulpwood prices were about twice as high as hardwood pulpwood prices in the early 1990s, but the two products are now roughly equal in price (fig. 9.4).

Looking jointly at price and harvest changes for the three largest product classes in the South (fig. 9.5), we can define three distinct periods of development from 1977 to 2008.

Moderate growth phase (1977 to 1986)—During this period, harvests of all products increased at a moderate rate while timber prices stayed constant or even declined for all three of the major products. These trends are consistent with expansion of both supply and demand for the products—that is, forest investments generated additional wood supply and kept prices from increasing with output.

Rapid growth phase (1986 to 1998)—During this period, harvests of hardwood pulpwood, softwood pulpwood, and softwood sawtimber continued to increase but at faster rates than the earlier period. Prices for these products also increased, and at a higher rate than for harvests. This pattern is consistent with a strong expansion in timber demand but does not provide conclusive evidence of change in timber supply. It is consistent, however, with demand expanding faster than supply. In contrast, production was stable but price increased for hardwood sawtimber, signaling a tightening of hardwood sawlog supply.

Adjustment phase (1998 to 2009)—Following the production peaks on 1997 through 1998, fundamental changes in output and price trends suggest important changes in timber markets. For hardwood pulpwood, prices initially fell and then increased again from 2001 to 2009, and harvests declined steadily throughout the period, falling by about 60 percent. Falling output with increasing prices indicates a contraction in supply for hardwood pulpwood over the period, irrespective of demand changes. For softwood pulpwood, harvests fell about 7 percent from 1997 to 2000, and then stabilized, but prices fell by about 50 percent between 1998 and 2001 and have remained at this level through 2009. Decreasing prices with a stable output is consistent with a strong expansion in the supply of softwood pulpwood. For softwood sawtimber, simultaneous declines in harvest and prices indicate that markets were dominated by a contraction of demand from 2005 to 2009, coincident with strong declines in the demand for U.S. housing construction.

Demand Trends for Pulp and Paper Products

For several decades, the United States has produced more wood pulp than any other nation. In 2006, hardwood and softwood pulpwood made up 36 percent of the timber consumed in the South. The region's paper mills are concentrated in the few areas where plentiful water is available. These areas include southeastern Georgia, northeastern Florida, and southern Alabama and Mississippi. Concentration of paper production capacity organizes the demand for pulpwood within the South: demand for pulpwood is strongest in the vicinity of mills and weakens with distance from the mill gate (fig. 9.6). Although satellite chipmills distributed the demand for pulpwood over a wider area in the 1990s, pulpwood markets are still much more concentrated geographically than are markets for solid wood.

The raw material for production of paper products comes from pulpwood-grade trees, from wood product manufacturing residuals, and increasingly from recycled fiber. Ince (2000) shows that recycled material comprised 37.9 percent of U.S. paper products in 1998, up from 23.9 percent in 1985. This has resulted in a drop in the demand for virgin wood fiber. The amount of recycled material used in U.S. paper manufacturing may have reached a maximum, especially given strong export demand for recovered paper. So it is likely that expanding use of recycled material mitigated demand and price increases during the rapid growth phase (1986 to 1998), but that changes in demand for recycled material have not been a major influence in the adjustment phase (since 1998).

Pulping capacity within the region defines the upper limit for pulpwood demand, at least in the short run. Because expanding capacity through construction requires a large commitment of capital (typically in the $2 billion range), trends in capacity provide a strong indicator of current and anticipated demand for pulpwood. Through 1998, both U.S. and southern pulpmill capacity trended upward (fig. 9.7). Since then, U.S. capacity has decreased only slightly, while Southern capacity decreased by 16 percent before stabilizing in 2003 (fig. 9.8). The rate of decrease in southern capacity was much lower than decreases in the number of paper mills, reflecting an increased concentration of production in remaining plants.

Accompanying these declines in domestic capacity was an expansion in capacity by other countries such a Sweden, Finland, Chile, and Brazil (fig. 9.9). Although the United States and the South continue to lead in pulpwood production, their share of worldwide capacity has declined since 1991. By 2003, pulp capacity in the South had returned to its 1985 level (well short of the 1998 level), where it remained through 2008.

New pulpmill capacity and pulp production is feeding increased worldwide (and especially Asian) demand for paper products. With level-to-declining capacity in the United States, it is clear that the new capacity is being developed elsewhere. These changes are likely explained by shifts in comparative advantage resulting from several factors, including labor costs, raw materials costs, and proximity to

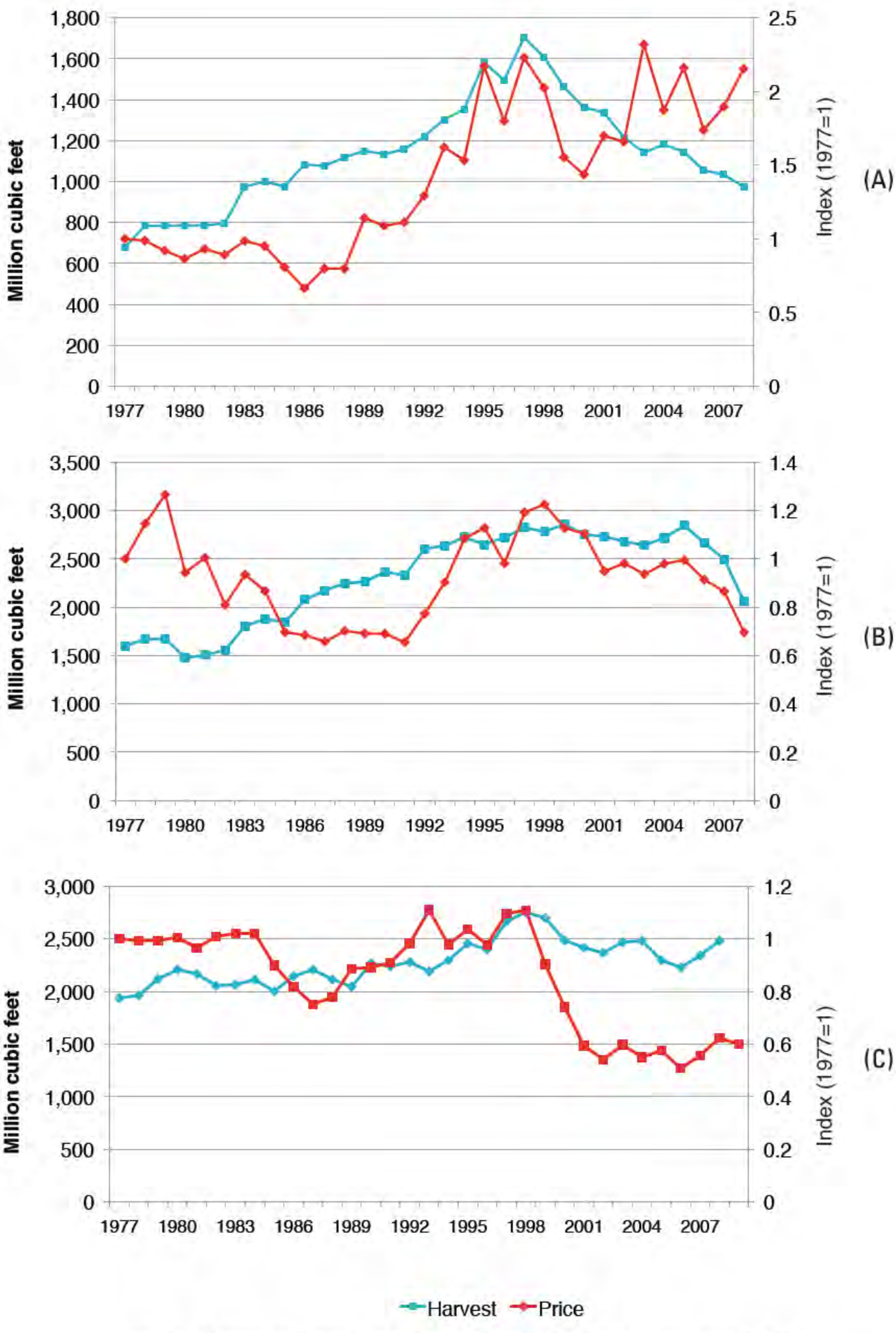


Figure 9.5—Harvesting and price for (A) hardwood pulpwood, (B) softwood sawtimber, and (C) softwood pulpwood in the South, 1977 to 2008. [Sources: Price data from Timber Mart-South (Norris Foundation, various issues); production data from Smith and others (2009) and interpolated as explained in Wear and others (2007).]

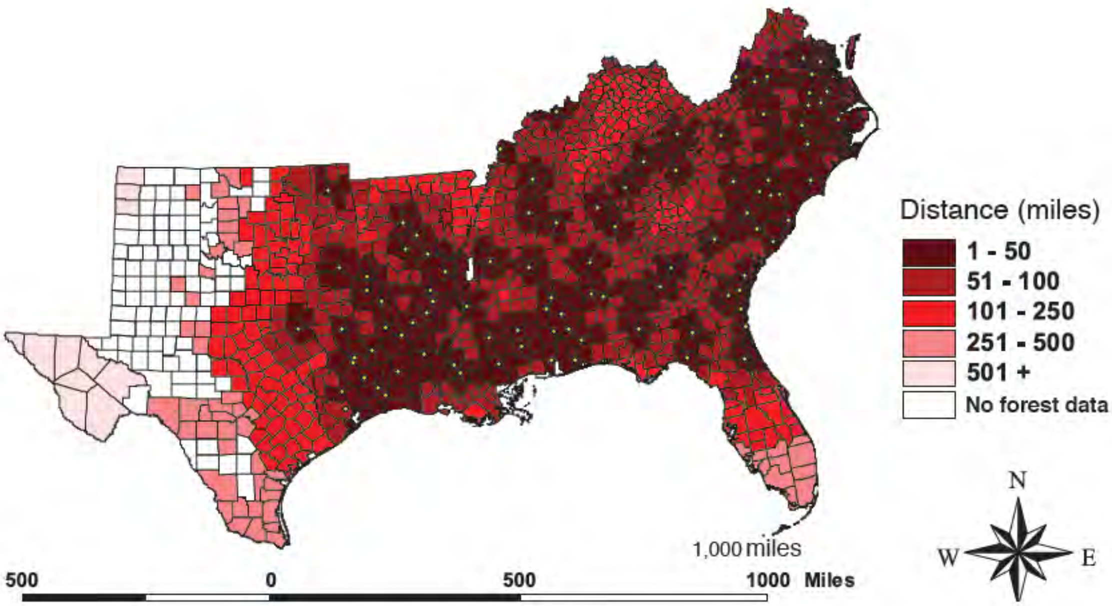


Figure 9.6—Distance in miles from the forested centers of southern counties to the closest pulpmill or chipmill, with yellow dots marking pulpmills and chipmills. (Source: Wear and others 2007)

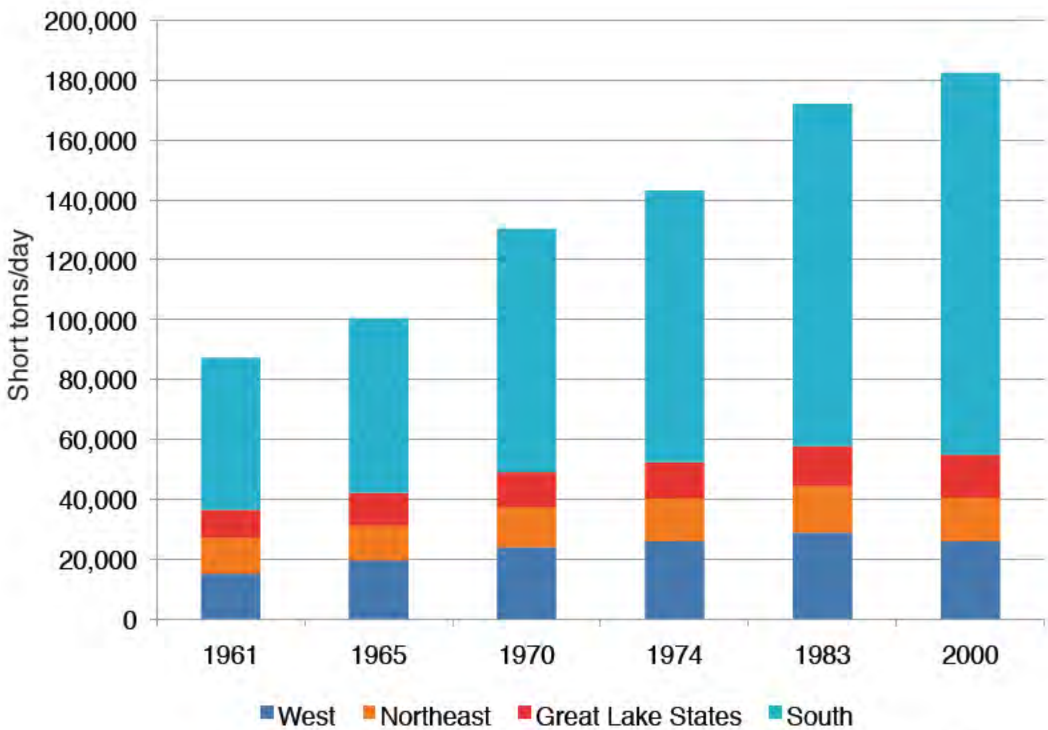


Figure 9.7—U.S. pulp output processing capacity, 1961 to 2000. (Source: Smith and others 2003)

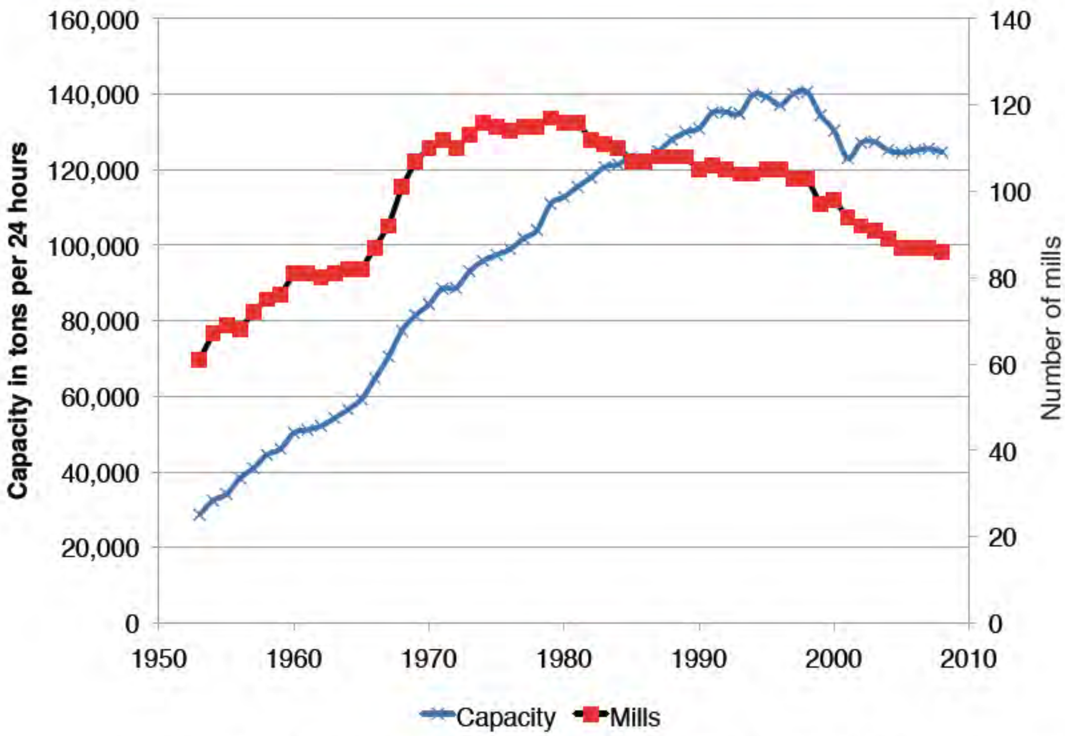


Figure 9.8—Pulpmills and pulpmill capacity (tons per 24-hour period), 1953 to 2008. (Source: Johnson and others 2010)

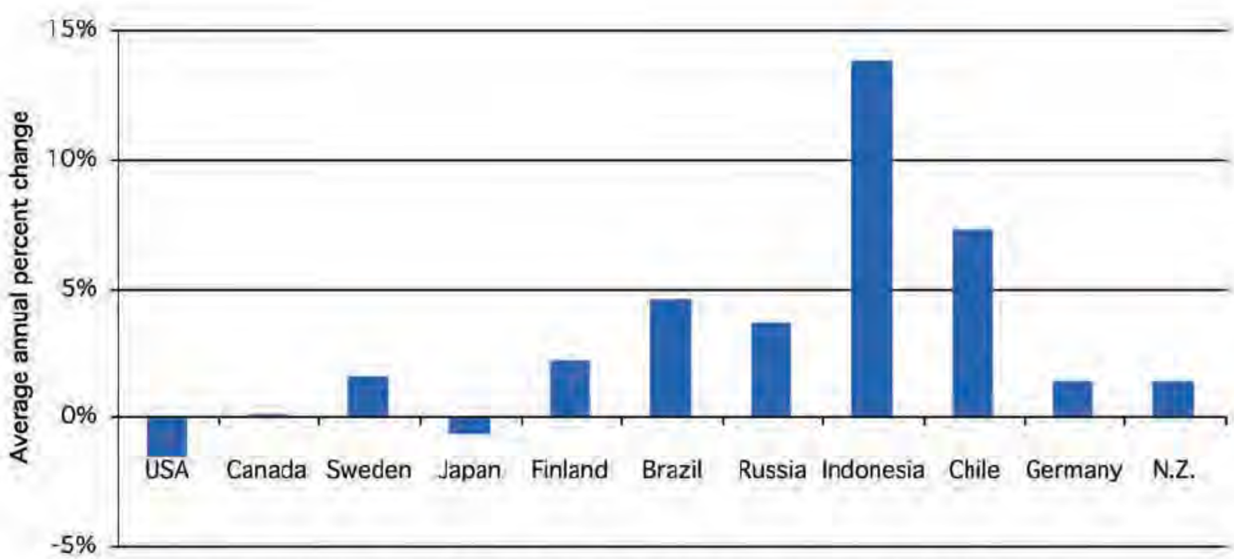


Figure 9.9—Average annual rates of change in pulp production for various countries, 1995 to 2002. (Source: FAO forestry database accessed at: http://faostat.fao.org/DesktopDefault.aspx?PageID=626&lang=en#ancor)

final product markets, which controls transportation costs. Other contributing factors include the shrinkage of U.S. manufacturing, which requires paper for packaging, and the demand for pulpwood in products like oriented strand board.

Manufacturing costs for kraft linerboard (fig. 9.10) provide an example of differences in comparative advantage among regions and countries. The South is competitive in this market compared to the Western United States, Canada, and Europe, but its cost structure lags behind Latin American countries (primarily Brazil and Chile), mainly because fiber and labor costs are significantly lower in less industrialized countries. The South retains comparative advantage because of its proximity to U.S. demand centers (thereby lowering transportation costs), but labor and wood cost differentials make Latin American producers viable competitors.

In 1995, 1999, and 2004, both Brazilian and Chilean producers could deliver softwood and hardwood (mostly Eucalyptus) pulpwood to mills at substantially lower cost than producers in the South (fig. 9.11). In 2004, delivered southern softwood pulpwood was 24 percent higher than in Brazil (21 percent for hardwood pulpwood) and 27 percent higher than in Chile (27 percent for hardwood pulpwood). Price differentials are not static however, and prices in Brazil and Chile have risen since 1999. The comparative advantage held by these nations would decrease if this trend were to continue.

Demand Trends for Solid Wood Products

The large majority of the solid wood produced in the South goes into lumber and panel products, comprising about 52 percent in 2006. The region's lumber mills, unlike its pulp and paper mills, are widely dispersed (fig. 9.12). Southern softwood sawmill capacity grew steadily from 1995 to 2005 and then declined slightly through 2009 (Spelter and others 2009), mirroring a strong decline in lumber production associated with the decline in U.S. housing construction (fig. 9.13). Comparable data are not available for hardwood lumber capacity in the South.

McKeever and Spelter (1998) report that southern panel capacity expanded significantly in the 1990s (fig. 9.14). From 1998 to 2009, oriented strand board capacity nearly doubled (APA-The Engineered Wood Association 2010) from 7,900 to 13,840 square feet (3/8-inch basis), representing 81 percent of total U.S. capacity. In contrast, southern pine plywood, which dominated panel production through the 1970s, peaked in the 1990s and has since declined (APA-The Engineered Wood Association 2010). At the 1996 peak, plywood capacity was 14,530 million square feet (3/8-inch basis) but fell to 9,190 square feet by 2009 (APA-The Engineered Wood Association 2010). Capacity for medium density fiberboard production grew strongly through the 1990s.

More recent data indicate that although southern panel production remained stable from 1996 to 2007 and fell precipitously in 2008/ 2009 because of the 2007 recession and housing market collapse, oriented strand board as a share of production has continued to grow (fig. 9.15). Expanding oriented strand board capacity coupled with declining plywood capacity suggests increasing demand for less expensive, small-diameter timber, especially when compared to the veneer logs used in plywood production.

Unlike the demand for paper products, which is most clearly linked to general levels of economic activity, notably manufacturing activity, demand for solid wood products is strongly linked to the construction industry. Housing starts in particular provide a strong correlate to the consumption of solid wood products, and recent economic developments are a strong reminder that the housing market is cyclical. Peaks in housing starts in the early 1970s, in the late 1970s, in the mid-1980s, and in 2006 have all been succeeded by rapid declines of at least 30 percent (fig. 9.16), with these cycles centering on a base level of about 1.5 million units per year. Within this context, the most recent decline and continuing stagnation of housing markets is unprecedented. After exceeding 2 million units in 2005, housing starts fell to 554,000 units in 2009 and (as projected) 619,000 units in 2010 (fig. 9.16), compared to lows that had not dipped below 1 million from 1959 to 2007.

The Congressional Budget Office has constructed alternative forecasts of construction activity recovery from the current housing trough that incorporate existing housing stocks, population growth, household formation, depreciation, and employment. The forecasts predicted that housing starts could return to between 1.2 and 1.5 million units by 2012 (Congressional Budget Office 2008), a trend that longer term forecasts predicted would continue. From the perspective of a long run analysis, this forecasted stability suggests recovery and subsequent stability in demand for solid wood products used in construction. In addition, the expansion in the overall number and age of existing residences may bring increased upkeep and repairs, stimulating a gradual expansion in demand for wood.

More recent data indicate that the recovery of construction activity projected by the Congressional Budget Office has yet to be realized. In March 2011, the U.S. Census Bureau (2011) estimated new private housing starts at a seasonally adjusted 479,000 units, considerably lower than the housing starts recorded in 2009 and 2010. The time-path of a recovery in housing influences the future of solid wood products demand. With a sustained suppression of housing demand, solid wood processing would likely shrink, eventually resulting in structural changes in these markets. Although necessarily difficult to predict, the implications of sustained suppression might include sustained declines in production

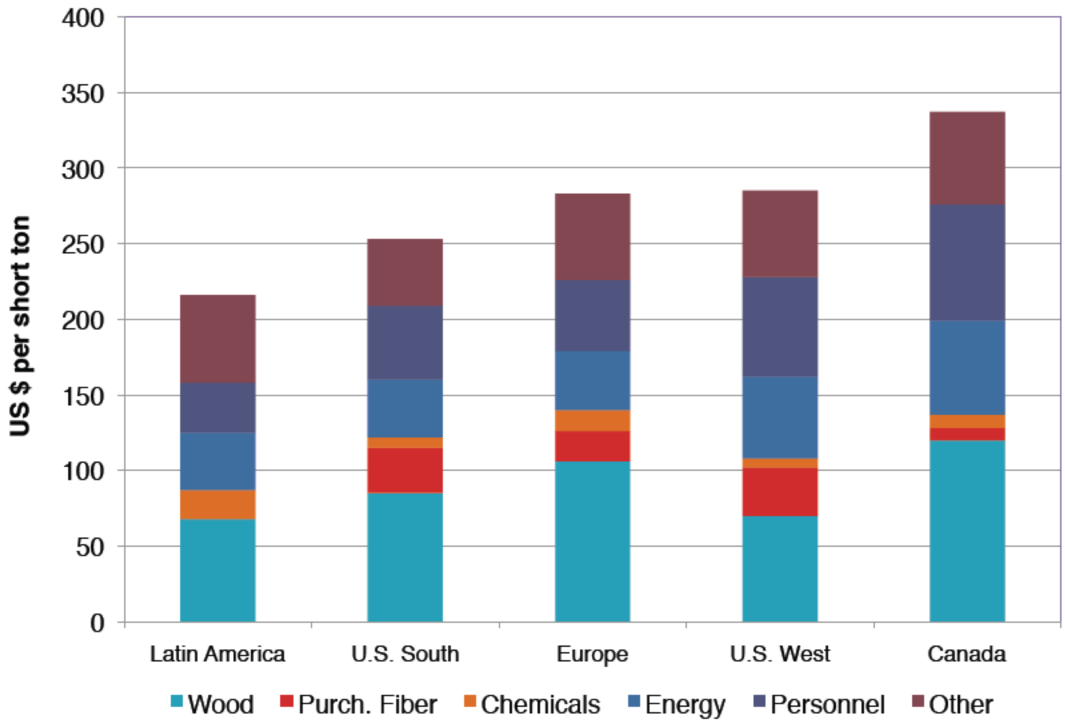


Figure 9.10—Kraft linerboard mills manufacturing costs, 2003. (Source: TAPPI, data available at http://www.tappi.org/Downloads/unsorted/UNTITLED-05EPE35pdf.aspx)

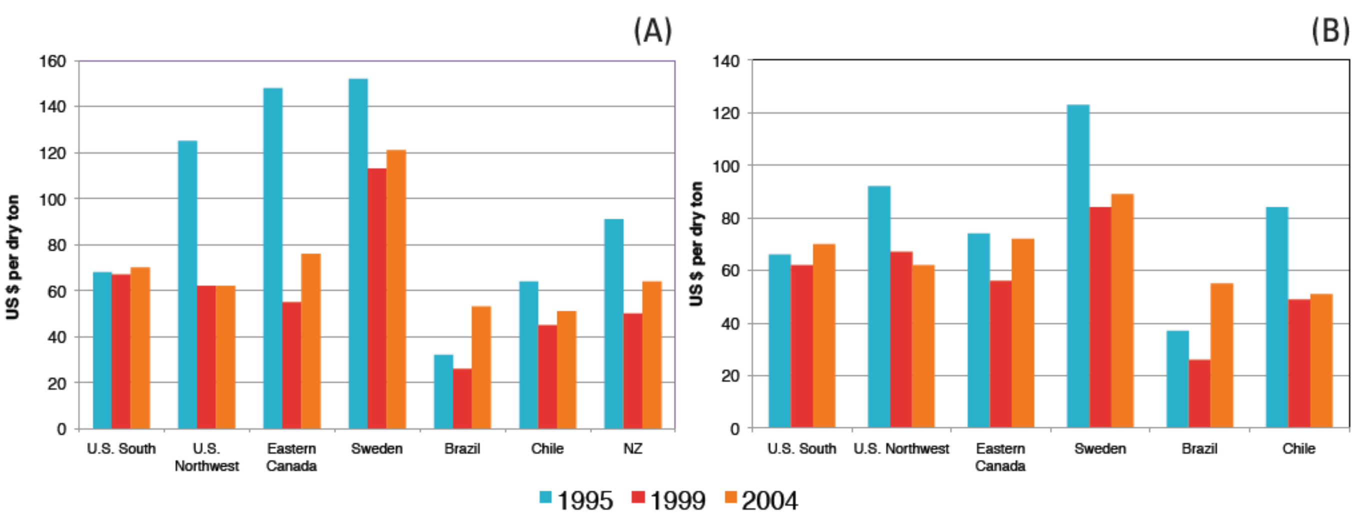


Figure 9.11—Third-quarter prices for (A) delivered softwood pulpwood and (B) delivered hardwood. (Source: TAPPI, data available at http://www.tappi.org/Downloads/unsorted/UNTITLED-05EPE35pdf.aspx)

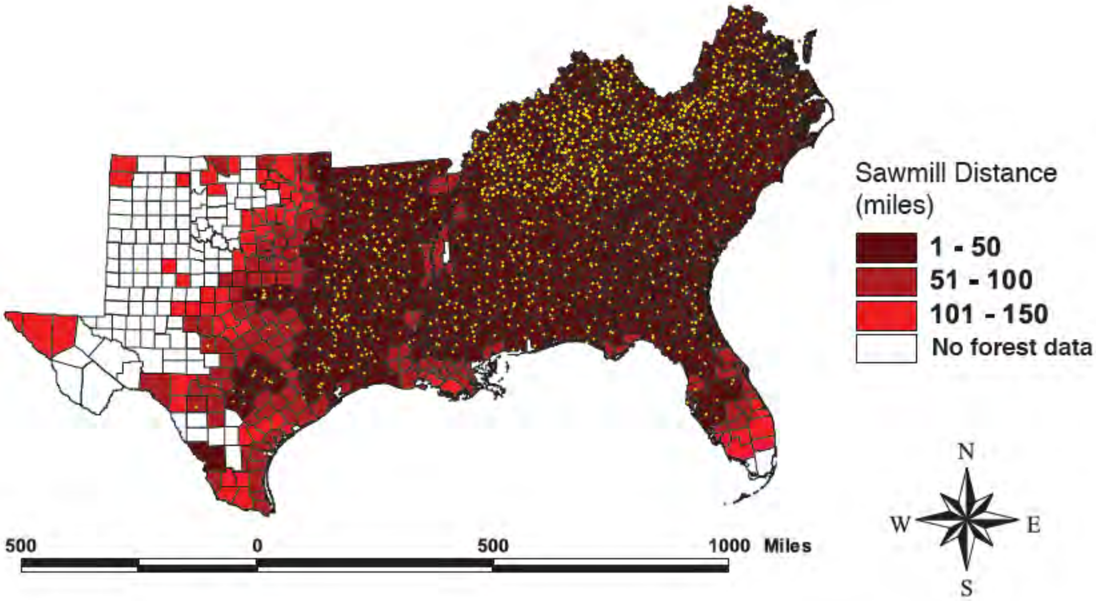


Figure 9.12—Average distance in miles by southern county from the forested center of the county to the closest five sawmills within 150 miles, with yellow dots representing sawmills; note that the universe of all sawmills within the United States were used in the distance calculation. (Source: Wear and others 2007)

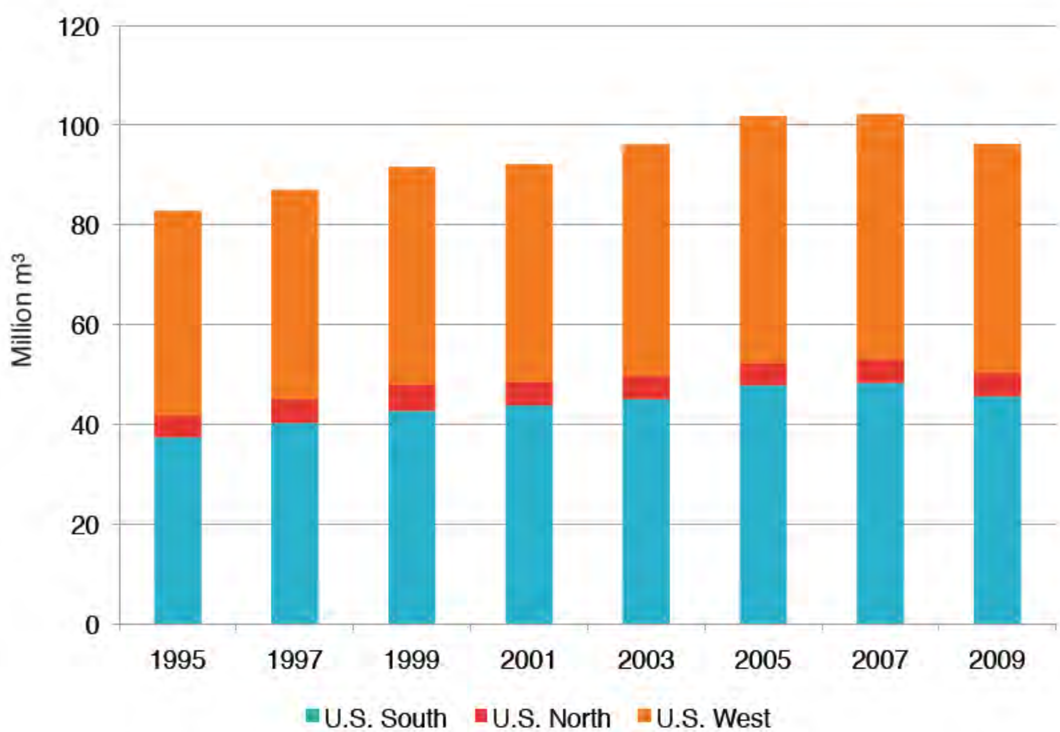


Figure 9.13—Softwood sawmill capacity by U.S. region, 1995 to 2009. (Source: Spelter and others 2009)

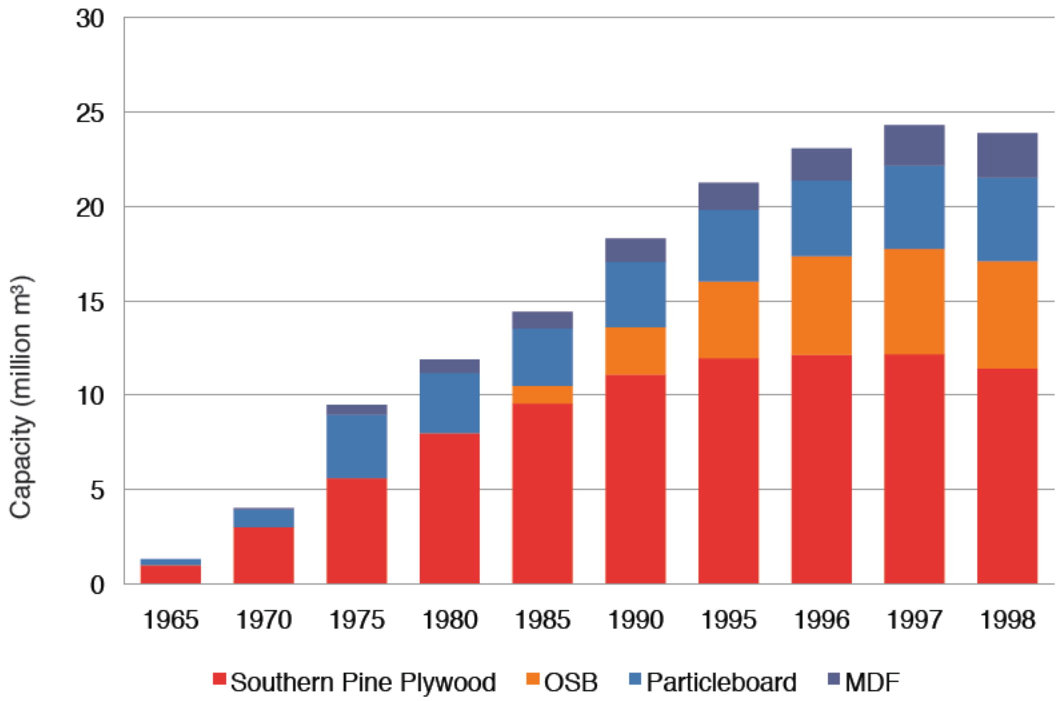


Figure 9.14—Panel capacity in the South. (Source: McKeever and Spelter 1998)

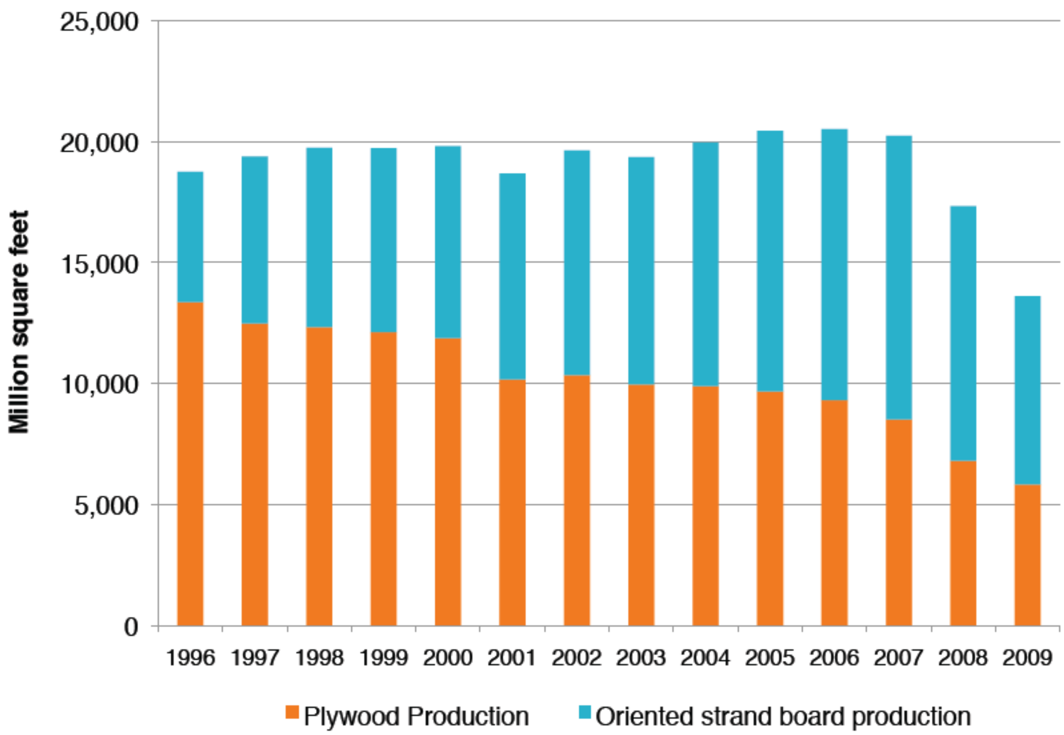


Figure 9.15—Southern panel production, 1996 to 2009. (Source: APA-The Engineered Wood Association 2010)

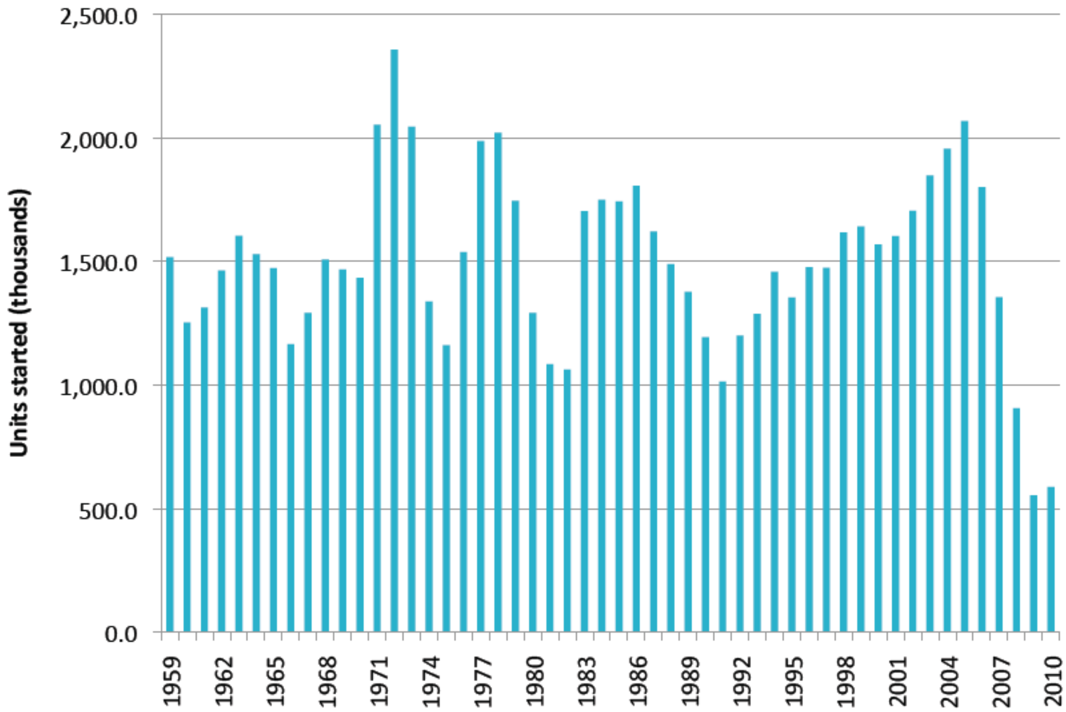


Figure 9.16—New privately owned housing units started in the United States, 1959 to 2010; note that 2010 value is based on projections using data through September 2010. (Source: U.S. Census Bureau, New Residential Construction Data, available at http://www.census.gov/construction/nrc/)

capacity, acceleration of changes in engineered wood products, or even shifts in the location of future production. Recovery of housing demand remains a critical short run uncertainty in forecasting U.S. wood product demand.

Product Substitution and Timber Demand

Wood is one of the many commodities that are used to produce final consumer products such as homes or paper and related products. Therefore, the demand for wood products is derived from the demand for final products into which they are a material input. Wood products compete with other construction inputs such as concrete, steel, aluminum, plastics, or other fibers. We therefore need to account for these commodities when evaluating changes in wood products markets. We also need to account for the continued growth in the use of engineered wood products, such as oriented strand board, which can utilize smaller diameter trees, as substitutes for traditional wood products.

The potential for substitutions between timber and other materials depends on the level of technology and relative prices of competing material inputs. Substitution away from paper for personal products (e.g., tissue) may be limited, but competition from plastic bags has clearly reduced demands for paper bags in the United States. The use of electronic media has similarly substantially reduced demands for newsprint.

Even during the rapid growth phase of 1986 to 1998, use of lumber in the United States did not grow at the same rate as housing starts. Increasing prices of timber compared to steel and cement resulted in substitutions during the last few decades of the 20th century. Very recent upturns in cement and steel prices may portend a moderating or reversal of substitutions (fig. 9.17). Although many factors contribute to price differences among raw materials, energy prices will have a strong influence on the future competitive position of wood. Generally, energy costs associated with production of steel and cement are higher than those associated with production of solid wood construction materials. It is therefore possible that recent upsurges in energy prices could have a positive influence on demand for domestically produced construction wood, relative to its substitutes.

Changing shares of construction inputs reflect shifting prices of non-wood and wood substitutes compared to solid wood. From 1995 to 1998, lumber lost market share in construction

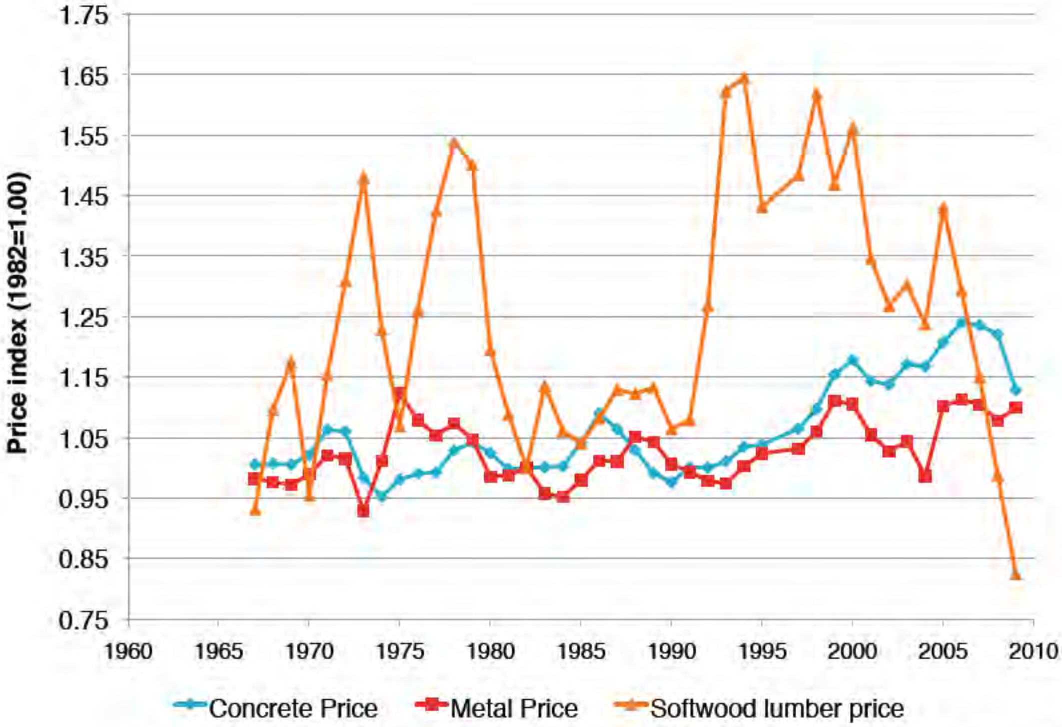


Figure 9.17—Real producer price indices (PPI) for concrete products, structural metal products, and softwood lumber products, 1967 to 2009; indices are constructed by dividing the PPI for each commodity by the all-commodity PPI with a base year of 1982. (Source: U.S. Department of Labor, Bureau of Labor Statistics, Producer Price Index data by commodity, available at: http://www.bls.gov/ppi/data.htm).

generally, and slid from 93 to 83 percent in wall framing (Fleishman and others 1999). Most of these losses could not be attributed to non-wood substitutes, but instead, to engineered wood products—laminated beams, wood I-joists, and laminated veneer lumber (fig. 9.18)—and somewhat to steel, reinforced concrete, and wood-plastic lumber. From 1991 to 2005, laminated veneer lumber production grew with no instances of decline in its market share, although since 2005 its use has declined significantly, along with glulam and I-joists. Lumber also lost market share in roof and floor applications during the 1990s (Fleishman and others 1999). All of these changes demonstrate the wide variety of solid wood products and the key roles played by technological innovation in determining wood use in both the past and the future.

Substitution away from forest products is only one explanation of reduced market share for U.S. forest products (Fleishman and others 1999; Zhang and Buongiorno 1997, 1998). Other determining factors were import increases, technological change, and evolving consumer preferences. In paper manufacturing, for example, information technology continues to shift news coverage away from newspapers and toward electronic media, with important implications for paper demand. In addition, the decline in demand for unbleached kraft pulp and other softwood pulpwood products is partially because of recent steep declines in U.S. paper bag manufacture and consumption.

Influences of International Trade on Demand

The United States is the world's largest importer and producer of forest products and the second largest exporter (fig. 9.19). Imports and exports of raw and value-added forest products can directly affect U.S. demand for timber, with increased imports often reducing demand and helping to depress domestic stumpage prices both in the short and long run.

Trade in forest products needs to be viewed in the context of international economic conditions. Although there are many reasons for changes in trade flows, the increase in imports and rising U.S. trade deficit in forest products during the 1990s was likely tied to the rising value of the dollar relative to foreign currencies (fig. 9.20). Economic doctrine suggests that exports increase and imports decrease when a domestic currency weakens. Since 2002, the relative value of the dollar declined, which suggests that the position of U.S. manufacturers improved.

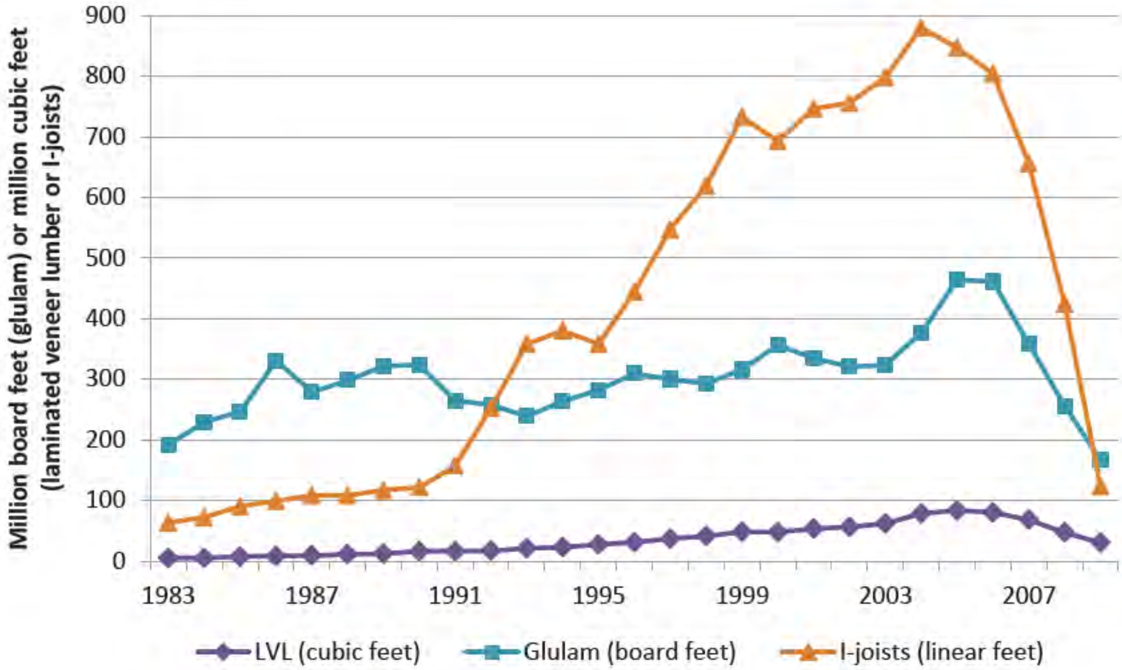


Figure 9.18—Production of engineered wood products, 1983 to 2009. (Source: APA-The Engineered Wood Association)

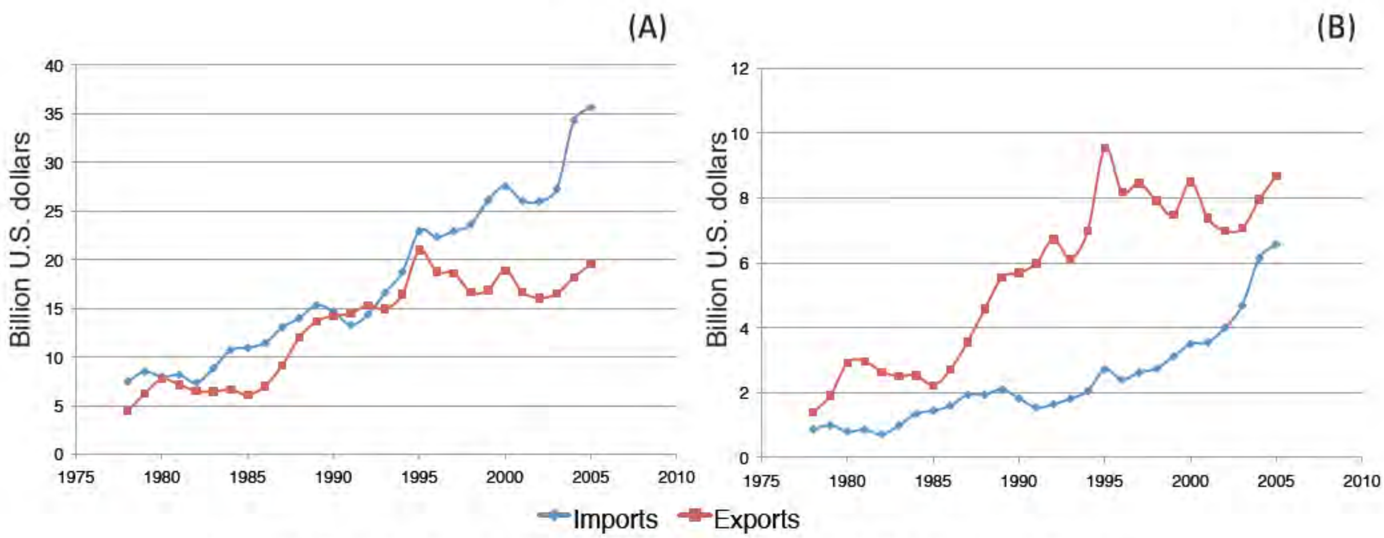


Figure 9.19—Total value of wood products imports to and exports from (A) the United States and (B) southern customs districts, 1978 to 2005. (Source: U.S. Department of Commerce, as reported by Daniels 2008)

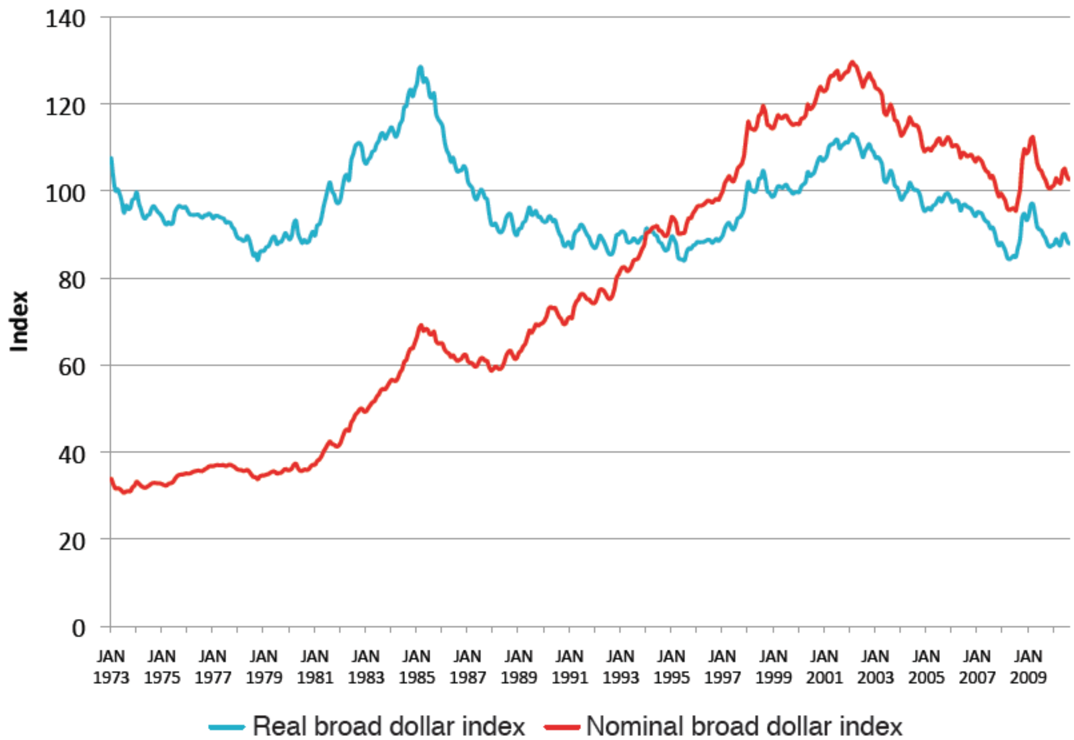


Figure 9.20—U.S. broad dollar index, 1973 to 2009. (Source: U.S. Federal Reserve)

However, changes in exchange rates take time to alter trade flows, and some evidence suggests that exchange rate shifts have only a small long run effect on forest products trade, because other production costs and supply-and-demand factors adjust to accommodate them (Uusivuori and Buongiorno 1991).

Wood pulp—Although the overall U.S. balance of trade in wood pulp has been roughly even in recent years (with imports equaling exports), southern ports exported approximately 7 times what was imported (fig. 9.21). From 1989 to 2003, Canada was the largest and Brazil the second largest source of U.S. imported wood pulp. Brazilian imports into southern ports rose sharply since the early 1990s and account for nearly all imports. Still, overall imports into Southern States in 2004 only accounted for between 2 and 3 percent of total southern wood pulp consumption. For southern pulpwood producers, the level of Brazilian imports—primarily hardwood pulp—factors mostly into local markets and are used to meet specific furnish demands.

Wood chips—Unlike patterns of trade in wood pulp, patterns of trade in wood chips have changed substantially since the late 1980s. Until 2003, Canada was the leading source of imported U.S. wood chips, supplying pulp and paper manufacturers in the North. After peaking in 1997, Canadian wood chip sales to the United States have declined to less than a third of their peak level. Producers in the southern hemisphere have also supplied hardwood wood chips to the United States at various times (note that the level of softwood chip imports and exports is largely inconsequential). In the mid-1990s, Chile supplied as much as a third of total wood chip imports into the United States. In 2004, Brazilian imports increased more than fivefold compared to 2003, making Brazil the largest supplier of wood chips imported into the United States. Brazilian imports are delivered mainly to southern ports and account for nearly all the imports to southern ports (fig. 9.22). Imports represented only about 0.9 percent of total southern pulpwood consumption and about 3 percent of total southern hardwood pulpwood consumption in 2004. Most enter the United States at Mobile, AL, and a few ports in Florida, potentially having significant localized impacts on hardwood markets near these ports.

The surge in Brazilian chip imports is the expected response to domestic price increases resulting from local scarcity of hardwoods—recall that hardwood pulpwood prices remained high through the 2000s. In addition, Eucalyptus chips, a highly preferred fiber source for some paper grades, may out-compete native hardwoods for some applications. The extent to which hardwood chip imports from South America might increase over the coming years is unknown. However, it is likely that the price of chip imports from South America now

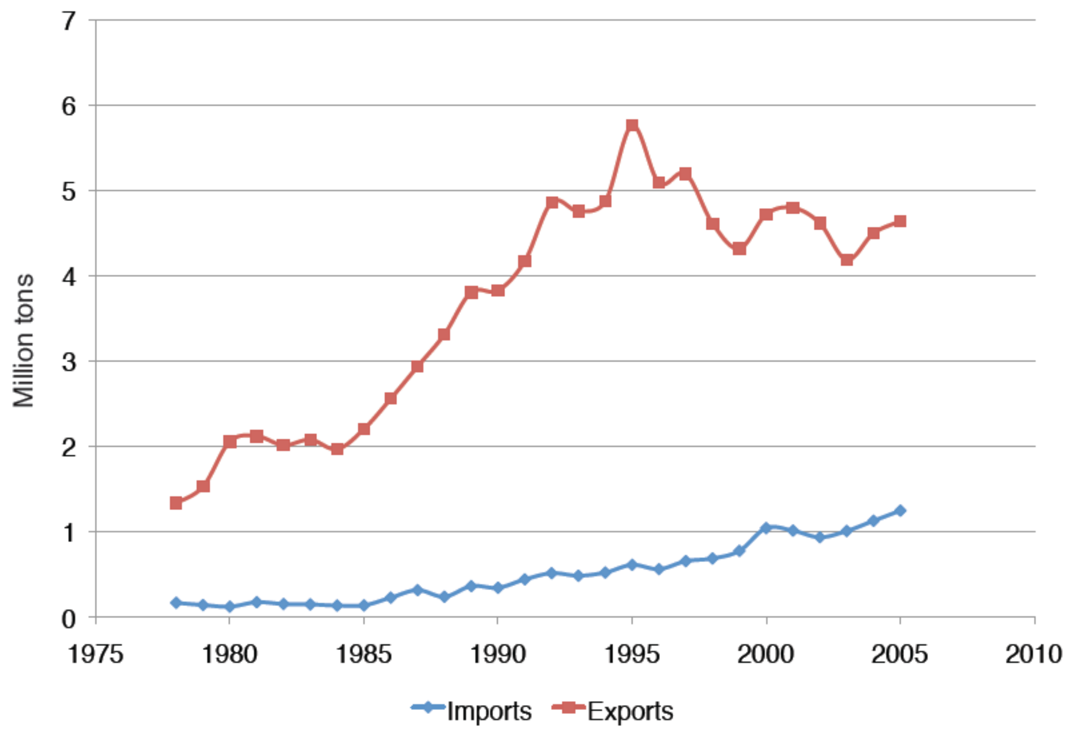


Figure 9.21—Wood pulp imports to and exports from southern customs districts, 1978 to 2005. (Source: U.S. Department of Commerce, as reported by Daniels 2008)

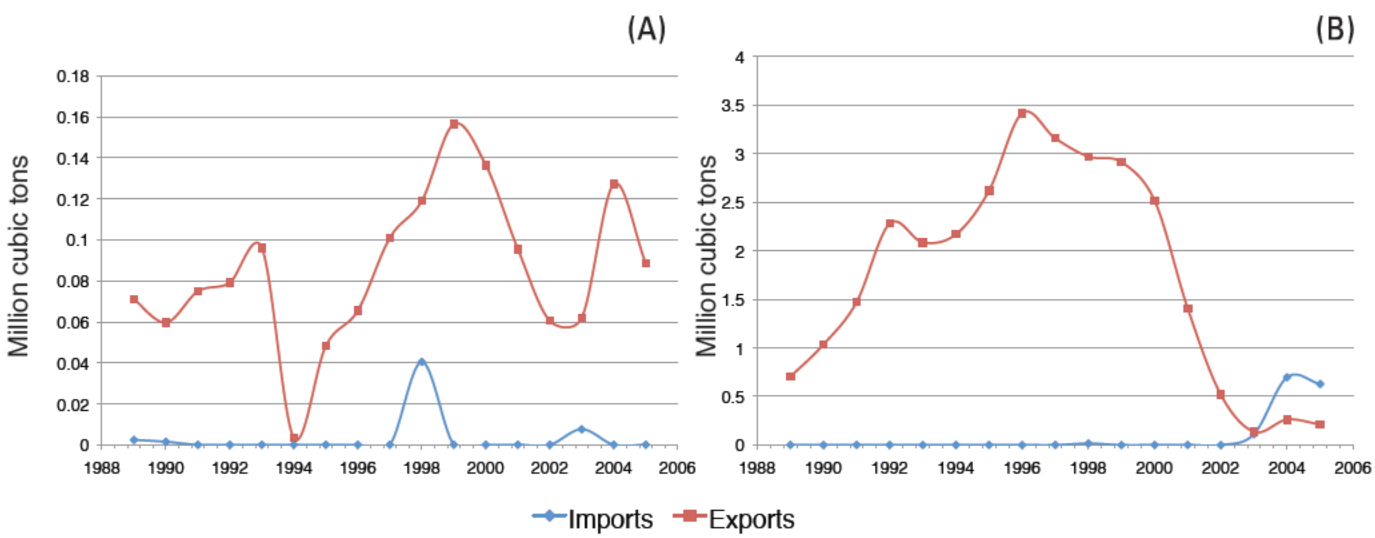


Figure 9.22—Southern customs district imports and exports for (A) softwood wood chips and (B) hardwood wood chips imports, 1989 to 2005. (Source: U.S. Department of Commerce, as reported by Daniels 2008)

defines a ceiling for domestic hardwood stumpage prices in certain areas of the South.

From the beginning of the data series (1989) to 2002, the United States has had a large trade surplus in wood chips (fig. 9.22)—with exports far exceeding imports. Since 1999, however, the trade surplus has fallen steadily, from around 3 million tons in the mid-1990s to less than 0.1 million tons in 2003. From 1991 to 2002, nearly all of the wood chips exported from U.S. southern ports were shipped to Japan.

By 2002, chip exports from southern ports essentially ceased. In 2003, the reduction in southern chip exports—primarily hardwood chips—to Japan was equivalent to 5 percent of total southern pulpwood production and nearly 16 percent of southern hardwood pulpwood production. With most of the trade in wood chips moving through Mobile, we might expect the economic impacts of reduced demand to be strongest in Alabama and to decline in an outward radiating pattern.

Lumber—Since the late 1980s, the United States has been a large net importer of softwood lumber, primarily from Canada (fig. 9.23). Lumber imports from South America, although relatively small from 1989 to 2004, have been rising steadily. Although the United States exports some lumber, the balance of trade favors imports, and the trade deficit is growing.

Imports of lumber from Canada have an important influence on all U.S. timber markets, but the effects on southern markets are likely to be indirect. Lumber from Western Canada more directly substitutes for lumber of species that grow in the Western United States (Nagubadi and others 2004), and imports are generally not directly substitutable for the treated lumber produced in the South.

In 2004, the United States led all other temperate countries in producing (60 percent) and consuming (52 percent) hardwood lumber, with about 8 percent of domestic production exported. Hardwood lumber is a much more heterogeneous commodity than softwood lumber, so its production and trade serves a wide variety of end uses—from flooring to furniture to shipping pallets—and aggregate data provide only a very general description of trends. Note that about 10 percent of U.S. hardwood exports are from the Pacific Northwest (especially red alder) compared to about 90 percent from the Eastern United States.

Exports of hardwood lumber from the South increased from about 0.4 million m^3 in 1989 to just over 1.2 million m^3 in 2004 (fig. 9.23)—mostly to other North American countries, followed by East Asia and the 27 countries of the European Union (see fig. 9.24), and with about 10 percent going to all other countries combined. The distribution of exports among these destinations has changed somewhat since 1989, with shipments to Europe declining and shipments to other Canada and Mexico increasing substantially (fig. 9.24). Shipments to East Asia have been essentially constant in aggregate, with a changing mix of individual country destinations and large increases in shipments to China offset by decreases in shipments to other Asian countries. The 2007 recession led to a strong decline in total hardwood exports with the distribution among destinations remaining relatively constant (fig. 9.24).

Southern exports of softwood lumber have been relatively small and have declined over the last decade (fig. 9.25), falling to about a third of 1992 levels in 2004 and now representing only 1 to 2 percent of total production.

Panels—Trade in panel products is weighted toward imports, with about 15 percent of plywood consumption and 38 percent of oriented strand board consumption imported from Canada and other countries in 1999 (Spelter 2001). Particleboard, waferboard, and oriented strand board imports from Canada grew strongly through the mid-2000s, increasing from $1.53 billion in 1999 to $3.16 billion in 2004, before decreasing substantially at the end of the decade (APA-The Engineered Wood Association 2010) U.S. exports of panels cannot be considered negligible, although they are substantially lower than imports. For example, in 2009, plywood exports were 482 million square feet (3/8-inch basis) compared to 616 million square feet for imports. Oriented strand board trade has been significantly more imbalanced, tilted toward imports (APA-The Engineered Wood Association 2010).

Oriented strand board markets expanded through the mid-2000s. North America will likely continue to dominate World production in this commodity class, but the trade balance within North America—especially between Canada and the United States—could change with market expansion. In addition, a decline in demand for southern pulpwood could offer a competitive mill-siting advantage to U.S. manufacturers.

Overall, we see no dramatic change in international markets that would strongly affect southern timber demand in the short run. At the national level, the value of wood products imports exceeds exports so the wood products balance of trade is negative. For southern ports, the wood products balance of trade is positive, but a small share of total production.

Timber Supply Trends

Overall, changes during the adjustment phase (1997 to 2009) indicate some important changes in supply. An expanded supply of softwood pulpwood timber coupled with

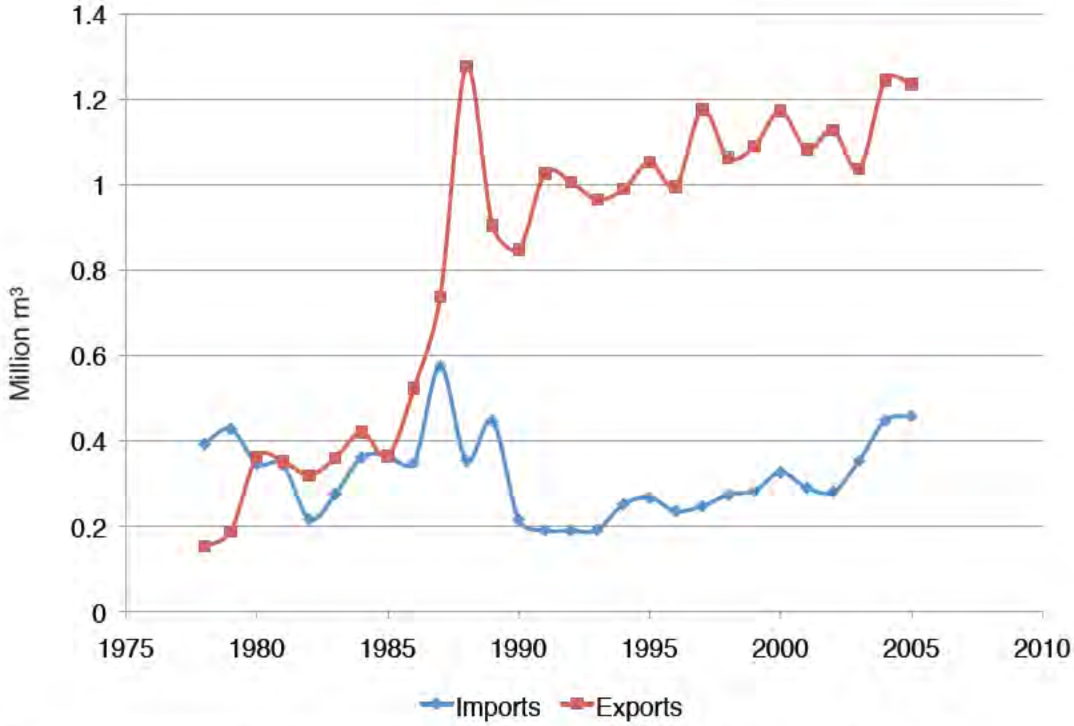


Figure 9.23—Hardwood lumber imports to and exports from southern customs districts, 1978 to 2005. (Source: U.S. Department of Commerce, as reported by Daniels 2008)

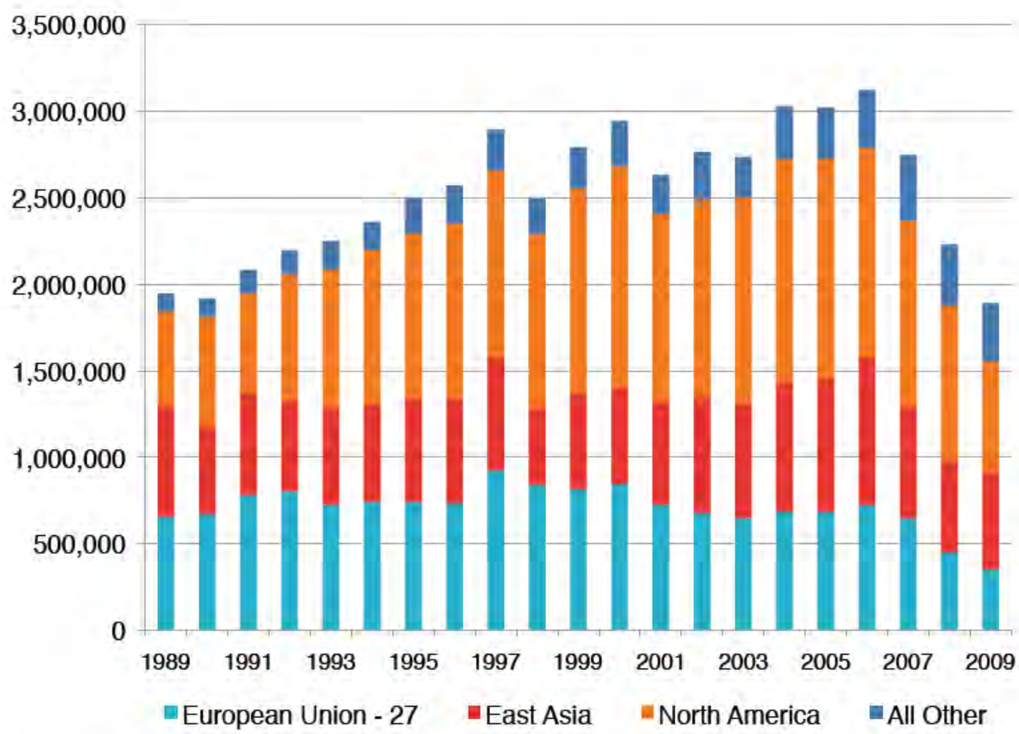


Figure 9.24—Exports of U.S. hardwood lumber to various regions, 1989 to 2009.

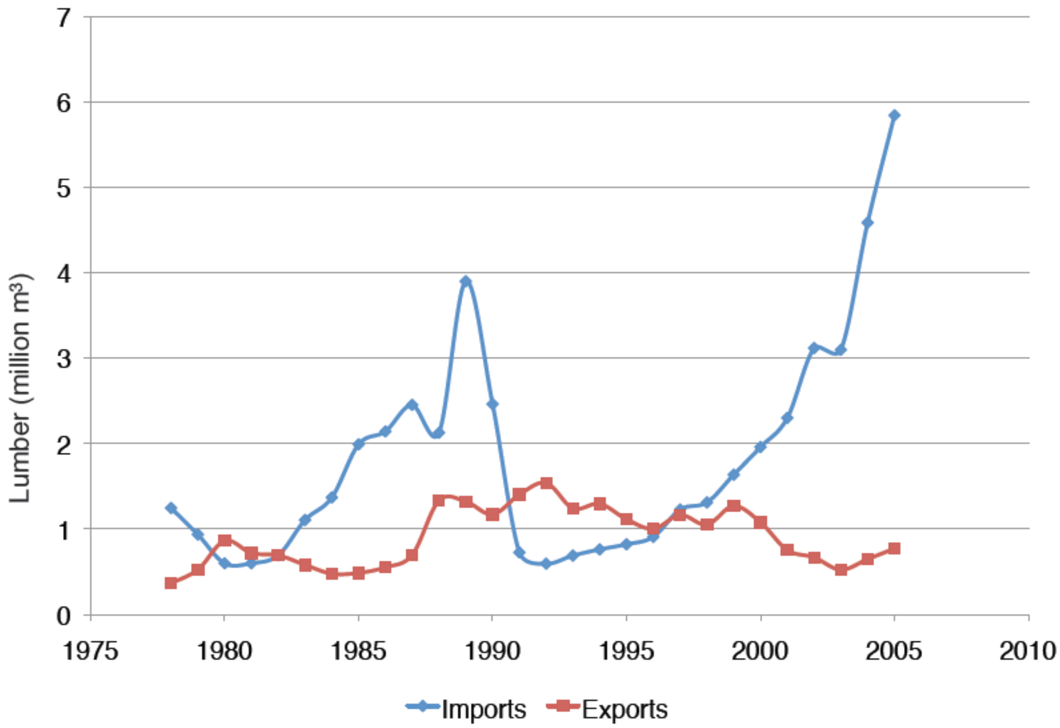


Figure 9.25—Softwood lumber imports to and exports from southern customs districts, 1978 to 2005. (Source: U.S. Department of Commerce, as reported by Daniels 2008)

a sustained price reduction is consistent with earlier high levels of tree planting (at least through the mid-2000s). From 1999 to 2010, the area of planted pine increased from 32 to 39 million acres (more than 25 percent) as harvesting of softwood pulpwood declined and then flattened (fig. 9.5). This implies that supply of this product will continue to expand at least over the next 10 to 20 years as the new plantations mature. Price and harvest patterns for softwood sawtimber are not consistent with a decline in supply, indicating that demand shifts dominated this market.

In contrast, patterns for hardwood products indicate a tightening of supply. Hardwood pulpwood harvesting has declined steadily since 1998 as prices have risen, reducing supply. This decline in supply is consistent with a loss of manageable upland hardwood forests associated with expanding urban and suburban landscapes.

Timber Supply Forecasts

Fundamental factors that will influence the structure of supply include the area of land that remains or becomes forested, as well as the propensity of landowners to harvest their forests and invest in planting and management. The U.S. Forest Assessment System provides integrated projections of these factors and provides some insights into how overall supply might evolve in the future. The area of forests in the South is forecasted to decline over all of the Cornerstone Futures evaluated for the Futures Project (chapter 2) with losses ranging between 12 million acres (7 percent) and 23 million acres (13 percent) from 1997 to 2060 (chapter 5). These forecasts reflect a more than doubling of urban land uses, a range of timber price futures, and constant returns for agriculture.

The forecasts suggest a shift in the distributions of forest management types. The forecasted area of planted pine varies substantially across the Cornerstones, reflecting a variety of economic conditions and assumptions about the propensity to manage forests. Area of planted pine, which was about 39 million acres in 2010 or about 19 percent of total forest area, is forecasted to range between 47 million acres (24 percent) and 69 million acres (36 percent) in 2060, with all projections reflecting a reduction in the planting compared to the past 20 years (chapter 5). All other forest types are forecasted to decline, with steepest losses in natural pine forest area and steady losses in hardwood types. Declines in hardwood types are most strongly affected by urbanization; declines in the natural pine type are most strongly associated with timber harvesting and conversion to planted pines.

High GDP scenario—Projections of softwood timber supply for the High GDP future are shown in fig. 9.26. Softwood pulpwood supply is forecasted to change over the five decades of the projection. One important element of change

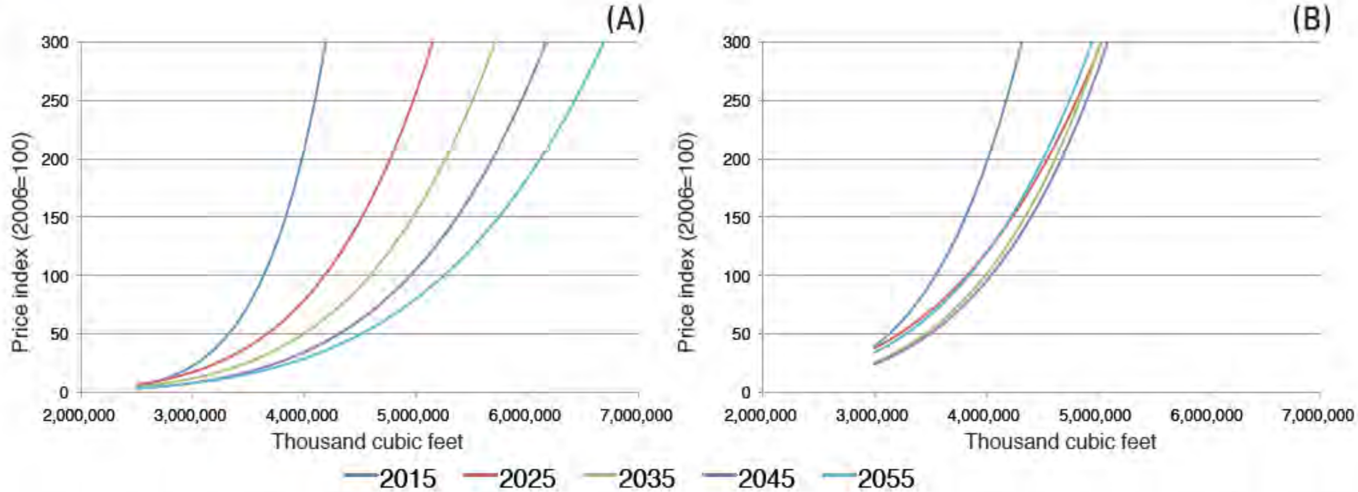


Figure 9.26—Projected softwood (A) pulpwood and (B) sawtimber timber supply curves, 2015 to 2055, associated with high Gross Domestic Product futures.

is that supply becomes more elastic over time, shifting from an own-price elasticity of 0.13 in 2015 to about 0.22 in 2055, consistent with more supply being derived from planted pine forests than from current demand. The net effect is a steady expansion in the supply function over time. To illustrate, if real prices of softwood pulpwood are held constant over time, harvesting would increase by about 17 percent by 2025 and by 44 percent by 2055. A doubling of prices (to an index value of 200) to near-1990s levels would yield an increase in harvesting of about 69 percent by 2055. Projected growth in softwood pulpwood supply reflects both the expansion in plantations since 1999 and a modeled continuation of expansion in planted pine.

Softwood sawtimber supply also expands, but only until 2025 (fig. 9.26), and the change in elasticity is smaller, ranging between 0.18 and 0.23. With constant real prices, softwood sawtimber harvesting would increase about 6 percent by 2025 and 8 percent by 2055. A doubling of prices would yield a 14-percent increase in softwood sawtimber harvests in 2055. Softwood sawtimber supply shifts as existing inventories mature and more natural pine forests are replaced by planted pines.

Projections of hardwood timber supply differ from the softwood projections (fig. 9.27). Hardwood pulpwood supply expands slightly from 2015 to 2025 (becomes less inelastic) but then begins to contract over the remainder of the projection period. Constant prices would decrease harvesting by about 6 percent from 2015 to 2055, and a doubling of prices would result in a 16-percent increase. Hardwood sawtimber supply shows a similar pattern, with an increase in elasticity through 2025, followed by a steady contraction over the remainder of the projection period. Constant prices would decrease harvesting by 3 percent from 2015 to 2055, and a doubling of prices would result in a 22-percent increase. Under High GDP scenarios then, hardwood supply does not change in any appreciable way after 2025.

Low GDP scenario—Projections of supply for the Low GDP future (figs. 9.28 and 9.29) are similar to High GDP, but the magnitude of change is smaller. For example, with constant prices, softwood pulpwood supply would be about 20 percent lower for Low GDP, and hardwood supply would be slightly higher reflecting less urbanization (and greater areas of hardwood forest types).

The Enhanced Productivity scenario shows the effect of a 50-percent increase in productivity for planted pine forests by 2055. Under this scenario, the supply functions for softwood pulpwood would expand by a substantial amount (fig. 9.30). With prices held constant, pulpwood harvesting would increase by about 75 percent; a doubling of price would nearly double harvesting. Softwood sawtimber supply would also expand, with increased production of chip-and-saw products from planted pine forests.

Recent changes in ownership—Most notably the transfer of vast forest holdings from the forest products industry to timber investment management organizations and real estate investment trusts, but also the gradual transitions in family forest ownership—suggest that owner preferences could shift substantially in the future. Although no associated changes in management approaches and investment patterns have been detected yet, this is a key and unaddressed source of uncertainty in our analysis. Chapter 6 provides a discussion of ownership transitions and the potential implications for forest management and conditions.

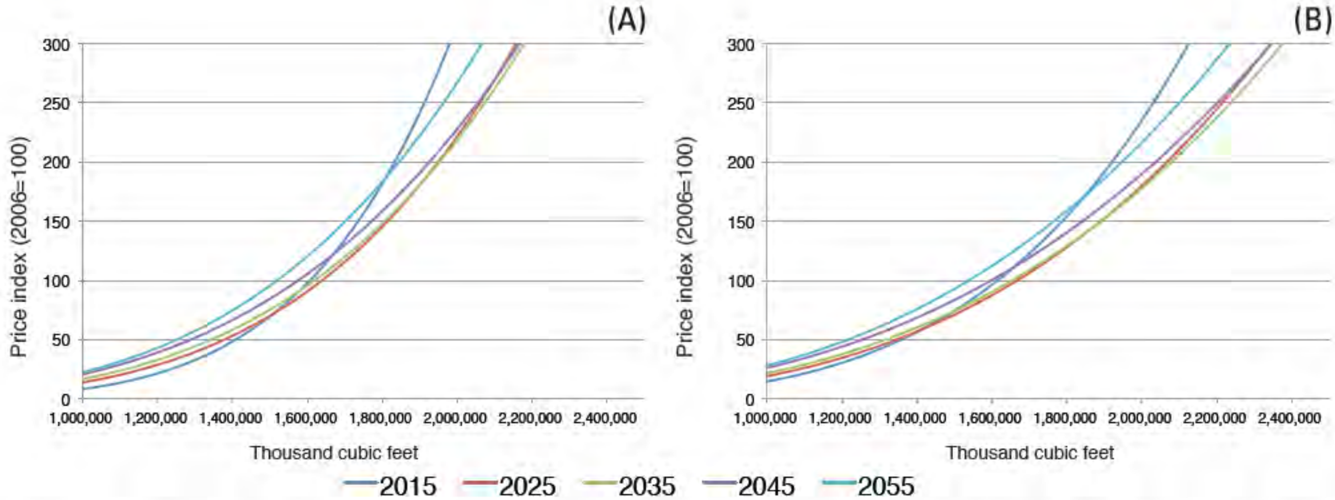


Figure 9.27—Projected hardwood (A) pulpwood and (B) sawtimber timber supply curves, 2015 to 2055, associated with high Gross Domestic Product futures.

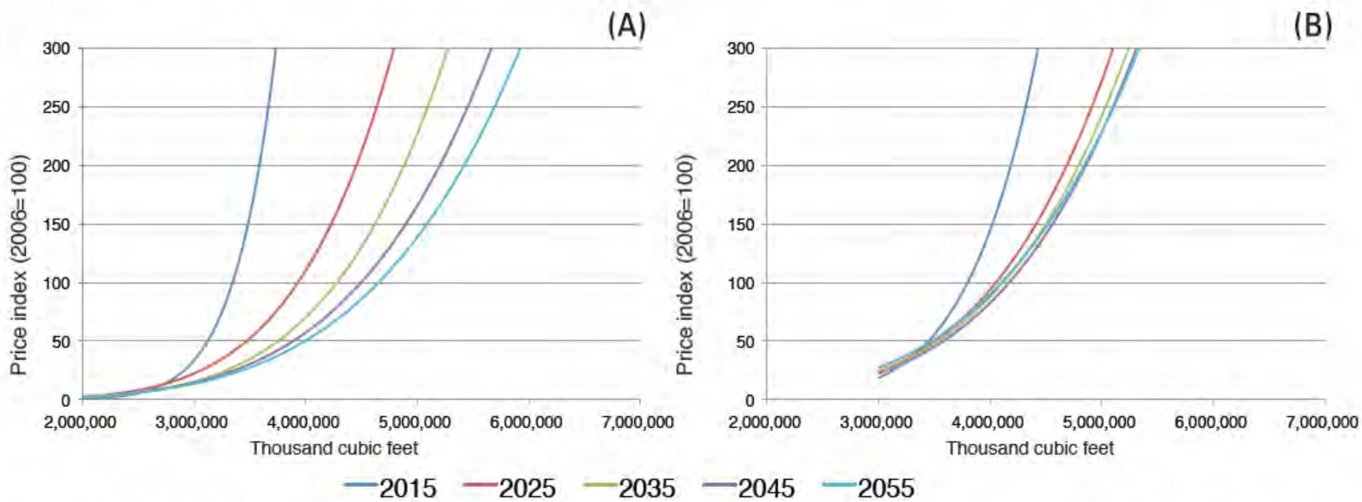


Figure 9.28—Projected softwood (A) pulpwood and (B) sawtimber timber supply curves, 2015 to 2055, associated with low Gross Domestic Product futures.

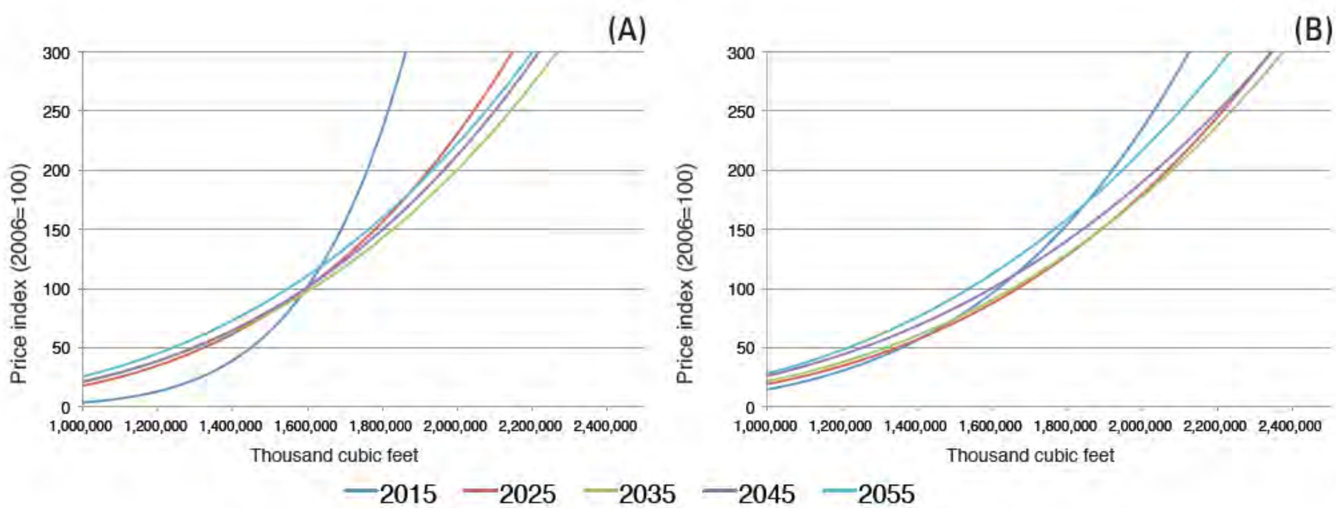


Figure 9.29—Projected hardwood (A) pulpwood and (B) sawtimber timber supply curves, 2015 to 2055, associated with low Gross Domestic Product futures.

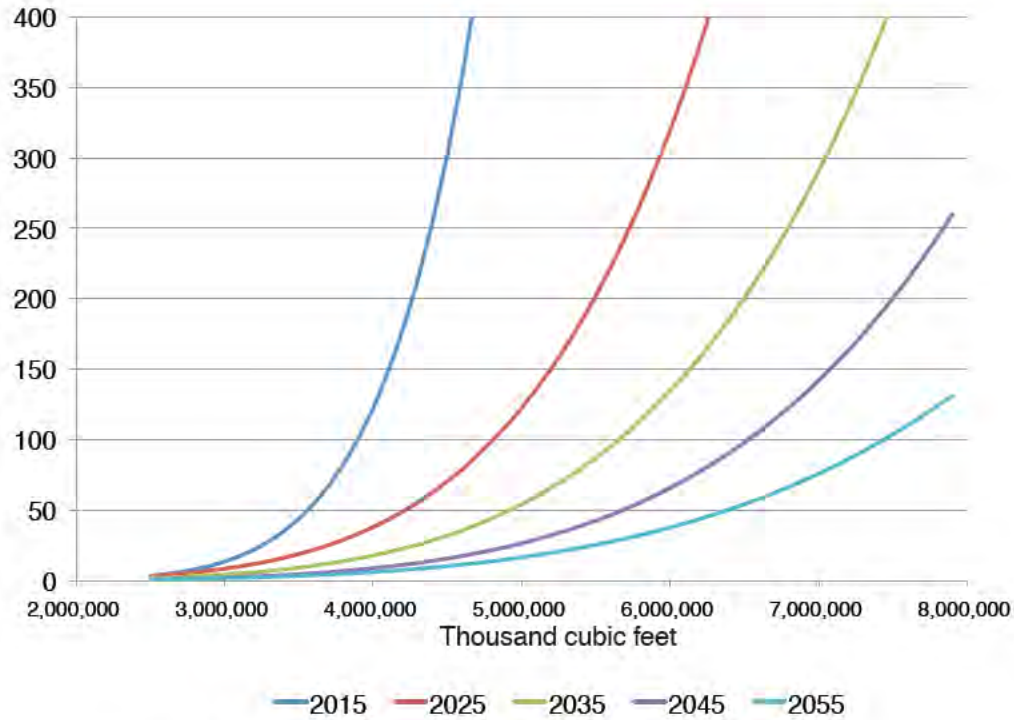


Figure 9.30—Softwood pulpwood supply projections under enhanced productivity.

Market Forecasts

The interaction of supply and demand defines current and future timber harvesting and timber prices. In forecasting future timber markets for the South, we compared the timber supply relationships developed from the U.S. Forest Assessment System (figs. 9.26–9.29) with two different assumptions about forest product demand. Recall that we model three different supply scenarios: a High GDP case based on the strong economic and moderate population growth projections of Cornerstones A and B (A1B storyline in the 2010 RPA Assessment); a Low GDP case based on the weak economic and low population growth projections of Cornerstones C, D, and F (B2 storyline in the 2010 RPA Assessment); and an Enhanced Productivity case based on High GDP and the 50-percent productivity increase from planting pines over the 50 years (Cornerstone E).

Standing timber harvest and price forecasts for the Constant Demand/High GDP supply scenario are shown in figure 9.31. Over the next 50 years, harvesting would increase by about 27 percent from the 2006 level, with softwoods outpacing hardwoods and with a leveling off beginning in the 2030s. Softwood sawtimber prices would return to their 2006 levels by 2015 and then decline somewhat over the projection period. Softwood pulpwood prices would fall substantially as supply expands throughout the period, but hardwood pulpwood prices would remain relatively constant throughout. When the Constant Demand scenario is combined with Low GDP, harvesting patterns would be similar to High GDP, but prices would be somewhat higher (fig. 9.32). Also, somewhat more softwood sawtimber and somewhat less softwood pulpwood would be produced in the later years of the simulation.

Harvesting and price forecasts for the Expanding Demand/ High GDP scenario are shown in figure 9.33. Harvesting would expand throughout this forecasting period, with especially strong growth for both softwood products and for hardwood sawtimber. By 2055 harvesting would be about 43 percent higher than the 2006 level. Prices would rise, reflecting increased scarcity—about 120 percent for softwood sawtimber and 34 percent for hardwood pulpwood—and softwood pulpwood prices would return to about 80 percent of the 2006 level. Scarcity would increase for all forest products except softwood pulpwood.

Combining Expanding Demand with Enhanced Productivity yields qualitatively different results. Harvesting would increase by about 70 percent from 2006 to 2055 (fig. 9.34), with all additional production coming from softwood products. Softwood pulpwood harvesting would more than triple and its price would fall by about 50 percent. Harvesting of softwood sawtimber would increase by about 46 percent and its price would fall by about 27 percent. Hardwood

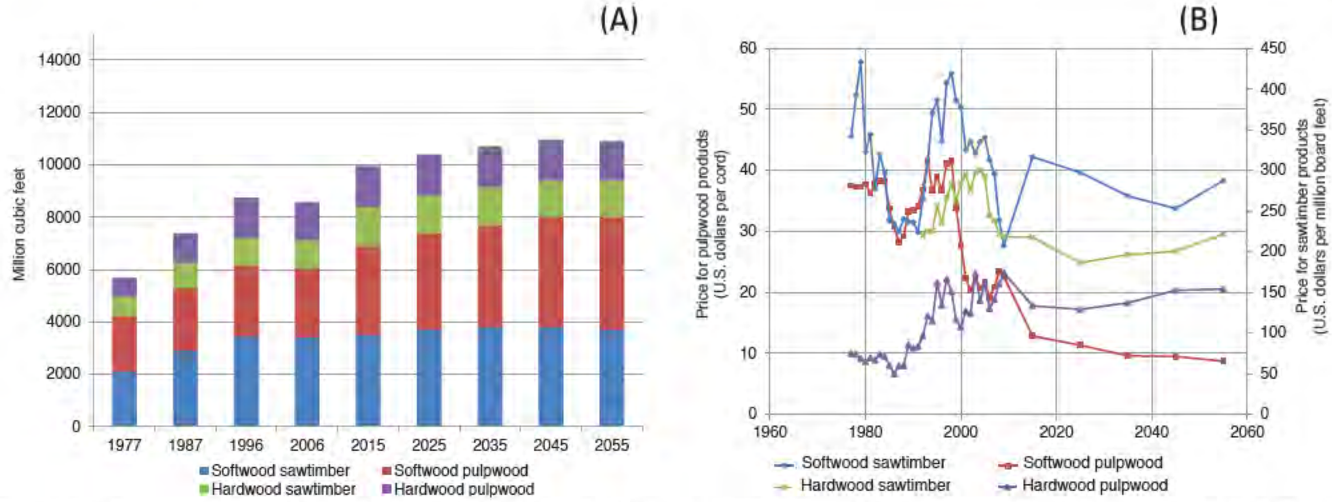


Figure 9.31—Forecasts of (A) standing timber harvesting and (B) real timber prices (2009=100), combining a Constant-Demand scenario with a High-Gross Domestic Product supply scenario.

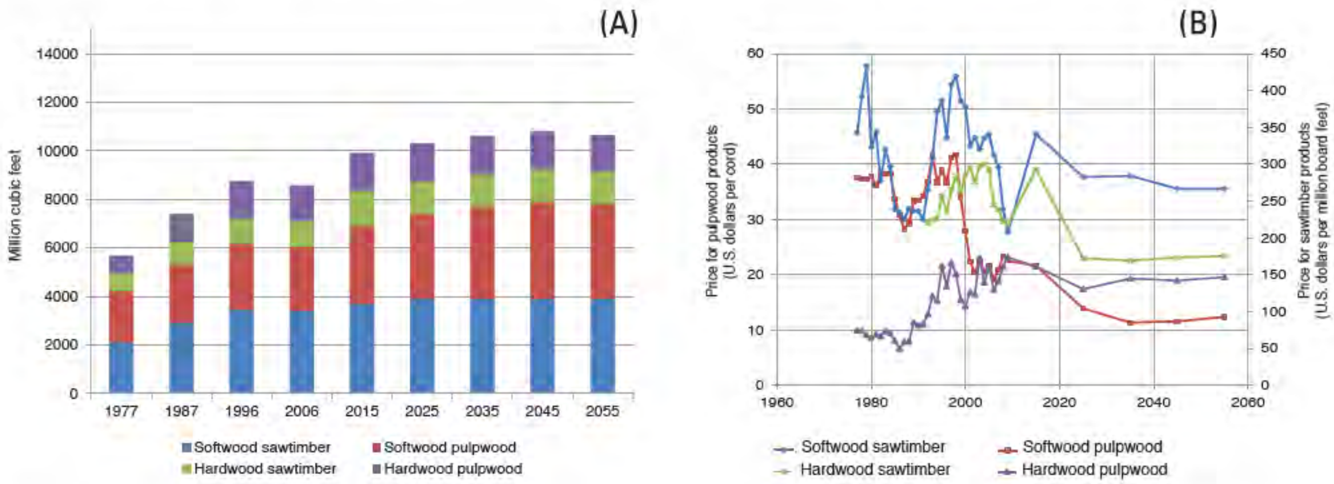


Figure 9.32—Forecasts of (A) standing timber harvesting and (B) real timber prices (2009=100), combining a Constant-Demand scenario with a Low-Gross Domestic Product supply scenario.

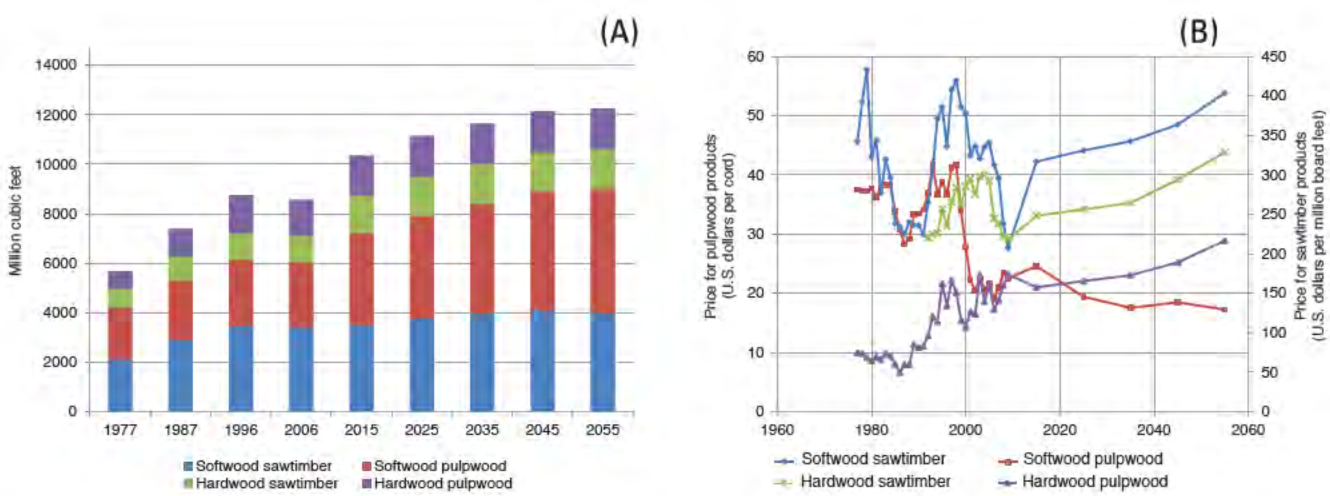
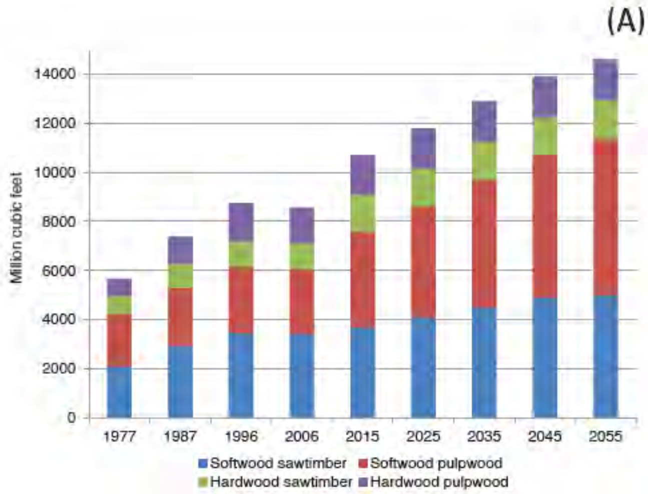


Figure 9.33—Forecasts of (A) standing timber harvesting and (B) real timber prices (2009=100), combining an Expanding-Demand scenario with a High-Gross Domestic Product supply scenario.



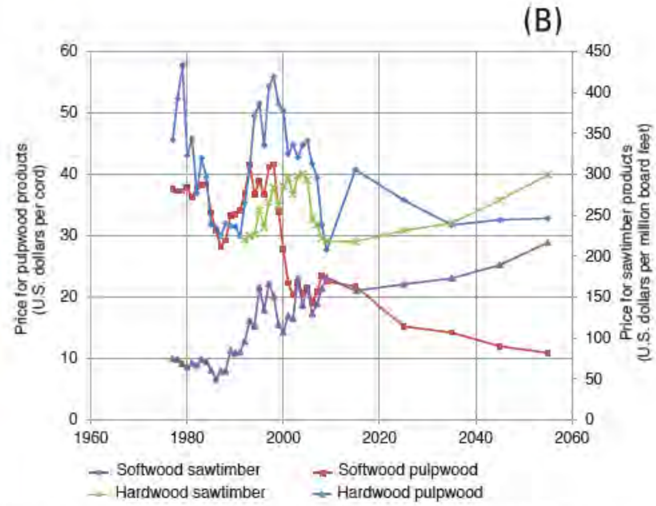


Figure 9.34—Forecasts of (A) standing timber harvesting and (B) real timber prices (2009=100), combining an Expanding-Demand scenario with an Enhanced-Productivity supply scenario.

pulpwood would become increasingly scarce with prices rising by slightly less than 1 percent per year.

The price trajectory for the Constant Demand scenario is consistent with the Cornerstone Futures that feature declining prices (Cornerstones B and D). The Expanding Demand scenario generates market outcomes that are more similar with the Cornerstone Futures that feature increasing prices (such as Cornerstone A), although the forecasted price increases for the Expanding Demand scenario are not quite as high. The results suggest that, at least considering the progression of markets for traditional forest products, the Cornerstone Futures bracket a reasonable range of market forecasts. The Enhanced Productivity scenario indicates a higher production potential within the South, which could accommodate more substantial demand growth in softwood products, especially for pulpwood.

DISCUSSION AND CONCLUSIONS

Strong growth in timber productivity from the 1960s to the late 1990s gave the South a strong comparative advantage in a variety of timber product markets. Output expanded for all products but it was especially strong for softwood sawtimber and pulpwood as intensive pine management replaced harvesting from naturally regenerated forests. Total production doubled from 1962 to 1987 and continued to grow through 1997. The region now produces more timber than any single country in the world, and its product mix is highly diverse.

Beginning in the late 1990s, production relationships changed in the South, with output leveling off or falling after a long period of sustained growth. Our analysis suggests that this leveling off was largely driven by a reduction in demand. Pulp and paper capacity in the United States and in the region, after declining at the turn of the century, have leveled off over the past several years. The recent housing downturn substantially reduced demand for sawlogs throughout the country, including the South.

At the same time, investments and changes in forest productivity significantly increased the supply of timber products from the South, even during the adjustment period of 1998 to 2009. Softwood pulpwood prices halved from 1998 to 2001 in response to a 10-percent decline in production, and have not recovered since. This is consistent with the coincident expansion in the area of planted pine forests from about 32 million acres in 1999 to about 39 million acres in 2009. The expansion in planted area not only explains recent market dynamics, but also foretells future market changes in the region.

In contrast to softwoods, hardwood products, especially hardwood pulpwood, have become scarcer in the South. Little active management is applied to produce hardwoods, and practically none of the region's supply is in planted hardwood forests.

Looking to the future, timber supply will be reshaped by a number of factors, including land use and land ownership. Urban growth is forecasted to consume several million acres of timberland from 2010 to 2060, with much of the losses concentrated in the Piedmont and along the coasts. Hardwood forest types, especially upland hardwoods, would be most impacted by urbanization.

Forest ownership is a source of uncertainty. The forest products industry, which until recently owned a large majority of the most productive and heavily managed lands, sold most of its holdings over the past decade, with most forests still in production but with a very different set of owners. Forecasts of the impacts of this ownership change on investment can only be speculative at this point, but will play an important part in determining future supply.

Forecasts of supply indicate a substantial expansion in softwood supply over the next decade as new pine plantations mature. This portends continued low prices for softwood products, especially softwood pulpwood. Beyond 2020, supply depends on a much lower rate of expansion in forest plantations—generally the rate of planting harvested forests is assumed to be about half of what it was in the 1990s. Even at these lowered levels, the supply of timber would grow and the price of products would generally decline if demand does not grow over the next decades. While supply growth could also be affected by policy changes affecting future management options—e.g., potential restrictions on the use of herbicides for site preparation—our analysis focuses on a future with no substantial changes in policy environment. Policy changes could lead to different outcomes.

Growth in harvesting can be supported by the forest land of the South. A return to 1990s demand levels would result in a price stabilization for softwood pulpwood prices and an increase of less than 1 percent per year for softwood sawtimber and hardwood pulpwood, as well as an increase in total output of about 40 percent from 2006 to 2055. If, in addition, productivity in pine plantations grows by 50 percent, then output could increase even more substantially—up to 70 percent for softwood pulpwood.

Demand is perhaps the most crucial uncertainty in this analysis. Current demand is suppressed by the unprecedented fall in housing construction in 2008, and by long run phenomena, such as the decline in paper production capacity in the South in line with broader economy-wide shifts that are impacting the timber products industry and global capacity shifts. Recovery from the 2007 recession will strongly affect the course of future demand, but policy developments may also play a role. Incentives for using renewable biomass in various bioenergy operations could provide a potentially large new demand for timber products in the South (chapter 10).

What is clear from our analysis is that, absent renewed growth in demand for traditional southern forest products, production growth could be sustained in support of new markets without substantial increases on timber prices, although regional stability could coincide with important scarcities in local timber markets, for example if some individual States develop their own Renewable Portfolio Standards. The question that remains is, “How much?” Without productivity gains, the largest projections of demand for wood-based bioenergy products (under strong economic and moderate population growth projections of Cornerstones A and B, and the A1B storyline in the 2010 RPA Assessment) outlined by the U.S. Department of Energy and described in chapter 10 would lead to large price increases (as much as 400 percent by 2055). With the 50-percent productivity growth for plantations, this demand could more readily be accommodated without strong price increases, even with existing industries consuming their current levels of timber products. Under the Expanding Demand scenario and holding pulpwood consumption for existing industries at 2006 levels, an additional 2.4 billion cubic feet or 36.6 million green tons per year of softwood pulpwood harvesting are forecasted for 2055. Combining Enhanced Productivity to the above scenario would increase softwood pulpwood harvesting to 3.7 billion cubic feet or 57.9 million green tons per year.

In summary, the South has the capacity to expand production well into this century, but demand for forest products seems to be a limiting factor. Timber supply has continued to grow while demand has slackened over the past decade, inducing disinvestment in pulp and paper manufacturing and slower investment in other wood products by the forest products industry. Given this reality, the future of timber markets will largely be determined by demand growth that would emerge primarily from the requirements of forest fiber inputs to supply bio-based energy.

KNOWLEDGE AND INFORMATION GAPS

Our market models are based, to the extent possible, on empirical models of biological changes and management behavior. One area where empirical models have not proved sufficient is in forest investments. Better information on how various owner and investor groups adjust their management plans, particularly by expanding tree planting in response to market signals, could reduce the uncertainty of market projections. Better models of the demand for final wood products and timber inputs to their production could also improve market projections.

Change in the ownership of forests is another key source of uncertainty. Given the information at hand, we assume that the management objectives and management models of timber investment management organizations are similar to those of the vertically integrated forest products companies that they have replaced over the past 10 years (chapter 6). Little is known about the broader implications of these changes in ownership and associated changes in management strategies for the land that has been transferred. For example, the productivity of planted forests derives from other treatments, including fertilization, weed control, and thinning which have not been modeled here. We have assumed that management strategies have not been greatly impacted by these changes, but this remains an untested hypothesis.

Past attempts to model southern timber markets have been successful because of the dominance of private owners. Our models indicate that forest harvesting can be modeled as a function of market signals and is therefore predictable. However, an important uncertainty may well be the development of new demands for bioenergy and biofuels that are driven, not by markets, but by new State and Federal policies, which are unknowable at this point. In addition, the spatial scope of our models addresses the region's timber markets as one entity, given the current distribution of production demands and forest management types. However, policies at the State level, especially State Renewable Portfolio Standards, may create local demands that could result in local scarcities and a spatial realignment of production; these we cannot address with our models.

ACKNOWLEDGMENTS

Thanks to Shan Liu, Southern Research Station, U.S. Department of Agriculture Forest Service; Ruhong Li, Department of Forestry and Management, University of Wisconsin, Madison; and Robert C. Abt, Department of Forestry and Environmental Resources, North Carolina State University.

LITERATURE CITED

APA-the Engineered Wood Association. 2010. Structural panel and engineered wood yearbook. APA Economics Report E176. Tacoma, WA: American Plywood Association. 80 p.

Congressional Budget Office. 2008. The outlook for housing starts, 2009 to 2012. Background Paper. U.S. Congress, Congressional Budget Office. 23 p. http://www.cbo.gov/ftpdocs/98xx/doc9885/11-17-HousingStarts.pdf. [Date accessed: October 28, 2010].

Daniels, J.M. 2008. United States trade in wood products, 1978–2005. Gen. Tech. Rep. PNW-GTR-738. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 124 p.

Fleishman, S.J.; Eastin, I.L.; Shook, S.R. 1999. Material substitution trends in residential construction, 1995 vs. 1998. Center for International Trade in Forest Products Working Paper Number 73. Seattle: University of Washington. 76 p.

Ince, P. 2000. Industrial wood productivity in the United States, 1900-1998. Res. Note FPL-RN-0272. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 14 p.

Johnson, T.G.; Steppleton, C.D. 2005. Southern pulpwood production, 2003. Resour. Bull. SRS-101. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 38 p.

Johnson, T.G.; Steppleton, C.D.; Bentley, J.W. 2010. Southern pulpwood production, 2008. Resour. Bull. SRS–165. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 42 p.

McKeand, S.; Mullin, T.; Byram, T.; White, T. 2003. Deployment of genetically improved loblolly and slash pines in the South. Journal of Forestry. 101(3): 32-37.

McKeever, T.; Spelter, H. 1998. Wood-based panel plant locations and timber availability in selected U.S. States. Gen. Tech. Rep. FPL-GTR-103. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 53 p.

Nagubadi, R.; Zhang, D.; Prestemon, J.; Wear, D.N. 2004. Softwood lumber products in the United States: substitutes, complements, or unrelated? Forest Science. 50(4): 416-426.

Norris Foundation. 1977–present. Timber Mart-South State Timber Price Reports. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA.

Poylakov, M.; Wear, D.N.; Huggett, R. 2010. Harvest choice and timber supply models for forest forecasting. Forest Science. 56(4): 344-355.

Smith, B.R.; Rice, R.W.; Ince, P.J. 2003. Pulp capacity in the United States, 2000. Gen. Tech. Rep. FPL–GTR–139. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 23 p.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture Forest Service. 336 p.

Smith, W.B.; Miles, P.D.; Vissage, J.S.; Pugh, S.A. 2004. Forest resources of the United States, 2002. Gen. Tech. Rep. NC-241. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station. 137 p.

Smith, W.B.; Vissage, J.S.; Darr, D.R.; Sheffield, R.M. 2001. Forest resources of the United States, 1997. Gen. Tech. Rep. NC-219. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station. 190 p.

Spelter, H. 2001. Wood-based panels—supply, trade and consumption. In: ECE/FAO Forest Products Annual Market Review 1999-2000:113-130. Chapter 10.

Spelter, H.; McKeever, D.; Toth, D. 2009. Profile 2009: softwood sawmills in the United States and Canada. Res. Pap. FPL-RP-659. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 55 p.

U.S. Census Bureau. 2011. Press release: new residential construction in February 2011. March 16, 2011. http://www.census.gov/const/www/newresconstindex.html. [Date accessed: April 5, 2011].

Uusivuori, J.; Buongiorno, J. 1991. Pass through of exchange rates on prices of forest product exports from the United States to Europe and Japan. Forest Science. 37(3): 931-948.

Wear, D.N.; Carter, D.R.; Prestemon, J. 2007. The U.S. South's timber sector in 2005: a prospective analysis of recent change. Gen. Tech. Rep. SRS-99. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 29 p.

Zhang, Y.; Buongiorno, J. 1998. Paper or plastic? The United States' demand for paper and paperboard packaging. Scandinavian Journal of Forest Research. 13: 54-65.

Zhang, Y.; Buongiorno, J. 1997. Communication media and demand for printing and publishing papers in the United States. Forest Science. 43(3): 362-377.

CHAPTER 10. Forest Biomass-Based Energy

Janaki R. R. Alavalapati, Pankaj Lal, Andres Susaeta, Robert C. Abt, and David N. Wear[1]

KEY FINDINGS

- Harvesting woody biomass for use as bioenergy is projected to range from 170 million to 336 million green tons by 2050, an increase of 54 to 113 percent over current levels.
- Consumption projections for forest biomass-based energy, which are based on Energy Information Administration projections, have a high level of uncertainty given the interplay between public policies and the supply and investment decisions of forest landowners.
- It is unlikely that the biomass requirement for energy would be met through harvest residues and urban wood waste alone. As consumption increases, harvested timber (especially pine pulpwood) would quickly become the preferred feedstock.
- The emergence of a new woody biomass-based energy market would potentially lead to price increases for merchantable timber, resulting in increased returns for forest landowners.
- While woody biomass harvest is expected to increase with higher prices, forest inventories would not necessarily decline because of increased plantations of fast growing species, afforestation of agricultural or pasturelands, and intensive management of forest land.
- Because it would allow more output per acre of forest land and dampen potential price increases, forest productivity is a key variable in market futures.
- The impacts that increased use of woody biomass for energy would have on the forest products industry could be mitigated by improved productivity through forest management and/or by increased output from currently unmanaged forests.
- Price volatility associated with increased use of woody biomass for energy is expected to be higher for pulpwood than for sawtimber.
- The impacts of wood-based energy markets tend to be lower for sawtimber industries, although markets for all products would be affected at the highest levels of projected demand.
- Different types of wood-based energy conversion technologies occupy different places on the cost feasibility spectrum. Combined heat and power, co-firing for electricity, and pellet technologies are commercially viable and are already established in the South. Biochemical and thermochemical technologies used to produce liquid fuels from woody biomass are not yet commercially viable.
- Current research does not suggest which woody species and what traits would likely be most successful for energy production. The future of conversion technologies is uncertain.
- In the absence of government support, research, pilot projects, and incentives for production, woody bioenergy markets are unlikely to grow substantially.
- Under a high demand scenario for bioenergy, the resulting intensity of woody biomass harvests could have deleterious effects on stand productivity, biodiversity, soil fertility, and water quality.
- Although research provides some guidelines for the design of management to protect various forest ecosystem services, forest sustainability benchmarks are not well defined for a high bioenergy demand future and existing certification systems may need modifications to address multiple resource values.

INTRODUCTION

The United States is the largest consumer of petroleum products, consuming about 19.5 million barrels per day in 2008 (Energy Information Administration 2009), with a significant portion imported from politically unstable regions of the world. This reliance on imported fossil fuels, coupled with their associated greenhouse gas emissions, has led to economic, social and environmental concerns. Bioenergy may offset fossil fuel use, diversify energy sources, reduce emissions, and provide socioeconomic benefits in the form

[1] Janaki R.R. Alavalapati is a Professor and Department Head of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061. Pankaj Lal is an Assistant Professor, Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ 07043. Andres Susaeta is a Postdoctoral Scholar, Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA 24061. Robert C. Abt is a Professor, Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695. David N. Wear is the Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695.

of additional income and new jobs. Bioenergy from woody biomass could contribute by increasing U.S. renewable energy resources, reducing competition between agricultural crops destined for food and those for fuel production (Hill and others 2006), and perhaps improving the condition of some forests. Some analysts, for example the Manomet Center of Conservation Sciences (2010) in their analysis of wood-based bioenergy in Massachusetts raise doubts about the greenhouse gas mitigation potential of forest bioenergy. Others, e.g., Lucier (2010) and O'Laughlin (2010), challenge these findings. In the South, some studies, e.g., Dwivedi and others (2011), indicate that southern pine based energy could reduce greenhouse gas emissions as compared to using fossil fuels.

Although historically limited to residues from the production of wood products, biomass could be sourced from logging residues, stands damaged by natural disturbances (such as wildfire, pest outbreaks, and hurricanes), small-diameter trees thinned from plantations and other forests, and energy crops such as eucalyptus and poplar; these sources would likely be tapped as woody bioenergy markets become competitive. At high enough prices, even merchantable timber could be diverted to bioenergy uses. Hughes (2000) suggests that the combination of forest bioenergy plantations and continued use of wood residues from forest product industries could supply 7 to 20 percent of the U.S. electricity generation in the future.

Many pine plantations established to supply pulpwood for paper and engineered wood products are overstocked and therefore susceptible to wildfires and pest attacks (Gan and Mayfield 2007a). For example, nearly half of over 1.1 million acres of nearly pure pine stands are at risk from southern pine beetle in Oklahoma (Oklahoma Department of Agriculture Food And Forestry 2008). Wood-based bioenergy markets could increase thinning and removals, thereby reducing these risks (Belanger and others 1993, Gan and Mayfield 2007a, Neary and Zieroth 2007, Speight 1997). Schmidt and others (2002) estimated that 2.7 billion dry tons of forest biomass needs to be removed through forest fuel reduction treatments in the South, about 20 million dry tons annually. Furthermore, wood-based bioenergy markets would improve profitability for landowners in the South (Nesbit and others 2011, Susaeta and others 2009). Furthermore, southerners appear willing to pay more for cleaner sources of energy such as wood based biofuels (Susaeta and others 2010).

Federal policies such as the 2002 Farm Bill, 2005 Energy Policy Act, 2007 Energy Independence Security Act, and 2008 Farm Bill have specifically encouraged the production of cellulosic biofuels such as those produced from wood, ranging from grants and loans to the establishment of renewable fuel standards (15.5 billion gallons in 2012, and 36 billion gallons by 2022 of which 21 billion gallons must be cellulosic). Federal law provides differing definitions of acceptable forest biomass for bioenergy. For example, under the 2007 Energy Independence Security Act biomass from public lands, municipal solid waste, plantations established after the enactment of the Act, 'old growth' or 'mature' forests, and most other woody biomass (except for slash and pre-commercial thinning) is excluded from private and non-industrial forests (NIPFs) landowners. The 2008 Farm Bill on the other hand is less restrictive, as it allows for biomass derived from Federal lands and other forests (i.e., not tree plantations) as biofuels. The American Clean Energy and Security Act of 2009 (H.R. 2454), as passed by the House of Representatives, sought to create a broadened universal definition of renewable biomass that applies to the Renewable Fuel Standard, and a national Renewable Electricity Standard. We followed a non-restrictive definition of biomass while simulating supply variations and southern forests and considered that aboveground biomass on private forestlands in the South could be used for energy production. This is based on the assumption that policy would not restrict the allocation of forest biomass to bioenergy uses.

This chapter analyzes the potential effects of the emergence of a bioenergy market on southern forests, forest owners, traditional forest product industries, and ecosystem integrity and services; with emphasis on the following key issues:

- How markets for wood for energy production might evolve and potential implications for traditional forest product industries and landowners
- The status of current and potential technologies that can help realize large-scale production of woody bioenergy
- How bioenergy policies could impact forest landowners and forest industry
- Effects of woody bioenergy markets on forest ecosystems health; benchmarks for sustainability

METHODS

We surveyed the literature to address questions about technology development, bioenergy policies, and sustainability, and we developed detailed modeling to project market changes and incorporate an analytical component into the results of the literature survey.

To assess tradeoffs between the traditional forest product industry and the woody bioenergy industry, we evaluated woody biomass supply variation through time and associated price, inventory, and removal responses following Rossi and others (2010). In the face of future competition for raw materials and the potential competitive advantage that policy incentives would provide to woody bioenergy sector, this tradeoff analysis was considered critical for the future of southern forests (Wear and others 2009). Many authors have explored this issue; what has been lacking is a systematic analysis of regional trends that assesses woody biomass supply in response to variation in future consumption for energy.

We modified the Subregional Timber Supply (SRTS) model (Abt and others 2000), to assess the potential effects of bioenergy consumption on wood products markets. The model provided price, inventory, and removal responses for different wood-for-energy consumption and supply scenarios; and allowed us to estimate impacts on traditional forest industries and landowners.

Of the large-scale macro models available for conducting our analysis (Adams and others 1996; De La Torre Ugarte and Ray 2000; De La Torre Ugarte and others 1998, 2006), the SRTS model is the only one that treats standing timber as a potential supply of bioenergy and defines regions in a way that is congruent with Forest Inventory Analysis (FIA) survey units. Because it incorporates an inventory projection model into a timber market model framework, its projections are based on supply and demand interactions. It allows of larger diameter sawtimber to be downgraded for nonsawtimber (largely pulpwood uses) in response to price signals and is familiar to many forest industry analysts and State forestry agencies, having been used to model timber supply and prices in the Northeast (Sendek and others 2003) as well as the South (Bingham and others 2003, Prestemon and Abt 2002). It has also been used to assess the influence of nonmarket values on timber market decisions by nonindustrial private forest landowners (Pattanayak and others 2005), the effects of wood chip mills on timber supply in North Carolina (Schaberg and others 2005), the impacts of Renewable Energy Standards policy implemented in North Carolina (Galik and others 2009), and bioenergy demands in South (Abt and Abt, in press).

The SRTS model estimates two forest products, sawtimber and pulpwood product allocations for softwoods and hardwoods. Its equations—defined through supply, demand, and inventory elasticity values—are used to project the market-clearing price and quantity levels, which in turn are used to allocate subregional harvesting and to project the next period's inventory values. A Goal Program then categorizes the total wood requirement by management type and age class and makes allocations to subregions, owners, and products.

The separation of products and inventory in terms of sawtimber and pulpwood is based on user-specified definitions that allocate most of the largest diameter wood to saw mills, a percent of the largest diameter and all of the medium diameter wood to pulpwood, and the smallest diameter wood to the forest floor. With these allocations, a product mix is calculated for harvest in any management type and age class with the objective of defining the projected removal mix for the region/owner in a way that follows historical harvest patterns of existing removal-to-inventory intensities. For partial harvests, the model defines a stocking target (volume per acre) for each management type and age class; if the current stocking is greater than the target, the harvest is considered a thinning. After the volume-per-acre target is reached, the harvest considered final and acres are returned to age class zero. Under most circumstances, this approach ensures that average stocking is close to target (historical) levels throughout the projection (Abt and Abt 2010; Abt and others 2000; Abt and others 2009, 2010; Prestemon and Abt 2002; Rossi and others 2010).

We made a number of modifications to the SRTS model (fig. 10.1) to assess the effects of woody bioenergy industry on future prices, harvests, and inventories of four wood product categories—softwood sawtimber, other softwoods, hardwood sawtimber, and other hardwoods—derived from private owners of forest land (public forest lands have been excluded from the study, because public land harvest decisions are not necessarily price-responsive). Appendix B contains descriptions of these products and the allocation of consumption of each for woody bioenergy production. The model allocates woody biomass consumption among product groups based on the price variations. Pine plantations can be harvested for pulpwood as early as 10 years of age. To determine the availability of harvest residuals, we applied utilization percentages that are consistent with timber product output data for the South (Johnson and others 2009).

Alternative runs of the model allowed us to examine how management or genetic improvements would affect productivity. Rather than applying identical responses across the five forest management types (pine plantation, natural pine, oak-pine, upland hardwood, and lowland hardwood), we modified the model so that responses can be disaggregated across them.

Within the SRTS model, the area of timberland will change in response to the relative rents of crop and forest uses. We defined timber rents as weighted averages of sawtimber and nonsawtimber prices, with weighting specified by the present value difference in income between the two products while agricultural rents are held constant. Because woody bioenergy markets are expected to impact the nonsawtimber sector more than the high valued sawtimber sector (Aulisi and others 2007), the model allocates less weight to sawtimber prices.

We used the aggregate demand information gathered from each southern wood-based industry—forest products, woody biomass-based electricity, woody biomass-based liquid fuels, and wood pellets—to project the allocation of harvested

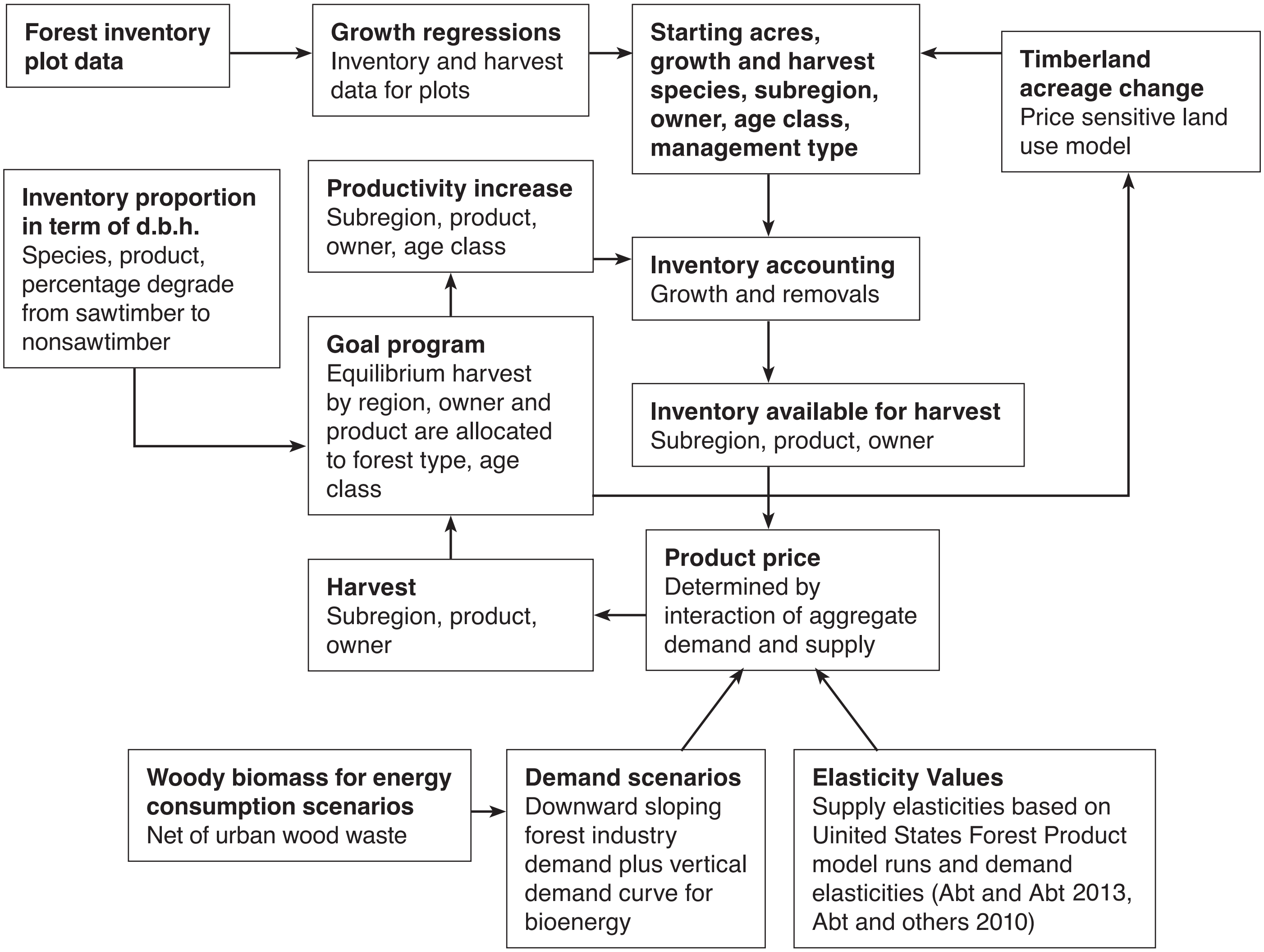


Figure 10.1—Methodology diagram for the modified Subregional Timber Supply model used to project levels and effects of woody biomass consumed for energy for the South.

timber. The modified SRTS model defines a market simulation model based on empirical relationships—demand and supply, price, land use, reforestation and inventory—for woody biomass and traditional forest products. A key assumption is that forest owners are price responsive and decisions to invest or harvest are made accordingly.

Consumption/Demand Scenarios

Our consumption scenarios were based on the three principal uses of woody biomass for energy: as power for electricity generation through combustion or gasification processes, co-firing with coal, or in combined heat and power systems in industrial facilities (Energy Information Administration 2010b); as liquid fuel (cellulosic ethanol) that can be blended with conventional transportation fuels (Energy Information Administration 2010b); and as bioproducts such as highly compact wood pellets used for heating purposes (Spelter and Toth 2009, appendix B).

The amount of wood consumed for electricity, liquid fuels, and pellets defines the total requirement for meeting bioenergy consumption projections. This can be met with wood from additional harvesting or with residuals and other wood waste. Although harvesting unutilized residues (discarded tree tops and limbs generated during the harvesting process) might provide a portion of woody biomass-based energy consumption, recent analysis (Galik and others 2009, Rossi and others 2010) indicates that merchantable timber is also likely to be required. In addition, woody biomass-based energy demand figures need to account for urban wood wastes that could be used for energy production (Rossi and others 2010). Because the SRTS model deals only in harvested wood, we backed urban waste and other sources of nonharvested woody biomass out of the consumption estimates, and defined the remainder as harvested-wood consumption (including harvesting residues) for woody biomass-based energy; appendix B shows the method used to estimate the harvesting residues and urban wood waste that can be diverted for energy production. Demand price elasticity, which like inventory supply elasticity can vary by product (Liao and Zhang 2008, Pattanayak and others 2002), was assumed to be -0.5 for all four SRTS products (softwood/hardwood sawtimber and nonsawtimber), the same assumption used by Abt and Abt (2010) for their Southwide timber supply analysis.

Demand for woody biomass for energy can also be met with fast-growing short rotation woody crop species, among them yellow-poplar (*Populus* spp.), willow (*Salix* spp.), cottonwood (*Populus fremontii* L.), sweetgum (*Liquidambar styraciflua*), sycamore (*Platanusoccidentalis*), black locust (*Robinia pseudoacacia*), silver maple (*Acer saccharinum* L.), and eucalyptus (*Eucalyptus cinerea*); these species have been identified by the U.S. Department of Energy as potentially viable for energy production. We followed the approach outlined by the Energy Information Administration (2010a) and assumed that short rotation woody crops would grow largely on nonforested lands (agricultural or pasture lands) and partially offset increased future wood requirements. We assumed of the offset to be 10 percent by 2050 and removed this material from woody biomass demands for bioenergy (in effect, treating short rotation woody crops as a part of the agricultural sector).

Although we describe our assumptions as consumption scenarios, it is important to understand that they are not demand projections, as we have not specified price-responsive demand relationships for woody biomass. The consumption projection is essentially a vertical demand curve added to the downward sloping demand curves for traditional forest products for each period using modified Energy Information Administration (2010b) projections. As a counterfactual, we also introduced a constant consumption scenario with no forest biomass-based energy market and ran the SRTS model to define the amount of woody biomass that would be required by traditional forest industry absent a bioenergy market. Subsequent years are held constant at the original 2010 level on the assumption that the traditional forest product industry will not increase wood consumption beyond what would be expected at the constant price level estimated by SRTS.

To account for uncertainty in bioenergy technologies, demands, and policies, we considered three consumption scenarios that we label high, medium, and low. The low-consumption scenario assumes that 7.74 percent of total electricity will derive from renewable sources based on Energy Information Administration (2010b) reference case projections. The medium-and high-consumption scenarios assume that 20 percent of total electricity consumption derives from renewable sources; in the high-consumption scenario, woody biomass is assigned a higher percentage of the total electricity generation from renewable sources (table 10.1).

Biomass Supply

The SRTS model accounts for forest inventory changes and timber removals based on historical forest inventory (FIA) data. However, southern forest productivity has seen a three-fold over the last 50 years from advancements in management and genetic improvements (Fox and others 2007). Siry and others (2001) projected that productivity gains for pine plantations could be as high as 100 percent of empirical FIA data (using data from the late 1990s) over the next 50 years. Prestemon and Abt (2002) assumed a 75-percent productivity gain in southern pine plantations from 2000 to 2040. With strong markets, other forest

Table 10.1—Allocation of woody biomass for energy production under woody biomass consumption scenarios by 2050

Woody biomass consumption scenario	Electricity	Liquid fuels	Wood pellets
Low	Based on Energy Information Administration (2010b) projections	Provides 30 percent of renewable energy sources	Based on Spelter and Toth (2009)
Medium	Increases to 20 percent of renewable energy sources by 2050, with share of total electricity sources remaining the same as in the low-consumption scenario	Increases to 50 percent of renewable energy sources by 2050, with 30 percent of total liquid energy coming from woody sources	Increases by 25 percent, 2015–50
High	Increases to 40 percent of renewable energy sources by 2050, with 20 percent of total electricity coming from woody sources	Increases to 50 percent of renewable energy sources by 2050, with 40 percent of total liquid fuel coming from woody sources	Increases by 50 percent, 2015–50

management types might experience productivity gains due to silvicultural improvements or improvements in management, although not as high as pine plantations.

We developed supply projections to examine alternative trajectories of productivity increases through 2050. In these projections, productivity growth is applied to every acre every year, so that over time the improved silvicultural practices on existing or new forest stands or genetic improvements of new plantations result in an aggregate growth response. For the "pine productivity" strategy, we assumed that pine plantation productivity increases steadily until it reaches 100 percent, while the productivity of other forest management types is held constant. For the "all productivity" strategy, we assumed a 100-percent pine plantation productivity increase and a 25-percent increase for other types. For the "low productivity" strategy, pine plantation productivity increases by 50 percent and the productivity of other types increases to 25 percent (tables 10.2 and 10.3). These assumptions are in line with hardwood field trials that report growth responses between 17 and 33 percent after stem density reduction, herbaceous competition control, and fertilization (Siry and others 2004).

Within SRTS, removals are treated as a function that responds to changes in the product price and the total biomass inventory. The timber supply elasticity with respect to inventory has been assumed to be 1.0 for all products and owners. For own-price elasticities of timber supplies (elasticity of product demand with respect to their own price), we used the average bootstrapped values for A1B and B2 cornerstone futures described in chapter 9, which vary across products and years and range from 0.18 to 0.32.

RESULTS

Market Analysis

By 2050, woody biomass consumption is projected to range from 150.16 million green tons for the low-consumption scenario to 235.88 million for the medium-consumption scenario and 316.12 million for the high-consumption scenario (fig. 10.2). The amount of urban wood waste amounts to about 12.72 million in 2010 and trends slightly upward throughout the projection period to reach 20.08 million by 2050. In contrast, the projection of biomass requirement for the forest products industry (held constant through the projection period) is about 278.46 million. By 2050, the biomass requirement for energy reaches about 54 percent of the forest products requirement for the low-consumption scenario and 85 percent for the medium scenario. For the high-consumption scenario, the bioenergy requirement exceeds the forest products requirement by 2045 and is 13 percent greater than the forest product requirement in 2050.

Adding urban wood waste and the forest biomass consumption requirement in 2050 would bring demand to 170 million tons for the low-consumption scenario, 256 million for the medium scenario, and 336 million for the high scenario. These estimates are comparable to other estimates in the literature if we assume that that supply of wood from the South mirrors the national harvest share—i.e., approximately 57 percent of national harvest as per Hanson and others (2010).

Without accounting for milling residues, Milbrandt (2005) estimated that just 86 million tons of woody biomass is readily available for energy production (roughly half of the projection for the low-consumption scenario). Walsh (2008) estimated that approximately 121 million tons of forest and mill residues could be supplied at a price of $100 per dry short ton, compared to estimates of 154 million tons by Kumarappan and others (2009). The Energy Information Administration (2007) estimated that approximately 414 million tons of wood from South might be required to meet the Federal goal of 25 percent of renewable fuel and electricity standards. Sample (2009) suggested that this demand figure could be much higher, estimating the yearly requirement at 992 million green tons. Perlack and others (2005) estimated that 420 million green tons of wood resources could be annually made available for energy production from southern forests.

Consumption increases of this magnitude (at a minimum, a 54 percent increase in timber harvesting) could imply a structural change in forest products markets. Analysis of traditional wood products markets (chapter 9) indicates that the supply of biomass could grow by about 43 percent under current levels of productivity without increased scarcity, largely because of declining demands for wood products. With plantation productivity growth at about 50 percent by 2060, forest biomass output could expand by as much as 70 percent without substantial impacts on market scarcity.

To identify the market implications of the three consumption scenarios, we ran the SRTS model, which provides projections of the removals from growing stock resulting from timber harvesting but does not distinguish among final products. To deduce the implications of increased woody biomass requirement for the traditional wood products industry, we disaggregated the removals projections into harvesting residues, additional removals that could not have occurred without woody bioenergy markets, and/or displacement from traditional wood product industry.

To ensure that some slash is left on the ground, we constrained the SRTS model so that no more than

Table 10.2—Simulations of supply responses when woody biofuels at three consumption levels are matched with four productivity strategies, 2050

Woody biomass consumption scenario	Productivity strategy	Details
Medium	Only improve pine plantation productivity	Productivity of pine plantations doubles; no change in other forest management types
Medium	Improve productivity on all management types	Productivity of pine plantations doubles by 2050 and productivity of other forest management types increases by 50 percent
High	Only improve pine plantation productivity	Productivity of pine plantations doubles; no change in other forest management types
High	Improve productivity on all management types	Productivity of pine plantations doubles and productivity of other forest management types increases by 50 percent
Short rotation woody crops	Improve productivity on all management types and expand short rotation woody crops	Short rotation woody crops growing on agricultural or pasture land offset 10 percent of wood energy demand; productivity of pine plantations doubles and productivity of other forest management types increases by 25 percent
High	Low productivity	Productivity of pine plantations increases by 50 percent and productivity of other forest management types increases by 25 percent

Table 10.3—Modified subregional timber supply model assumptions

Assumption	Scenario/Strategies	Details
Woody biomass consumption for electricity and biofuels	Low,Medium. High	Demand values in million green tons (Energy Information Administration 2010b)
Urban wood waste	Low,Medium. High	Per capita availability (Carter and others 2007)
Harvest residues	Low,Medium. High	SRTS model run based on Johnson and others (2009) data
Forest industry demand	Low,Medium. High	Auxiliary SRTS run for constant prices
Demand elasticity	Low,Medium. High	-0.5 for all products (Abt and others 2010)
Supply elasticity	Low,Medium. High	Different annual values for products based on RPA storylines[a]
Pine productivity	Pine productivity strategy	Pine productivity increases by 100 percent by 2050
All productivity values	All productivity strategy	Pine productivity increases by 100 percent and other forest type increases by 50 percent by 2050
Low productivity values	Low productivity strategy	Pine productivity increases by 50 percent and other forest type increases by 25 percent by 2050
Short rotation woody crops	Short rotation woody crops	Short rotation woody crops take care of 10 percent of total woody biomass for energy demand by 2050
Forest management type acreage	All scenarios and strategies	Forest land change as compared to agriculture and pasture land, in turn impacting acreage of pine plantations, natural pines, oak-pines, upland hardwoods, and lowland hardwoods (Abt and Abt 2013, Hardie and others 2001)
Timber rent	All scenarios and strategies	Weighted average of pulp and sawtimber prices. Model allocates weights, with pulpwood gaining more weight in total rent calculations
Degradation of sawtimber for pulp use	All scenarios and strategies	Percentage allocation of sawtimber that can be used as pulp (Abt and others 2010)
Pulp diameter range	All scenarios and strategies	<9 inch softwood <13 inch hardwood
Sawtimber diameter range	All scenarios and strategies	>9 inch softwood >13 inch hardwood
Forest products	All scenarios and strategies	Sawtimber softwoods, other softwoods, sawtimber hardwoods, and other hardwoods

[a]Personal communication. 2010. David N. Wear, Project Leader, Center for Integrated Forest Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Raleigh, NC 27695.

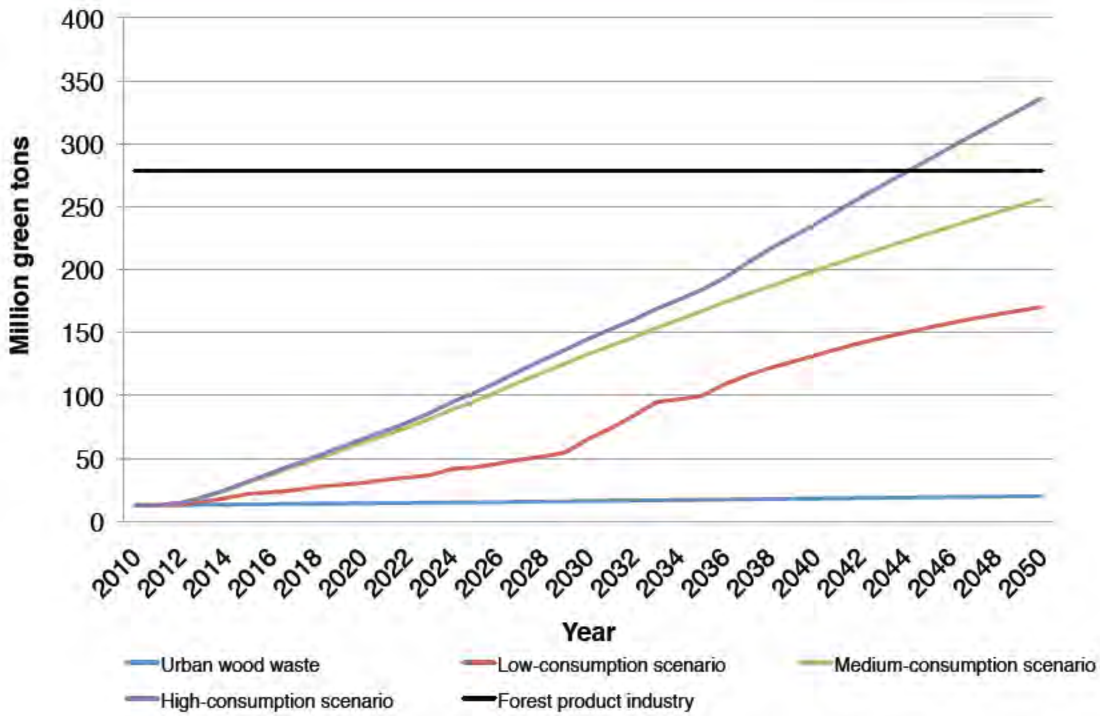


Figure 10.2—Woody biomass demand for energy in the South under low-, medium-, and high-consumption scenarios, with demand from traditional forest industry and availability from urban wood waste, 2010 to 2050.

67 percent of harvesting residues could be diverted for energy production. The constant consumption scenario (with no expanded demand for bioenergy) defines a base harvest projection for the traditional wood products industry. Comparing the SRTS projections for a bioenergy consumption scenario with the base harvest for forest industry defines the additional harvesting associated with the bioenergy scenario (new removals). Comparing new removals with the bioenergy requirement (less harvest residues) provides an estimate of the timber that would be diverted from forest industry for woody biomass-based energy production (displacement). Because the maximum amount of product displacement is constrained by forest product industry consumption, the possible product shortfalls that may arise due to additional biomass demands for bioenergy are met by other softwood and hardwood product removals.

The remaining paragraphs in this section summarize projections that assume a base harvest for forest industry and three bioenergy consumption scenarios without in the absence of supply expansion through productivity growth.

No consumption for bioenergy—Figure 10.3 shows the results of the SRTS model run for four product types (sawtimber softwoods, other softwoods, sawtimber hardwoods, and other hardwoods), expressed in terms of index values for prices, inventory, and removals with respect to 2007 levels. Prices decline, and inventory and removals increase for all hardwoods and for sawtimber softwoods; the reverse is predicted for the other (nonsawtimber) softwoods. This is consistent with a SRTS-based analysis (Abt and Abt 2010) that plays out the implications of a protracted recession. The scenario predicts 10 percent declines in Southern private forest acreage from 2010 to 2050 (fig. 10.4), which is consistent with the maximum projected forest losses described in chapter 4 and with the forest product demand analysis contained in chapter 9, which predicted constant or somewhat expanding harvest levels and declining timber prices.

Low woody biomass consumption—Harvest, inventory, and removals projections for sawtimber under the low-consumption scenario are similar to the no-consumption scenario projections (fig. 10.5), although the price reductions for sawtimber are somewhat lower. Change in prices, inventory, and removals reflect an inelastic market response as price changes more than removals or inventory.

Consistent with Rossi and others (2010), demand for wood energy leads to price increases for other (nonsawtimber) softwoods beginning in about 2016, when supplies of urban wood wastes are unable to meet the extra demand of wood for energy production, and somewhat later for nonsawtimber hardwoods. The associated price increases are more than triple 2007 levels. Substantial timber is diverted away from

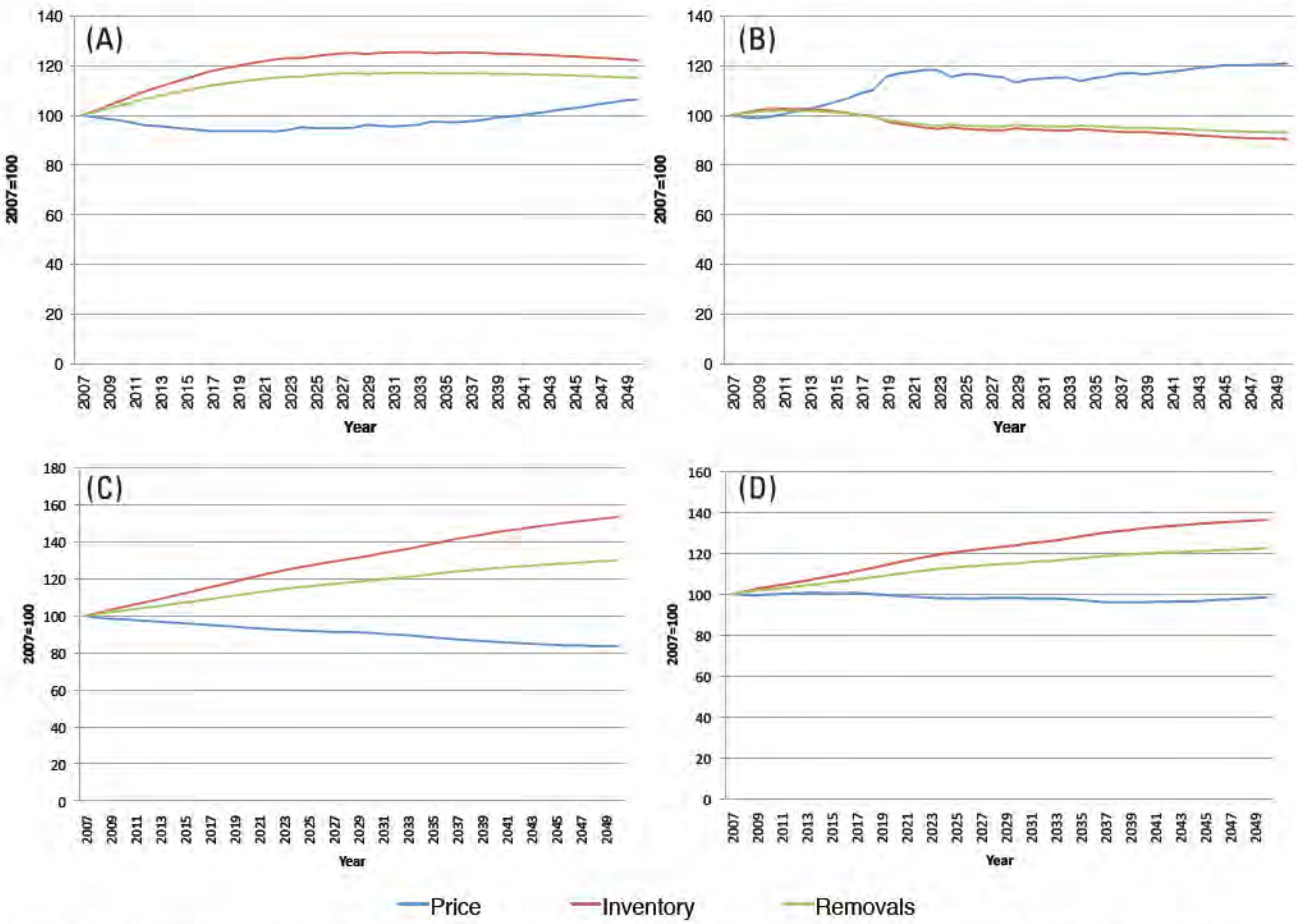


Figure 10.3—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods in a constant forest industry consumption scenario (no biomass diverted to energy).

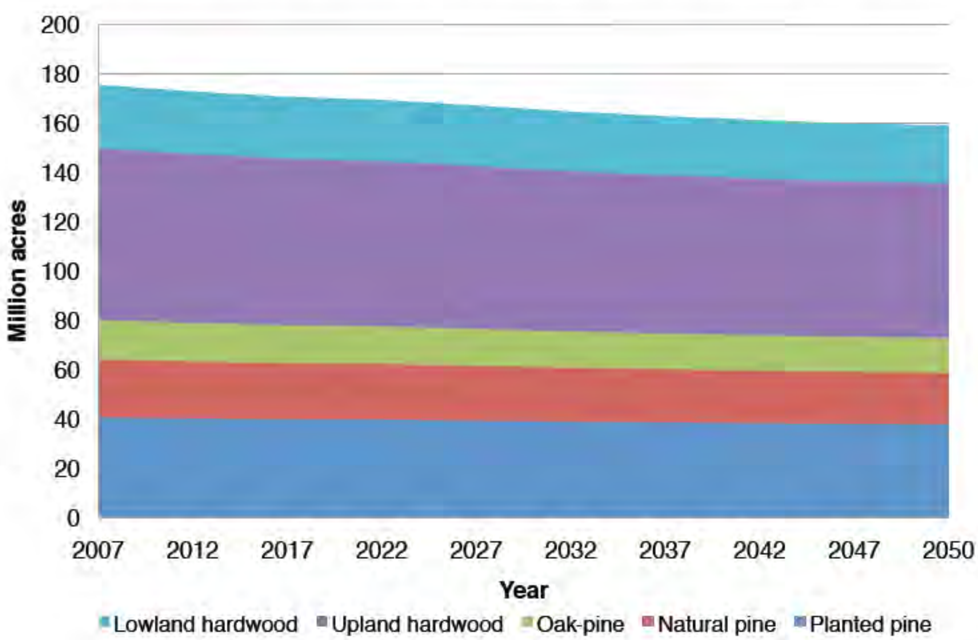


Figure 10.4—Private forest acreage change in the South under a constant forest industry consumption scenario (no biomass diverted to energy).

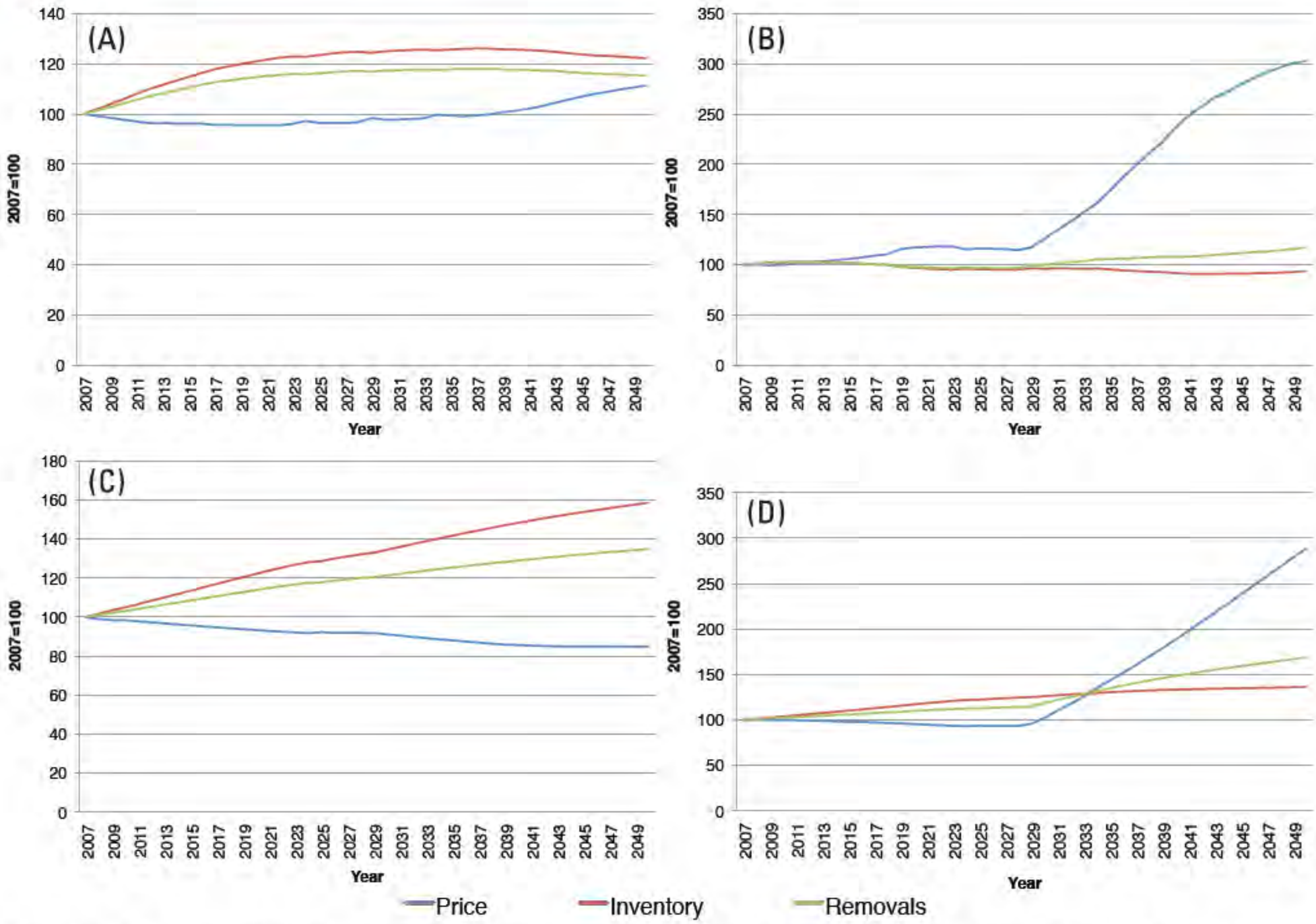


Figure 10.5—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming low consumption of woody biomass for energy.

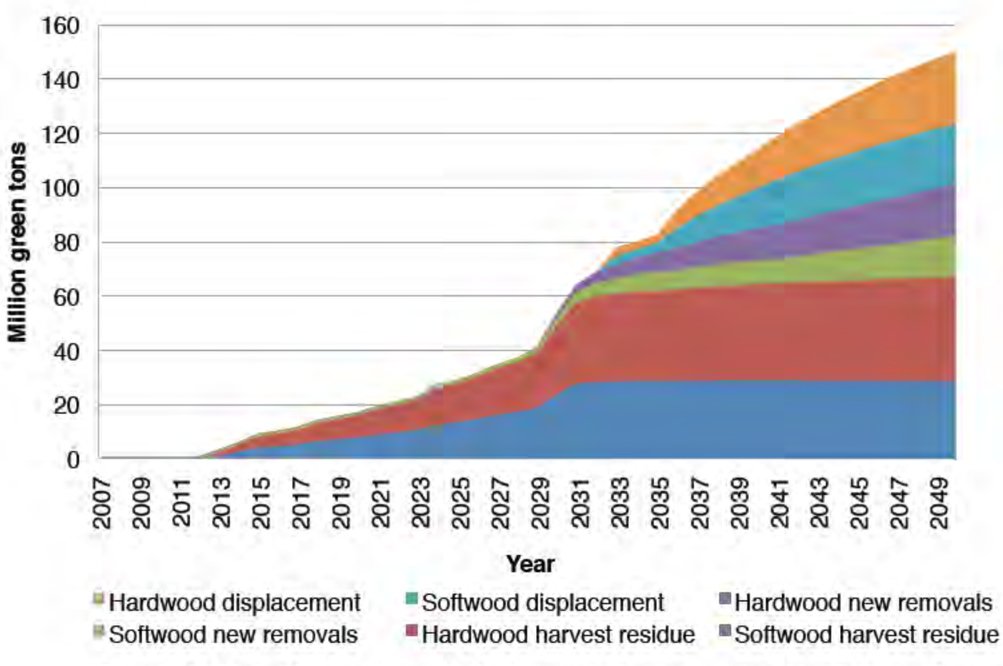


Figure 10.6—Feedstock composition in the South, assuming low consumption of woody biomass for energy.

forest industry for energy production (fig. 10.6), with 22 million green tons of softwoods and 26 million green tons of hardwoods diverted for bioenergy production by 2050. The impact of woody bioenergy markets on sawtimber is insignificant as the displacement of nonsawtimber products takes care of additional woody biomass requirements.

Under this scenario, private forest acreage declines by 3 percent from 175.39 million acres in 2010 to 170.86 million acres in 2050 (fig. 10.7), although still 8 percent higher than for the no bioenergy consumption scenario. Pine plantation acreage increases by 7 percent accompanied by declines in the other forest management types. The increase in pine plantation area is consistent with expansion in pine planting by landowners in response to increased product prices.

Medium woody biomass consumption—Compared to the low-consumption scenario, this scenario produces more dramatic price increases earlier (fig. 10.8). By 2050, prices of nonsawtimber softwoods, nearly four times higher than 2010 levels, are somewhat moderated as landowners by increase plantings and higher pine plantation acreages in response to greater demand, causing inventory to be higher than both the no-consumption and low-consumption scenarios. Nonsawtimber hardwood prices are even higher because the model assumes that landowners will not plant slow growing hardwoods in response to increased scarcity. Plantations of fast growing hardwoods (short rotation woody crops) have been treated separately as part of agriculture, and are not included in new plantation response. The pulp industry is adversely impacted as significant supply is diverted from forest industry to energy production (fig. 10.9). Forest industry demand for nonsawtimber hardwoods is completely wiped out by 2039, and 82 percent of stocking is diverted for energy production by 2050.

Price declines for sawtimber are lower, resulting in higher price levels in the later years of this scenario compared to the no-consumption scenario. The inventory and removals also respond to the price increase, as higher prices and inventory levels translate to increases in removals. The sawtimber industry faces significantly lower impact as most of the bioenergy demands are met by displacement and new removals of other hardwoods and softwoods.

Under this scenario, the private forest acreage increases by 3 percent from 175.39 million acres in 2010 to 181.41 million acres in 2050 (fig. 10.10), 14 percent higher than the no-consumption scenario, largely caused by increases in pine plantation acreage (19 percent from current levels) that offset the decline in the other four forest management types.

High woody biomass consumption—Compared to the medium- or low-consumption scenarios, this scenario assumes that a larger share of the U.S. energy portfolio is sourced from woody biomass (fig. 10.11); with prices

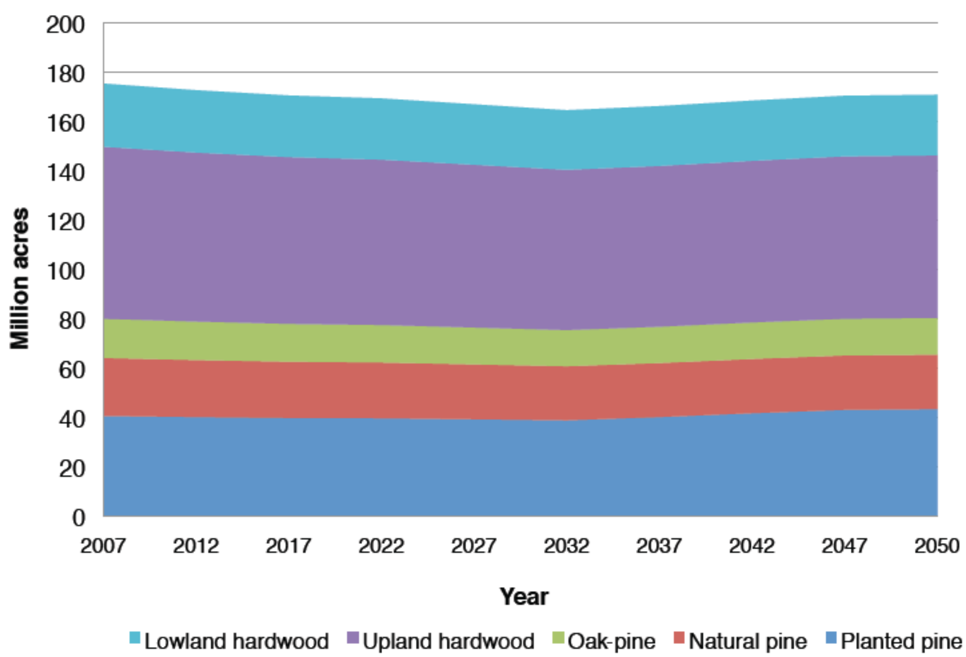


Figure 10.7—Private forest acreage change in the South, assuming low consumption of woody biomass for energy.

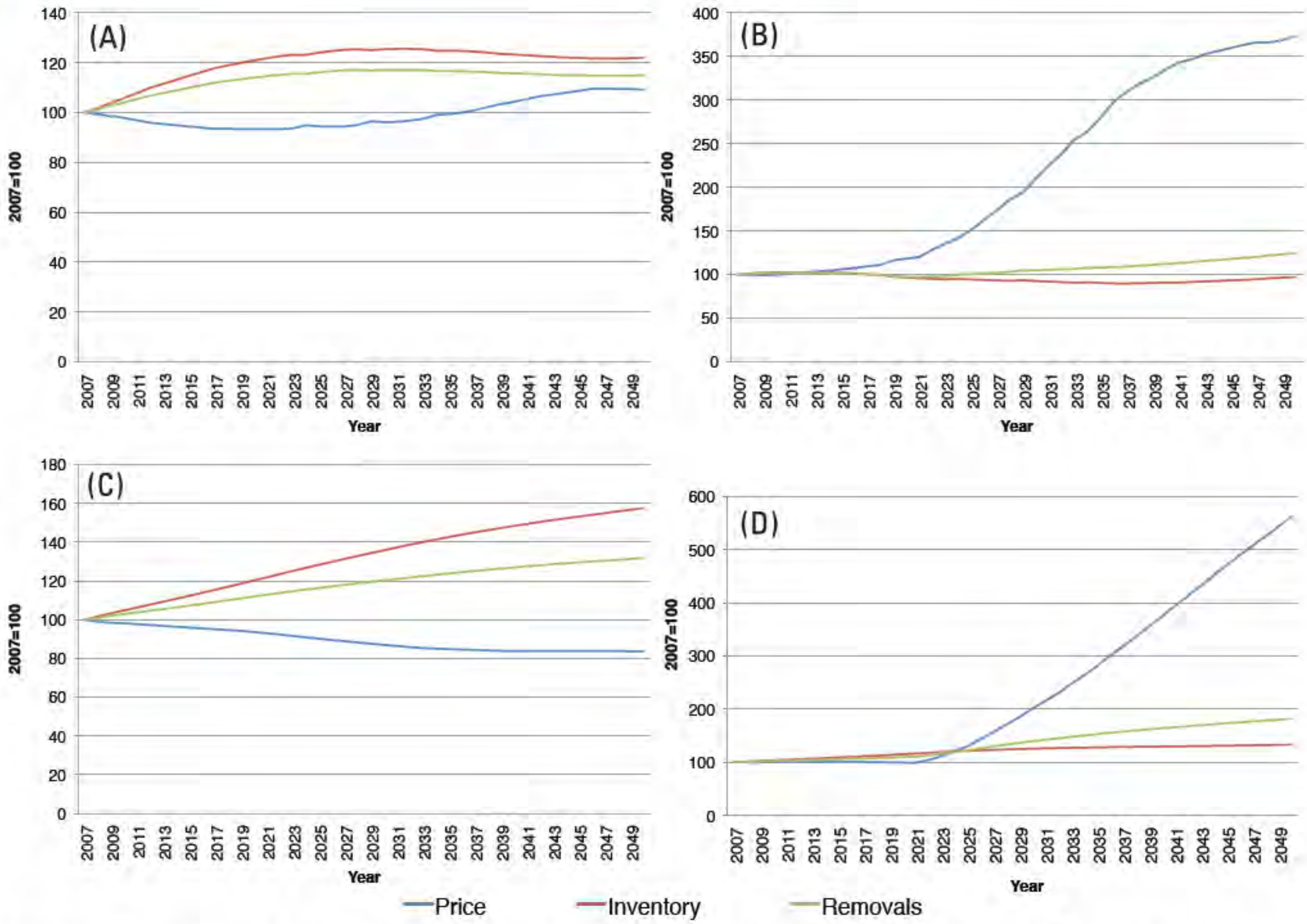


Figure 10.8—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming moderate consumption of woody biomass for energy.

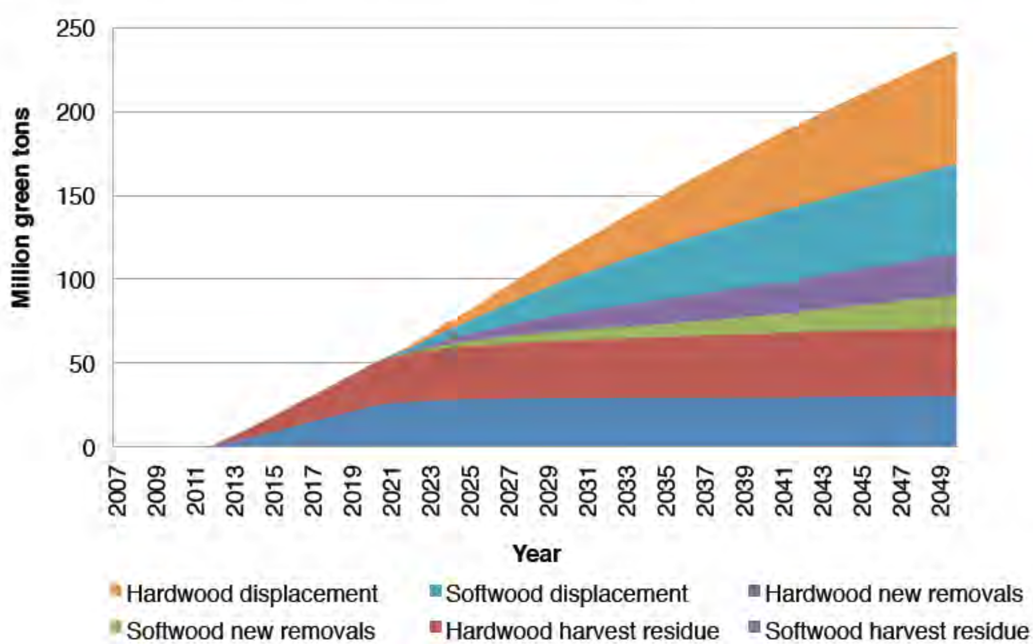


Figure 10.9—Feedstock composition in the South, assuming moderate consumption of woody biomass for energy.

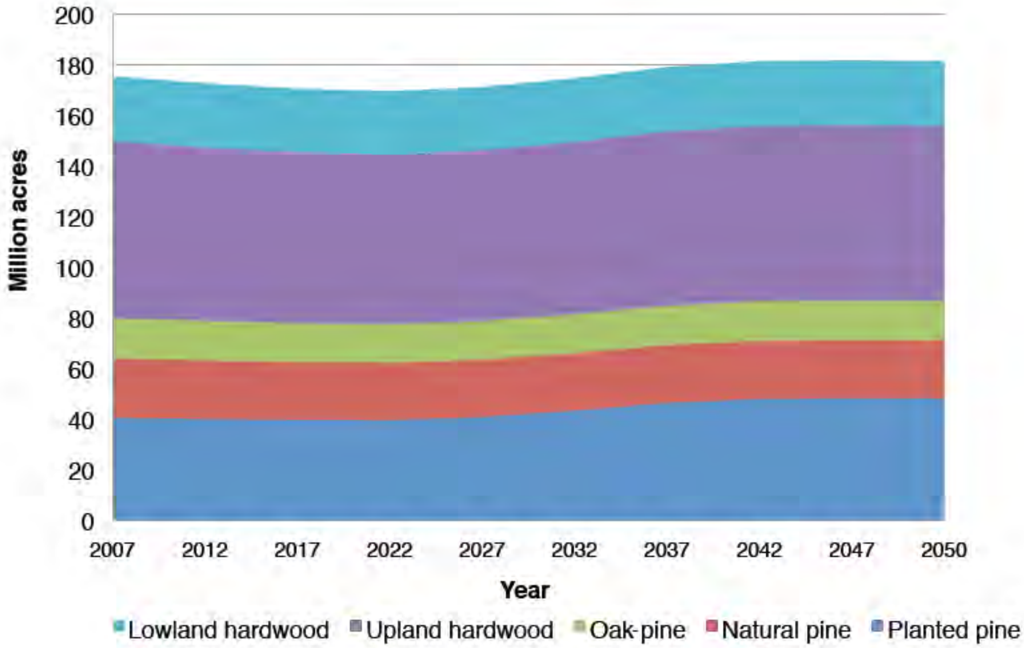


Figure 10.10—Private forest acreage change in the South, assuming moderate consumption of woody biomass for energy.

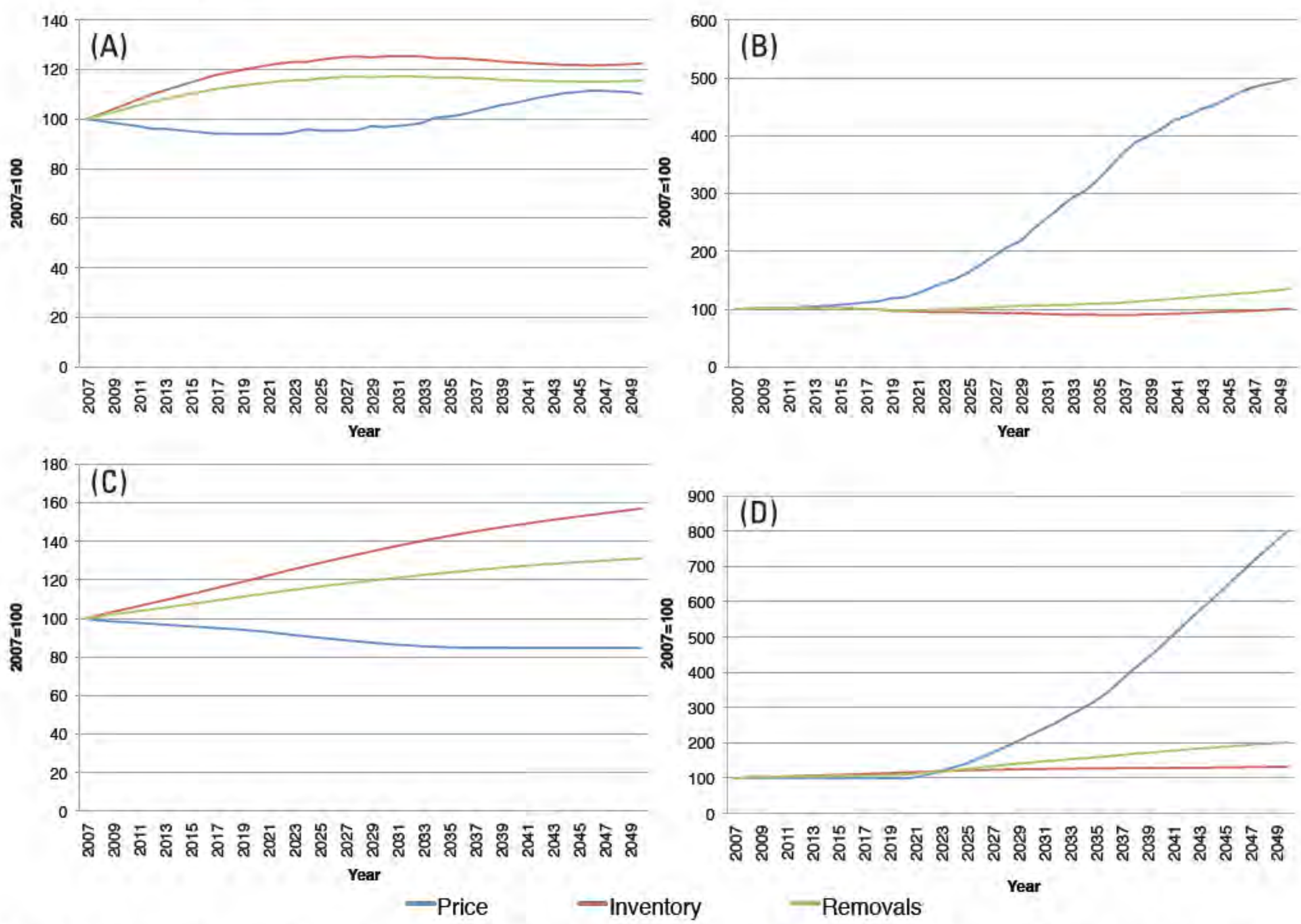


Figure 10.11—Market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods, assuming high consumption of woody biomass consumption for energy.

reaching five times the 2007 level for softwoods, and eight times the 2007 level for hardwoods. Inventory and harvest levels for softwoods are higher compared to low- or no-consumption scenarios, but lower than the medium scenario; for hardwoods, inventory levels are much higher than the no- or low-consumption scenarios and removals are higher than all other scenarios. The pulp industry is adversely impacted as significant supplies are diverted to energy production (fig. 10.12). The bioenergy requirement is not met by new removals, pulpwood, or harvesting residues, resulting in a complete elimination of forest industry demand for hardwoods by 2037 followed by softwoods in 2043.

The prices, inventory, and removal levels of sawtimber are similar to the other consumption scenarios. The industry would experience a significant impact as 91 million green tons of sawtimber is diverted to energy production. The increased acreage of pine plantations might result in some of the softwood timber moving to sawtimber diameters. Significant amounts of hardwood sawtimber are also diverted to energy production.

Private forest acreage increases by 9 percent from 175.39 million acres in 2010 to 191.6 million acres in 2050 (fig. 10.13), 21 percent higher than the no-consumption scenario. All forest management types except natural pines increase in area by 2050, led by a 33 percent increase in pine plantation acreage. Initial acreage declines for upland and lowland hardwoods and oak-pines are reversed after 2027, resulting in a 2-percent net increase by 2050.

Supply Adjustment Strategies

Increased consumption for wood by a new woody bioenergy industry can be expected to result in the supply side adjustments such as the use of short rotation woody crops and the increased productivity strategies described below.

Productivity increases limited to pine plantations—An increase in pine plantation productivity would do more to dampen nonsawtimber softwood price increases in the medium- and high-consumption scenarios (fig. 10.14) than in the no- and low-consumption scenarios (which do not stimulate productivity gains), with prices falling until the late 2020s before beginning to increase again. Inventory and removals levels are also higher. The increase in productivity of pines also lowers price responses for hardwoods, largely because increased softwood inventories fulfill the demands for bioenergy.

Figure 10.15 shows price, inventory, and removal projections for sawtimber under medium-and high-consumption scenarios. For softwood sawtimber, productivity increases in pine plantations also result in lower prices and higher inventory and removals under both increased productivity strategies, with the medium-consumption scenario providing a greater price dampening effect than the high-consumption scenario. Price trends are the same for hardwood sawtimber but the decreases are less extreme. Higher inventory levels result from the increase in productivity, which reduces prices. The impact on the sawtimber-using industry is also reduced. For example, in the high-consumption scenario 54.5 million green tons of sawtimber from both hardwoods and softwoods is diverted to energy use in the pine productivity strategy as compared to 91 million green tons associated with no productivity increases. The decreased impact on the forest industry is due to expanded removals supported by increased productivity.

Productivity increases result in higher removals and less displacement from forest industry (fig. 10.16). The softwoods being used by forest industry are still completely diverted for energy production in the high-consumption scenario, but this occurs later.

Forest management type trends are similar for the medium- and high-consumption scenarios, with increases in pine productivity resulting in lower levels of private forest acreage for both scenarios (fig. 10.17)—9.6 percent for the medium- and 10.2 percent for the high-consumption scenario—albeit much higher than for the no-consumption scenario. Because productivity gains are limited to softwoods, a higher share of the wood requirements for woody bioenergy markets is met by softwoods than hardwoods. Acreage declines across all five management types, with the highest rate of decline in pine plantations.

Productivity increase extended to all management types—A productivity increase for all forest types results in price, inventory, and removal responses that are similar to those observed for increases in pine plantations alone, the only difference being in the magnitude of change. Softwood price is lower and inventory and removal levels are higher (fig. 10.18). Hardwood trends for medium- and high-consumption scenarios are similar to the softwoods, with lower prices and higher inventories and removals than was projected for planted forest types alone (fig. 10.19).

Nonsawtimber softwoods used by forest industry are still completely diverted to energy production in the high-consumption scenario, but the impact on the sawtimber-using industry is reduced. For example, in the high-consumption scenario, 36.38 million green tons of sawtimber from is diverted to energy use as compared to 53.5 million green tons with pine productivity alone and 91 million green tons with no productivity (fig. 10.20). Higher removals of sawtimber are attributed to unharvested pulpwood timber moving into the higher diameter sawtimber class. The productivity increases therefore result in higher acreage and higher inventory at the aggregate level.

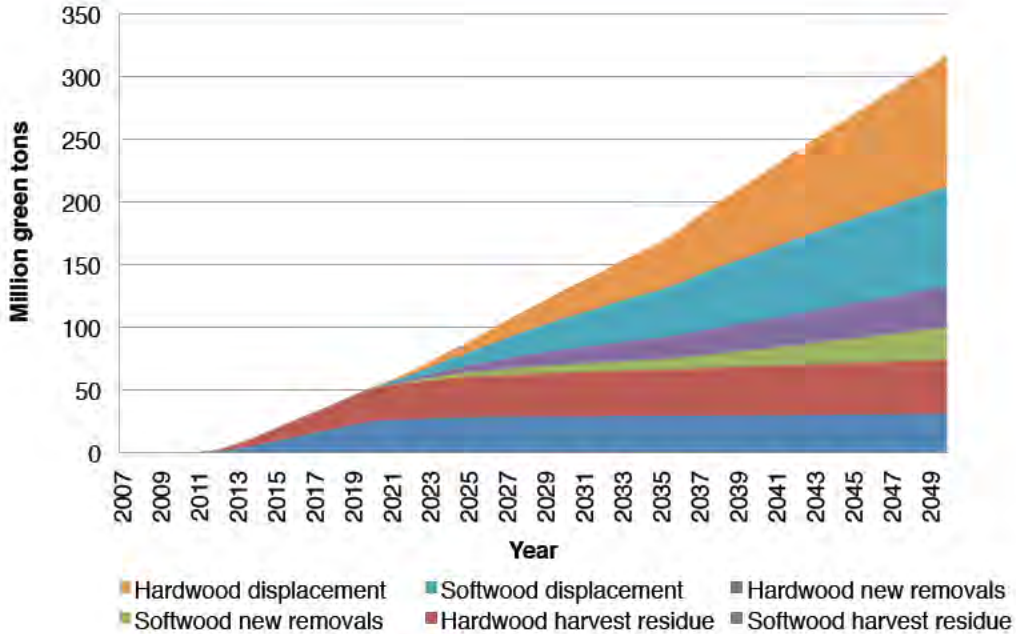


Figure 10.12—Feedstock composition in the South, assuming high consumption of woody biomass for energy.

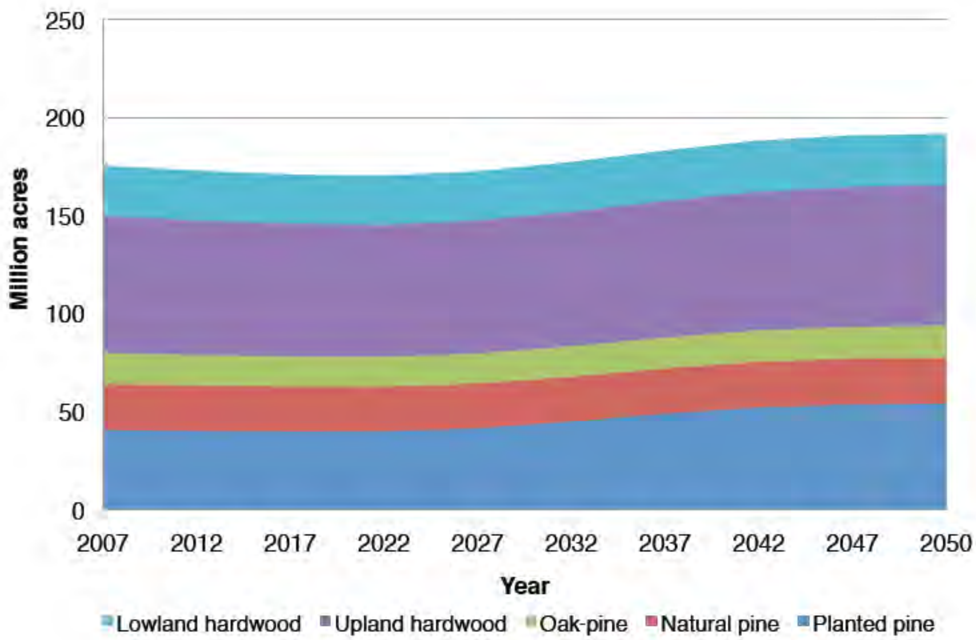


Figure 10.13—Private forest acreage change in the South, assuming high consumption of woody biomass for energy.

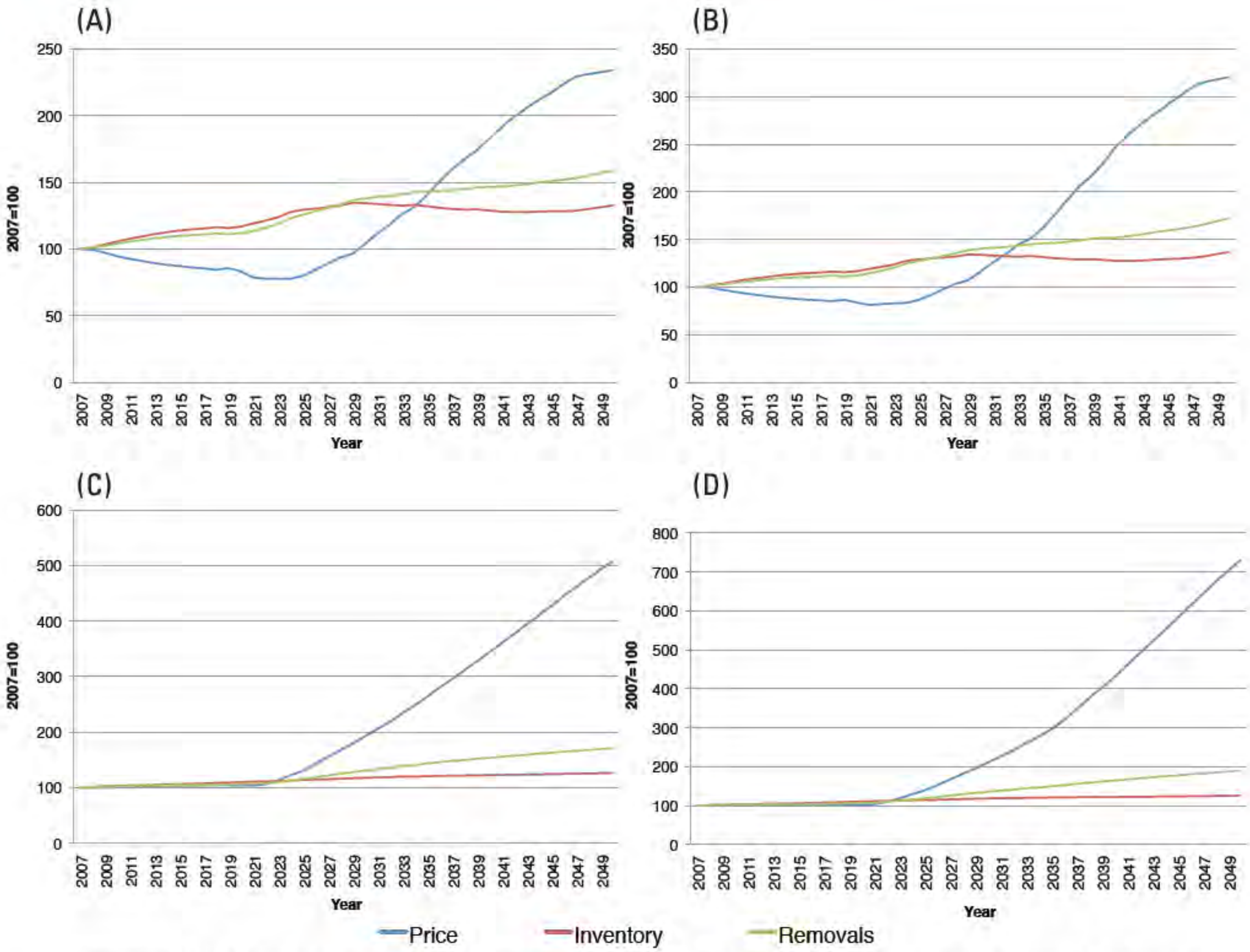


Figure 10.14—Under a productivity strategy that is limited to pine plantations, market responses in price, inventory, and removals for southern (A) nonsawtimber softwoods and (B) nonsawtimber hardwoods—both assuming moderate consumption of woody biomass for energy; and for southern (C) nonsawtimber softwoods and (D) nonsawtimber hardwoods—both assuming high consumption of woody biomass for energy.

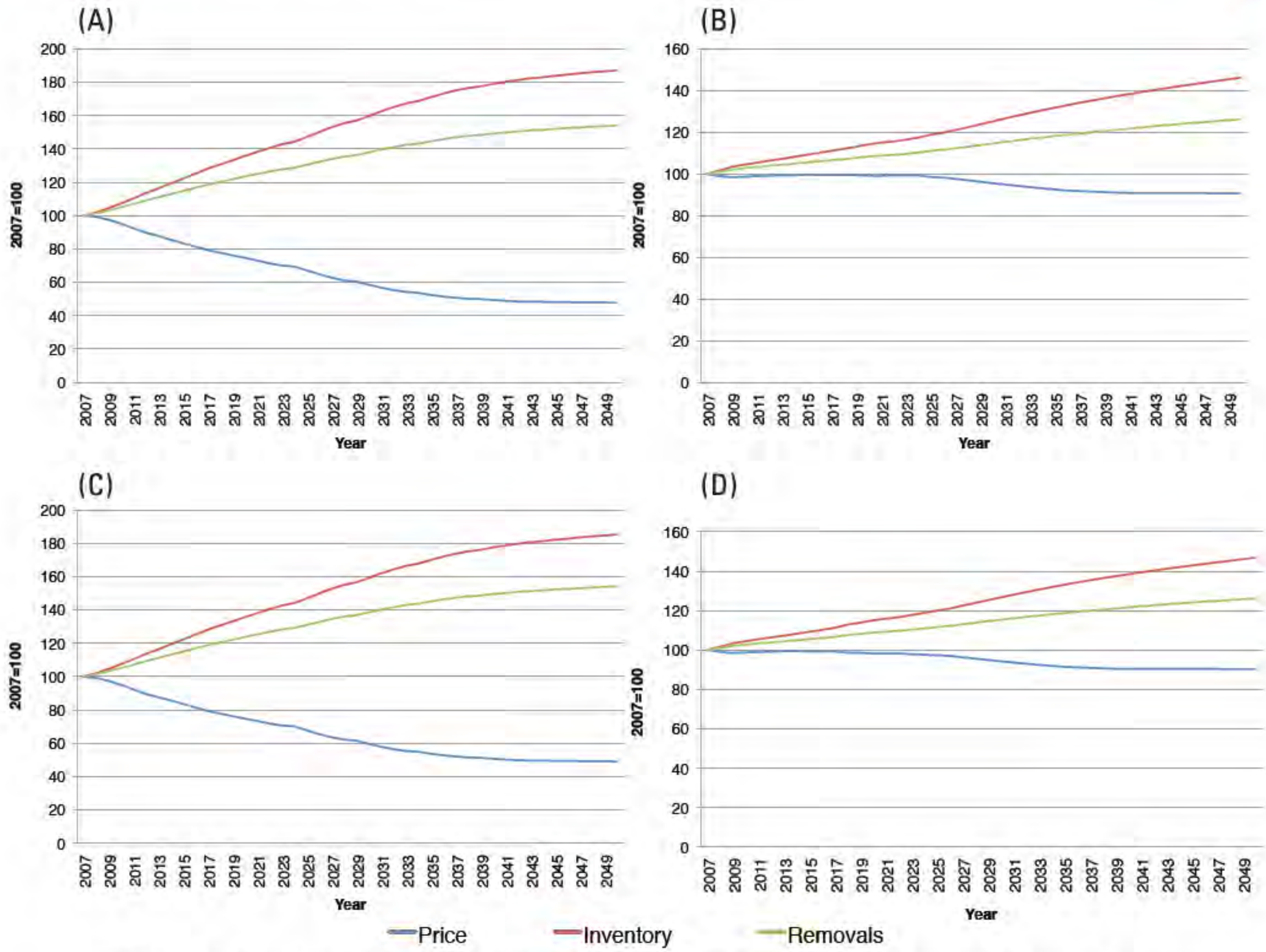


Figure 10.15—Under a productivity strategy that is limited to pine plantations, market responses in price, inventory, and removals for southern (A) softwood and (B) hardwood sawtimber—both assuming moderate consumption of woody biomass for energy; and (C) softwood and (D) hardwood sawtimber—both assuming high consumption of woody biomass for energy.

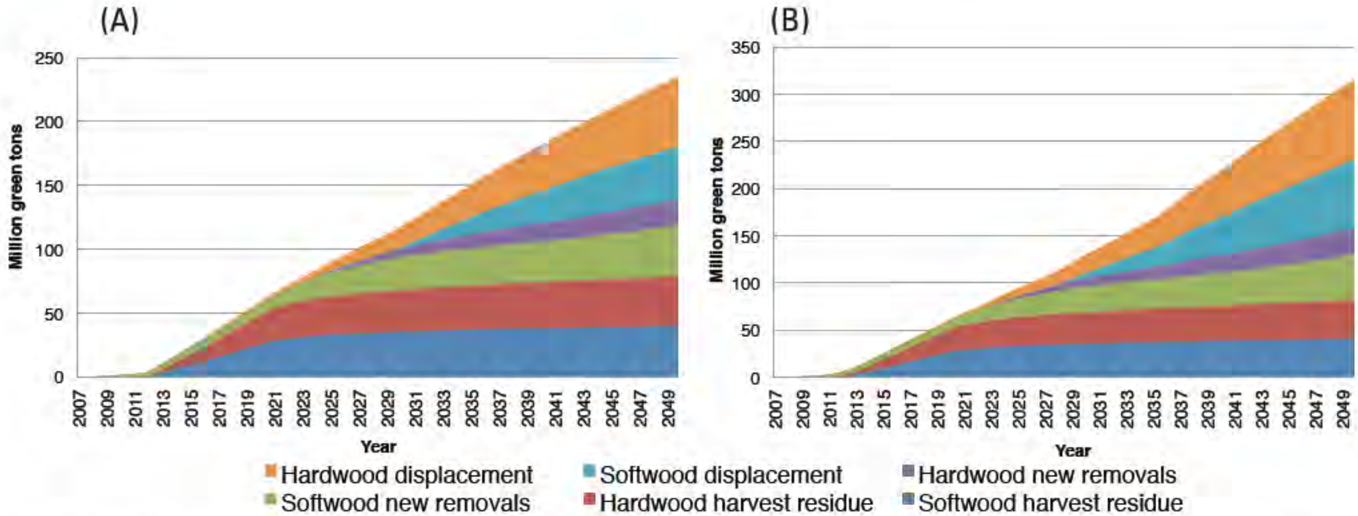


Figure 10.16—Under a productivity strategy that is limited to pine plantations, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

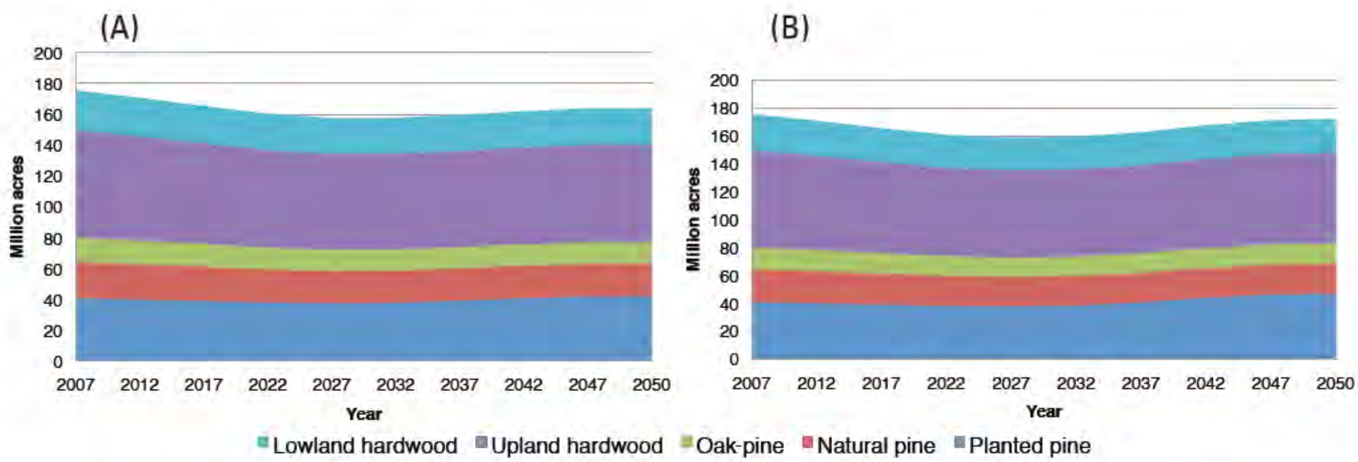


Figure 10.17—Under a productivity strategy that is limited to pine plantations, forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

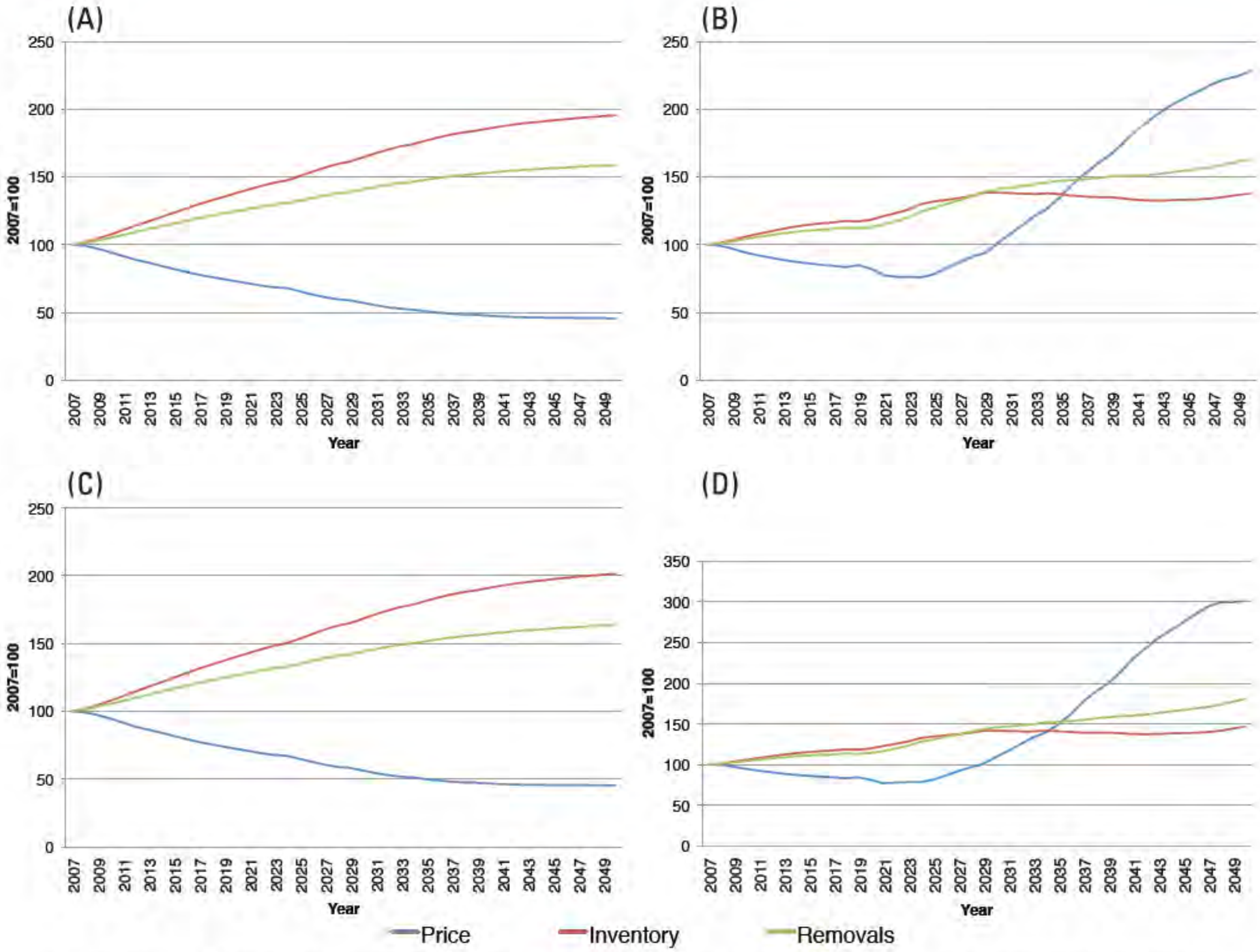


Figure 10.18—Under a productivity strategy that extends to all forest management types, market responses in price, inventory, and removals for southern (A) softwood sawtimber and (B) other softwoods—both assuming moderate consumption of woody biomass for energy; and (C) softwood sawtimber and (D) other softwoods—both assuming high consumption of woody biomass for energy.

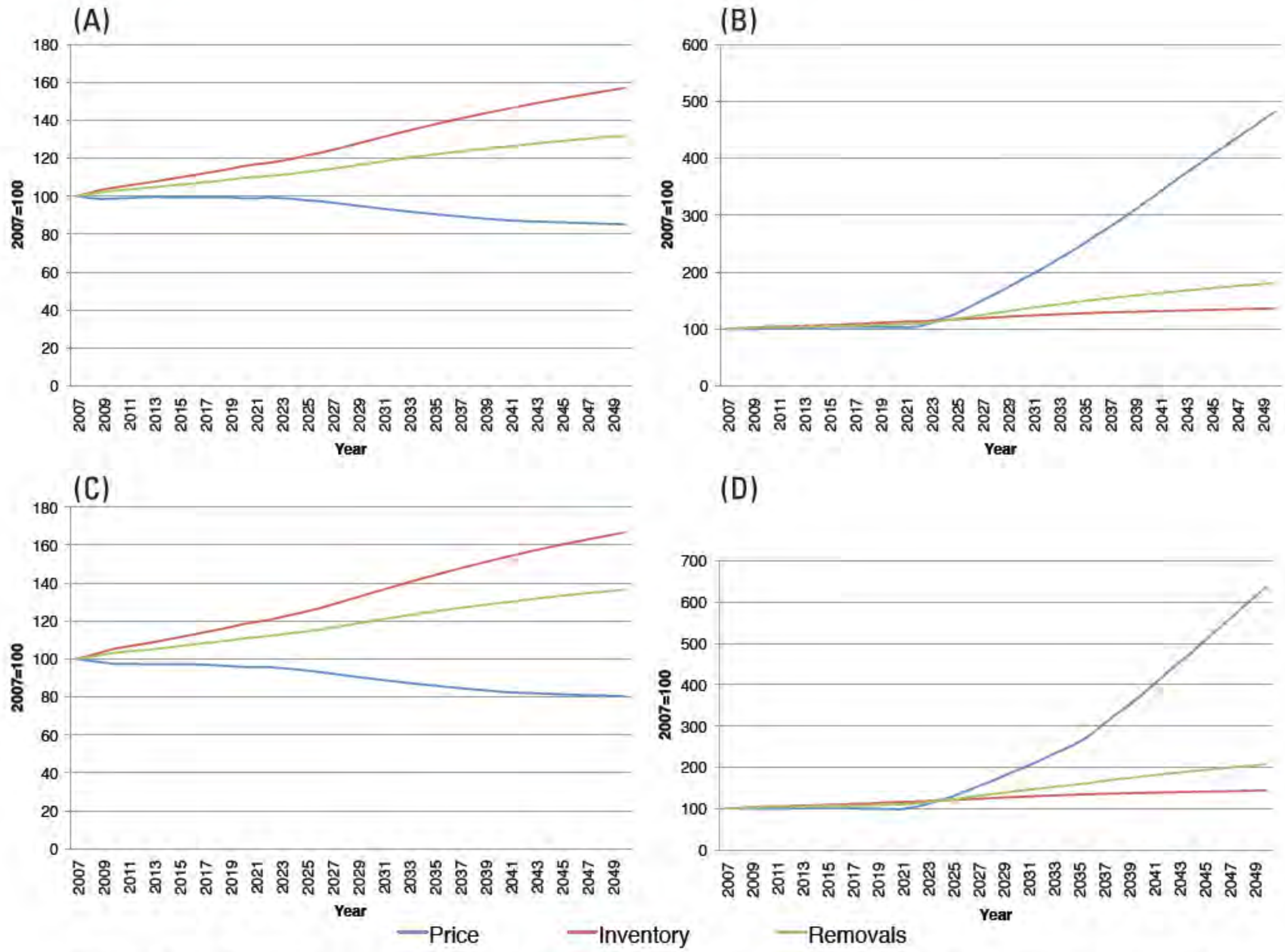


Figure 10.19—Under a productivity strategy that extends to all forest management types, market responses in price, inventory, and removals for southern (A) hardwood sawtimber and (B) other hardwoods—both assuming moderate consumption of woody biomass for energy; and (C) hardwood sawtimber and (D) other hardwoods—both assuming high consumption of woody biomass for energy.

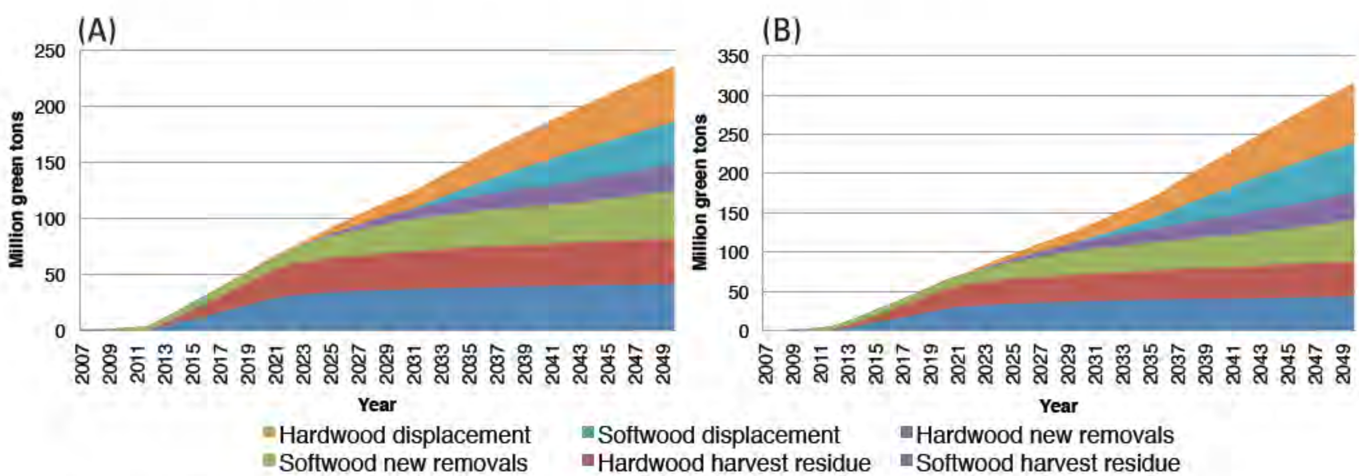


Figure 10.20—Under a productivity strategy that extends to all forest management types, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

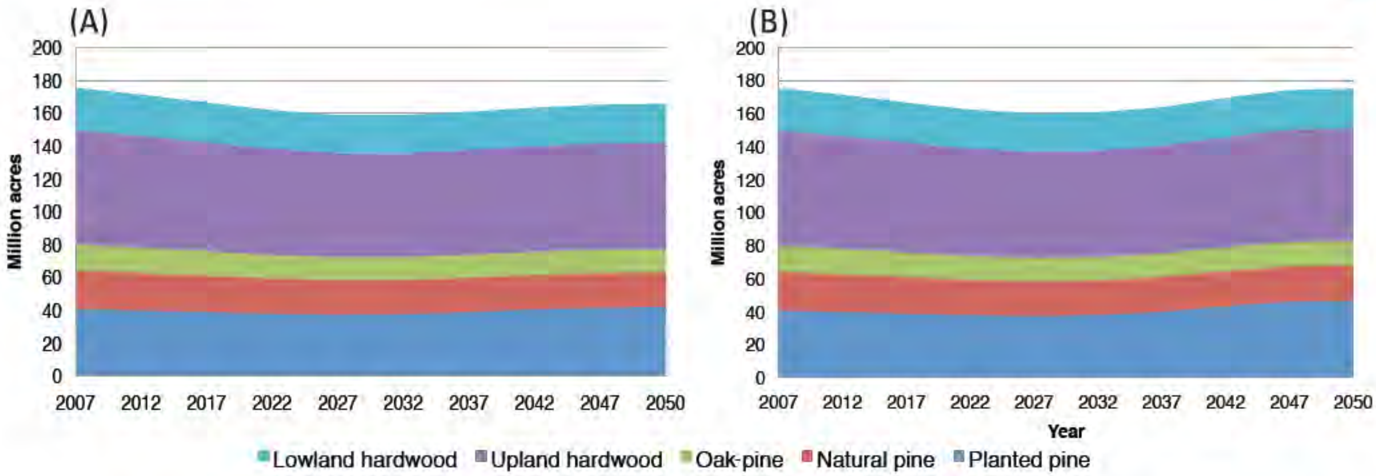


Figure 10.21—Under a productivity strategy that extends to all forest management types, private forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

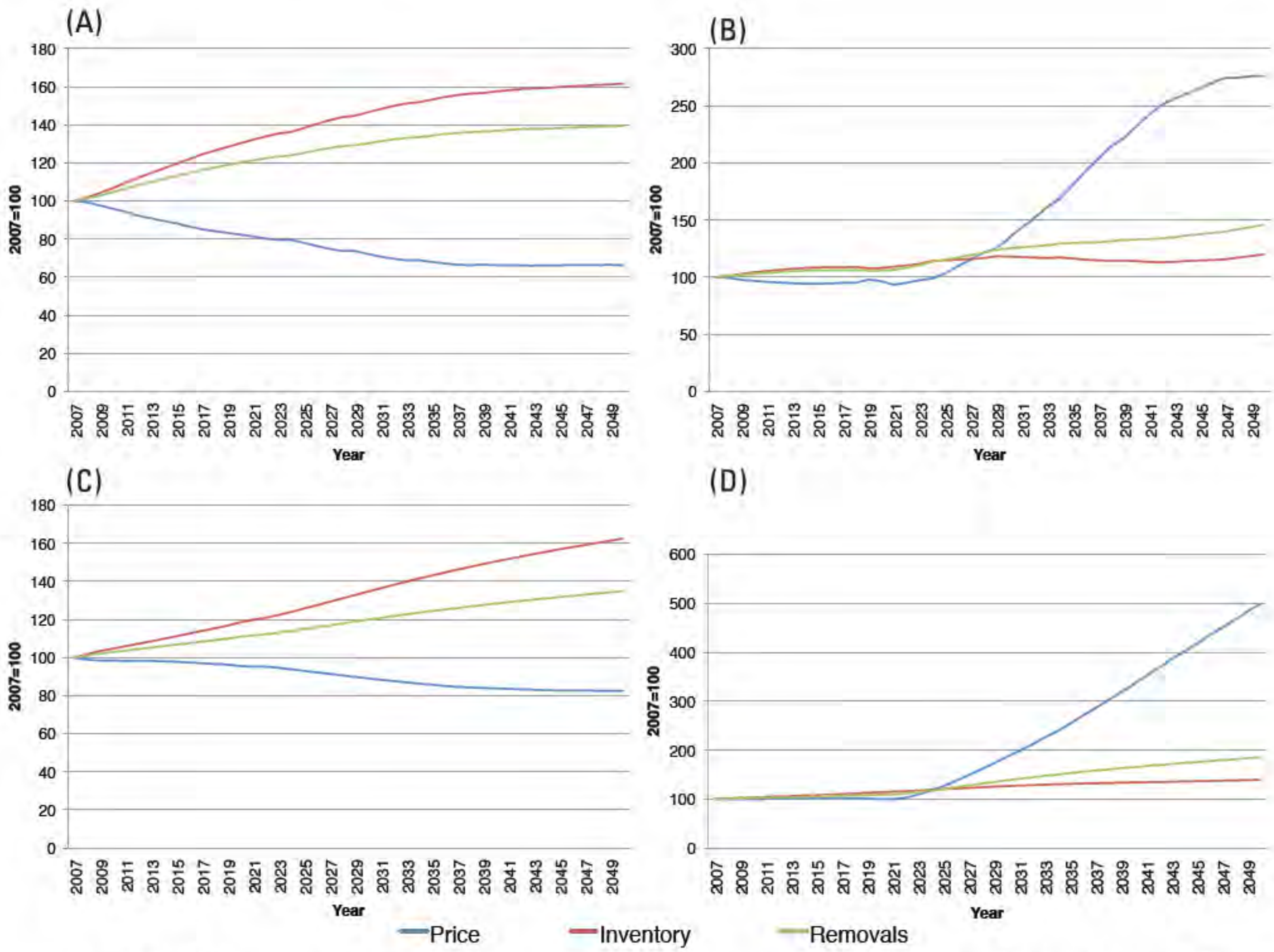


Figure 10.22—Under a low-productivity strategy, market responses in price, inventory, and removals for southern (A) softwood sawtimber (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods—all assuming moderate consumption of woody biomass for energy.

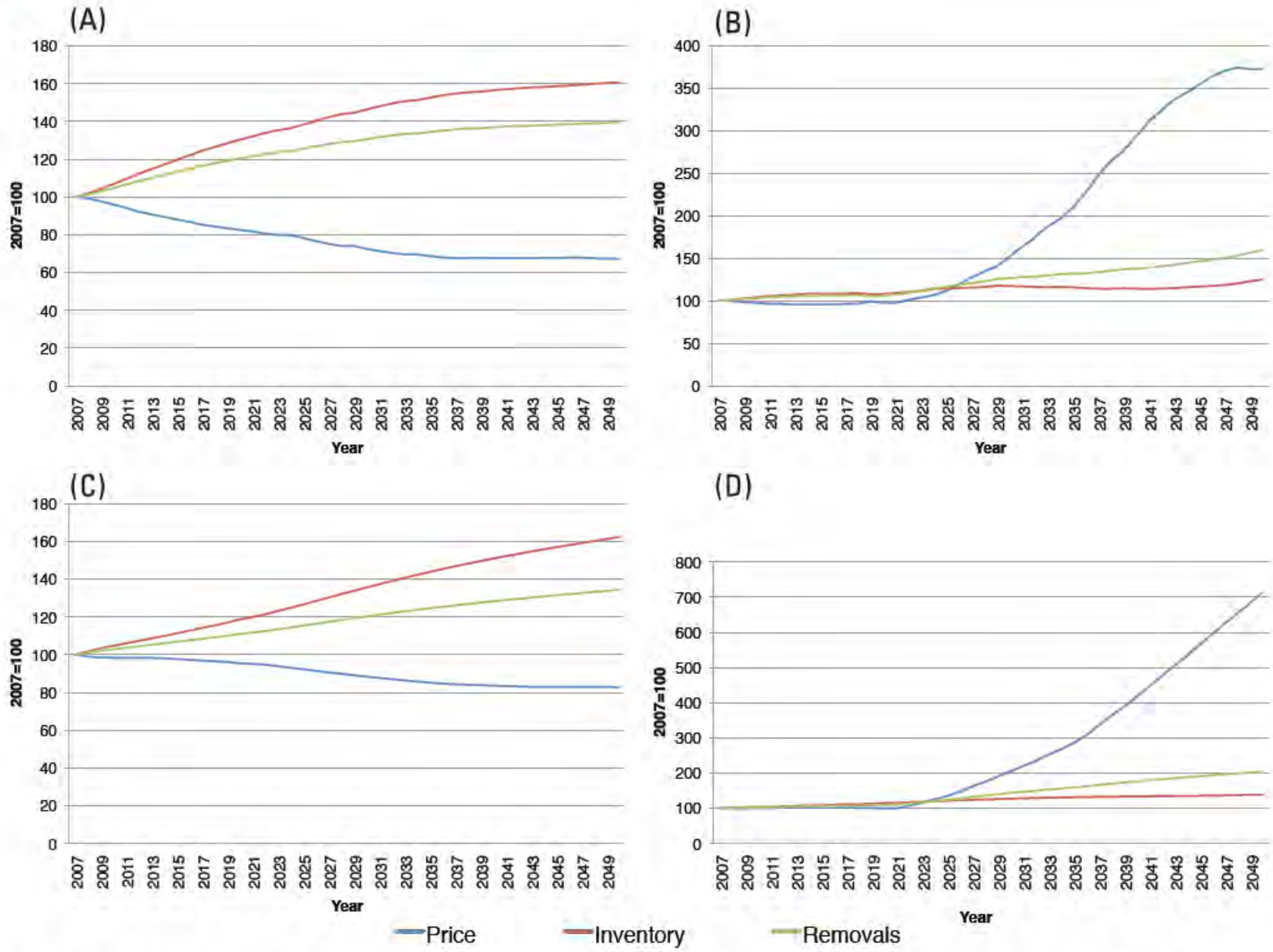


Figure 10.23—Under a low-productivity strategy, market responses in price, inventory, and removals for southern (A) softwood sawtimber (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods—all assuming moderate consumption of woody biomass for energy.

Compared to planted-pine-alone productivity strategy, this approach increases total forest area for both medium-consumption scenario (165.52 million acres) and the high-consumption scenario (175.01 million acres), with acreage increases for all forest management types except pine plantations (fig. 10.21).

Low productivity increase—Lower productivity increases combined with medium- and high-consumption scenarios result in price, inventory, and removal responses similar to the all productivity increase strategies (figs. 10.22 and 10.23).

The supply response of the low productivity strategy fails to offset the woody biomass requirements, with all nonsawtimber softwood being diverted from forest industry to energy production under the high-consumption scenario and a significant amount diverted under the medium-consumption scenario (fig. 10.24). The impact on the sawtimber-using industry is higher than for the all productivity or pine productivity strategies, but lower than if no productivity measures were taken. For example, in the high-consumption scenario, 57.18 million green tons of sawtimber is diverted to energy use as compared to 36.38 million green tons for the all productivity strategy, 53.5 million green tons for the pine productivity strategy and 91 million tons if no productivity measures were taken.

Private forest acreage is higher than for the other two productivity strategies. Forest land decreases from 175.39 million acres in 2010 to 172.47 million acres for the medium-consumption scenario, but increases to 181.85 million acres for the high-consumption scenario (fig. 10.25). Planted pine acreage increases more and other forest type acreage declines less as compared to the pine productivity or all productivity strategies.

Productivity increases on short rotation woody crops—We ran the model to simulate the results of a high productivity strategy coupled with the emergence of short rotation woody crops in the South. Inventories and removals (fig. 10.26) are higher than for the all productivity strategy coupled with high consumption (similar to results from a subsequent run combining a low productivity strategy with short rotation woody crops). Softwood and hardwood inventories are higher compared to the no-consumption scenario. Price increases for all products are dampened.

These results also suggest that the pulp industry would still face adverse impacts, as merchantable wood from forest industry would be diverted to energy production (fig. 10.27). However, the combination of increased supplies from short rotation plantations and from productivity gains on existing forests would provide most of the 'additional' sawtimber needed for energy production, resulting in just 26.7 million tons diverted from forest industry. The higher levels of aggregate inventory and removals counter the notion that diverting wood for energy would necessarily lead to inventory declines. Forest acreage is lower than for the other productivity strategies, but higher than the no-consumption scenarios (fig. 10.28).

Technologies

Considering the potential availability of wood that could be used in the traditional forest product industries and woody bioenergy industries, it is important to determine how current and likely suitable wood-to-energy conversion technologies can potentially impact the future of southern forests (for example, how technological preferences towards a particular species might increase its price, producing changes in inventory and removal). Dwivedi and Alavalapati (2009) found that a broad spectrum of stakeholders view conversion technologies as one of the main weaknesses for the development of forest biomass-based energy in the South. In addition, Nesbit and others (2011) found that under current levels of technology, slash pine ethanol is not a financially viable competitor for fossil fuels. They found that unit cost of producing ethanol from slash pine (*Pinus elliottii*) through a two-stage dilute sulfuric acid conversion process, and a synthesis gas ethanol catalytic conversion process was estimated to be $2.39 per gallon and $1.16 per gallon respectively. If adjustments are based on the lower energy content of ethanol relative to gasoline (Oak Ridge National Laboratory 2008), the cost of an energy equivalent gallon of ethanol increases to $3.55 and $1.74 per gallon for the two conversion processes, respectively.

Woody biomass can be converted into energy using a number of different processes. Broadly speaking, wood-to-energy conversion technologies can be grouped into two main categories: thermal technologies—such as co-firing and combined heat and power, direct combustion using wood pellets and wood chips, gasification and pyrolysis—and biochemical processes.

Co-firing and combined heat and power—Combustion of woody biomass can be applied to produce heat and electricity, particularly in industrial and residential sectors. Three major technology options are being developed for producing electricity and heat. These are: setting up dedicated cellulosic power plants, co-firing biomass in existing coal plants, and developing combined heat and power plants. All these options are being explored in the South, ranging from a dedicated power plant that will use urban wood waste, wood processing wastes, and logging residues in Gainesville, Florida to plants that blend biomass with coal or inject biomass separately into boilers. Currently, 27 co-firing plants supply a biomass/coal co-firing capacity of 2,971 megawatts. Virginia is the leader in the number of co-firing plants and capacity in the South, followed by North

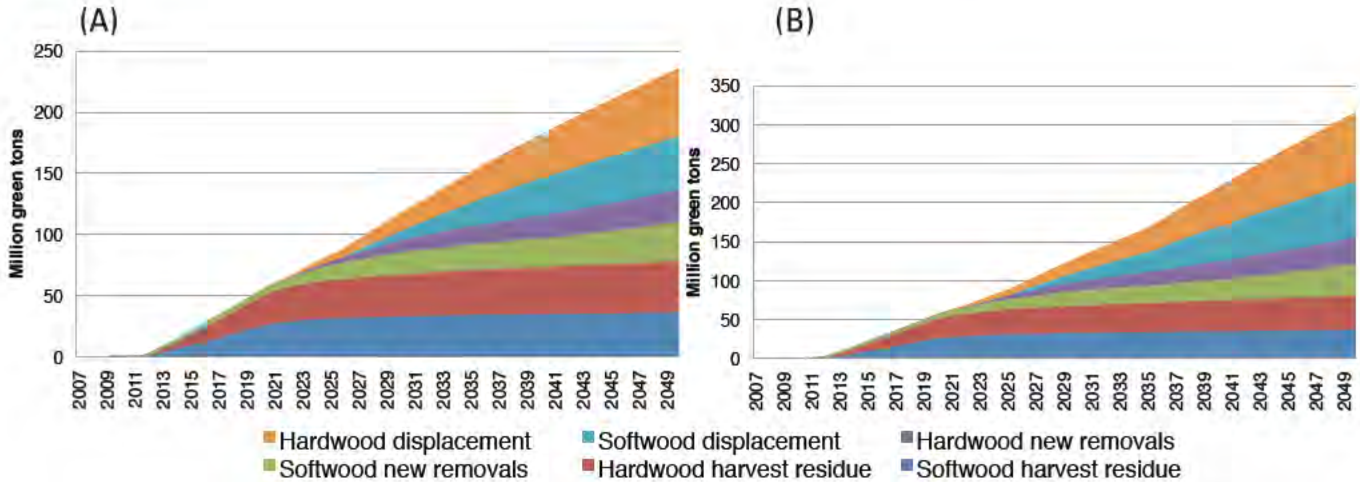


Figure 10.24—Under a low-productivity strategy, feedstock composition in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

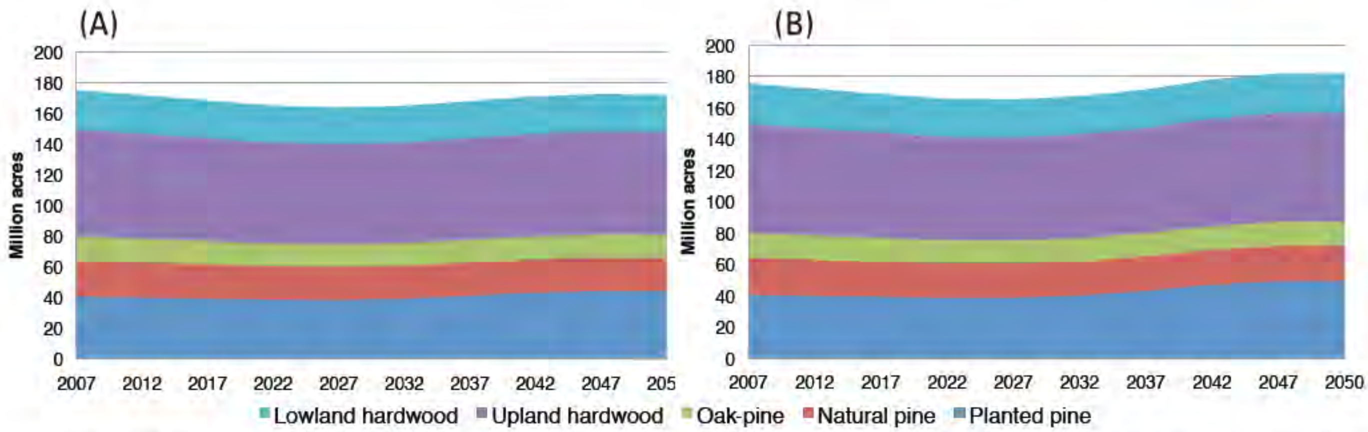


Figure 10.25—Under a low-productivity strategy, private forest acreage change in the South, assuming (A) moderate and (B) high consumption of woody biomass for energy.

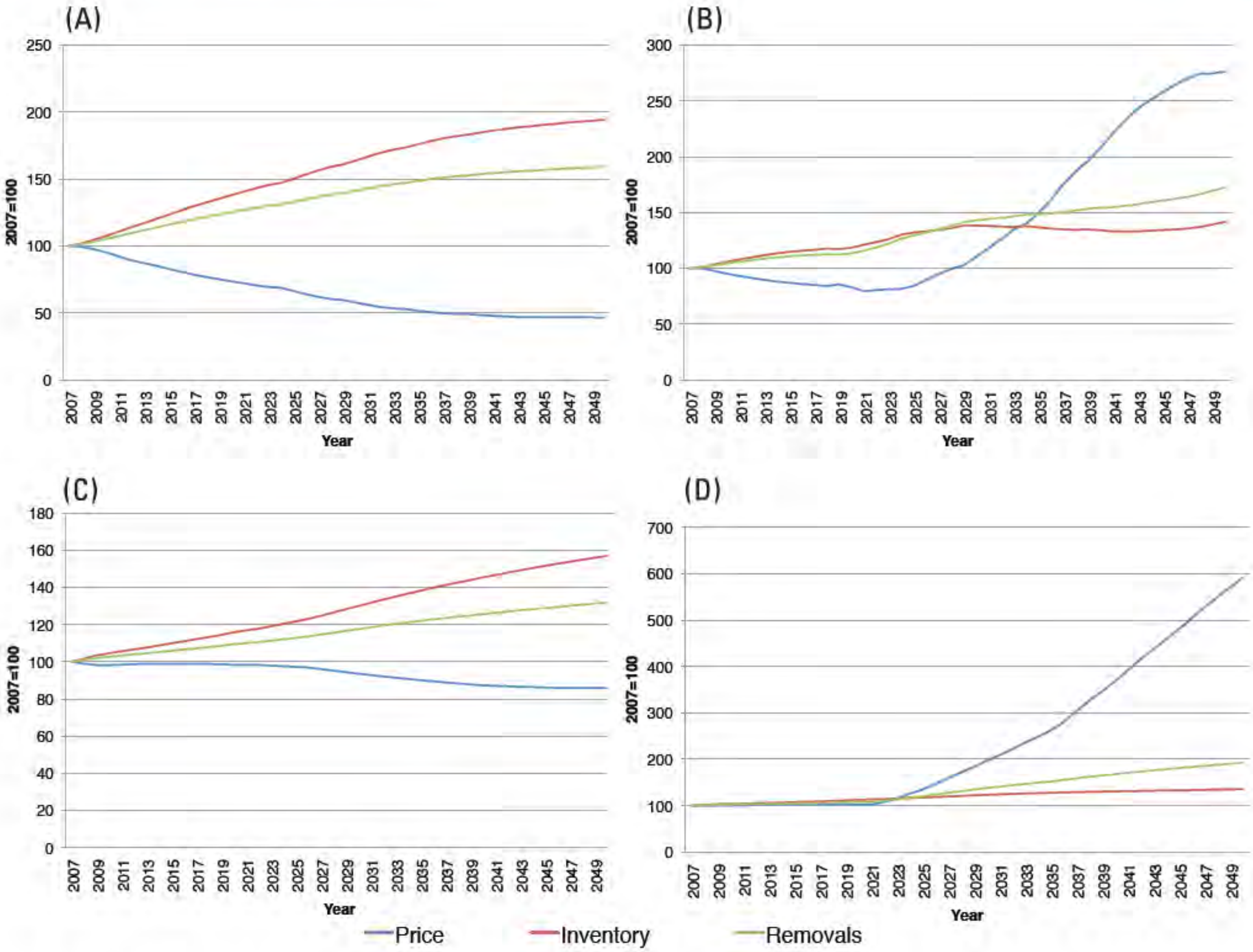


Figure 10.26—Under a high productivity strategy that expands short rotation woody crops, market responses in price, inventory, and removals for southern (A) softwood sawtimber, (B) other softwoods, (C) hardwood sawtimber, and (D) other hardwoods.

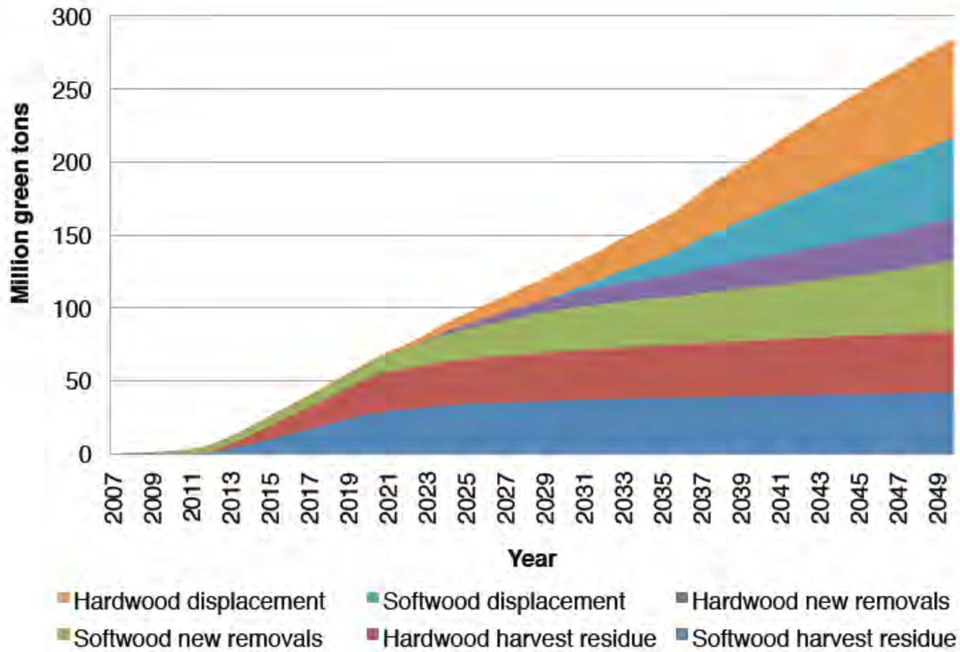


Figure 10.27—Under a high productivity strategy that expands short rotation woody crops, feedstock composition in the South, assuming high consumption of woody biomass for energy.

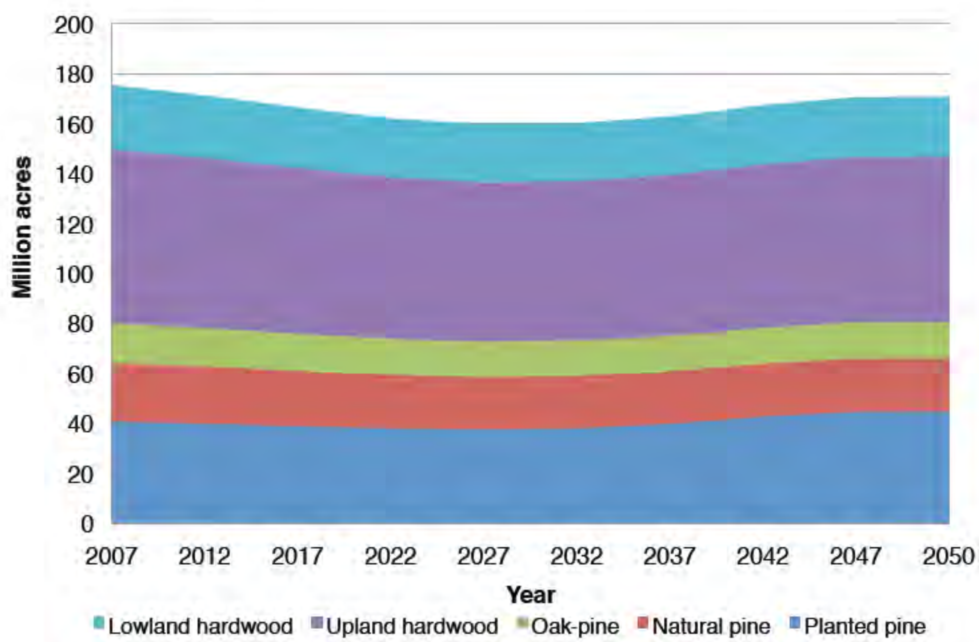


Figure 10.28—Under a high productivity strategy that expands short rotation woody crops, private forest acreage change in the South, assuming high consumption of woody biomass for energy.

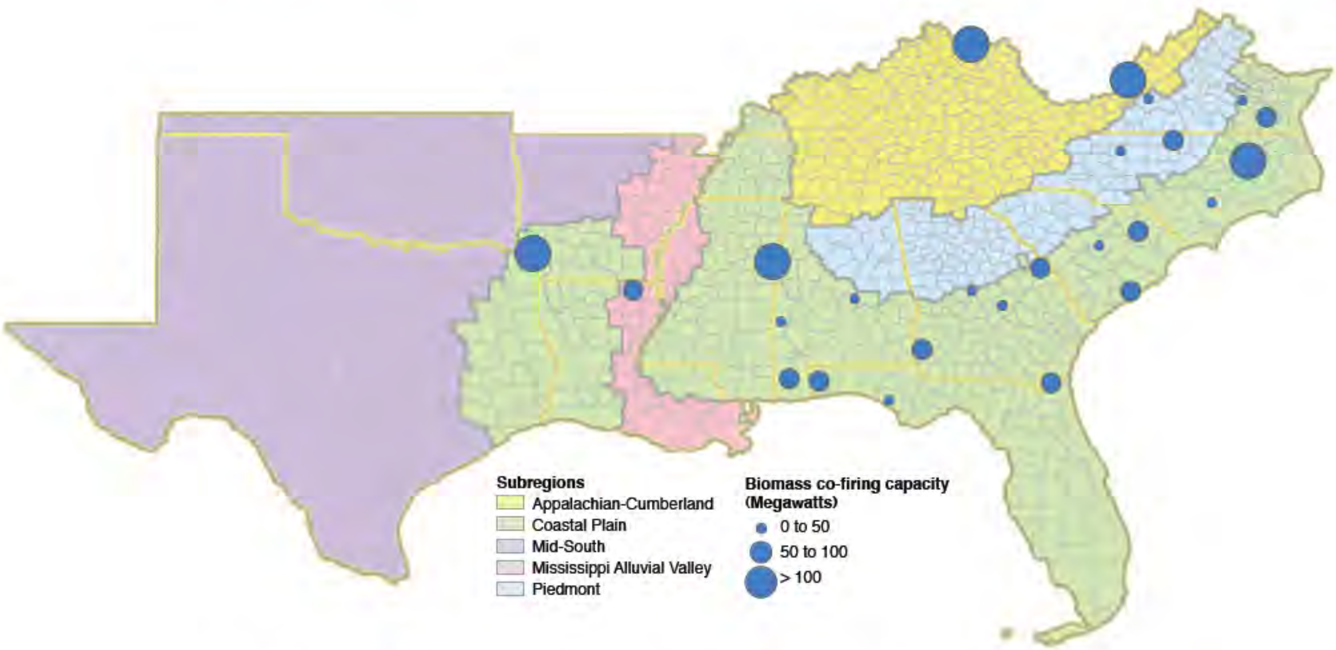


Figure 10.29—Co-firing plants, location and megawatt capacity, in the South, 2007. (Source: Energy Information Administration 2010c)

Carolina in terms of co-firing plants, and Kentucky in terms of co-firing capacity (fig. 10.29).

Combined heat and power plants are smaller and have lower electrical efficiency than co-firing plants, but they use a similar combustion system to generate heat and electricity. The primary product for small plants is heat, and electricity for the larger ones produce electricity as the primary product (Jackson and others 2010). They generate a net summer capacity of 20,336,000 megawatt-hours about 127,880 billion Btu of biomass fuels including agricultural crop byproducts, municipal solid waste, wood and waste solids, black liquor, sludge waste, wood waste liquids, and landfill gases. The South represents about 58 percent of the total consumption of biomass and 65 percent of the net generation of biomass-based electricity in combined heat and power plants (fig. 10.30). While it helps improve overall conversion efficiency, the Scandinavian-style community-based CHP systems might not work in the Southern United States. Most of the existing CHP use in the South is associated with the paper, pulp, and forest products industries. However, other entities are also focusing on CHP generation. For example, the Department of Energy is slated to replace coal for a steam plant at its Savannah River Site with woodchip and other biomass, while Baycorp Holdings Ltd. and the Nacogdoches Economic Development Corporation gained approval to set up the first woody biomass electricity plant in Texas.

Direct combustion using wood pellets and wood chips— Wood pellets, compressed byproducts from forest industry such as sawdust and woodchips, are used as fuel for domestic heating and for combined heat and power plants. These high-density pellets are characterized for having high energy content (about 40 percent higher than wood chips with 30 percent moisture content by mass and more than 300 percent by volume), being of uniform size and shape (facilitating automated handling), and being economically attractive. Rather than just using sawdust from mills for producing pellets, companies have built plants that use whole trees and chips as well. In the recent past, some of the largest pellet producers in the world have been established in the South, with 24 mills contributing about 46 percent of the country's 2 million ton annual capacity (Pellet Fuels Institute 2010, Spelter and Toth 2009). The States with the largest number of wood pellet mills are Georgia, Kentucky, and Virginia (fig. 10.31).

Gan and Mayfield (2007b) suggest that forest biomass, in general, is not cost competitive with coal for electricity production. Gan and Smith (2006a) through their comparative analysis of wood and coal based electricity found that the production cost of short-rotation woody crops was \$10.80 per Megawatt hour, more than double the national average price of delivered coal based electricity in 2005 (\$5.32 per Megawatt hour). Even the electricity from logging residues ranged between \$47 to \$50 per megawatt hour (Gan

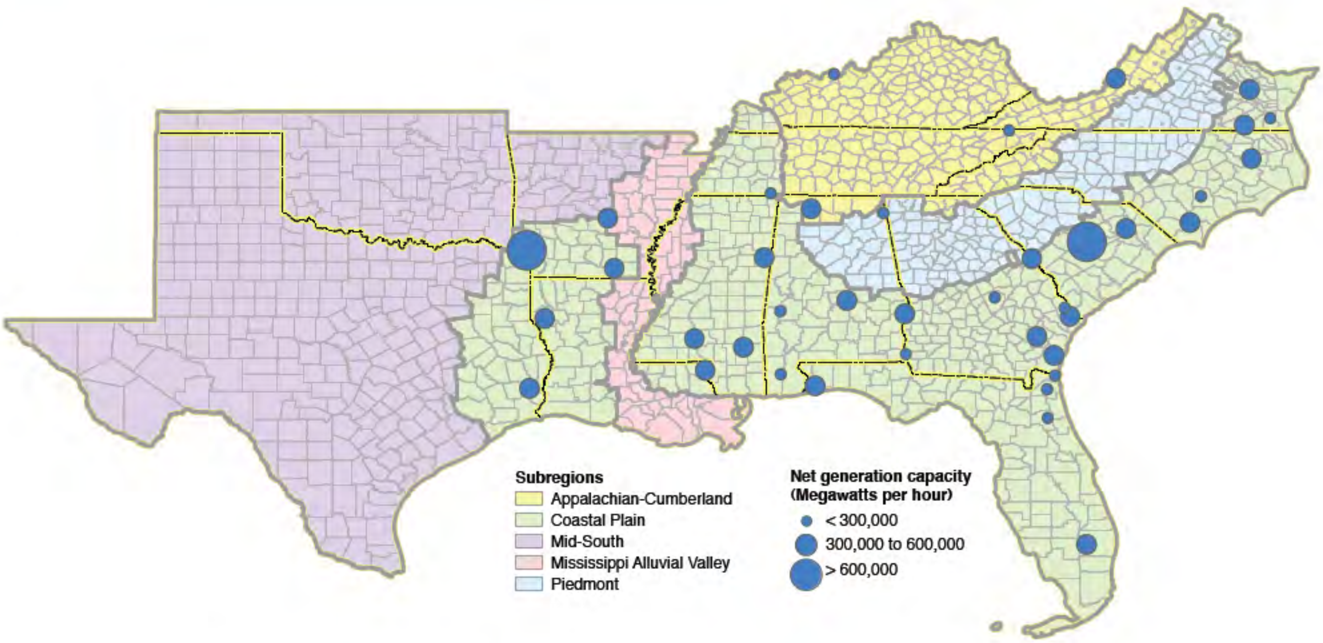


Figure 10.30—Combined heat and power plants, location and capacity, in the South, 2009. (Source: Energy Information Administration, 2010d)

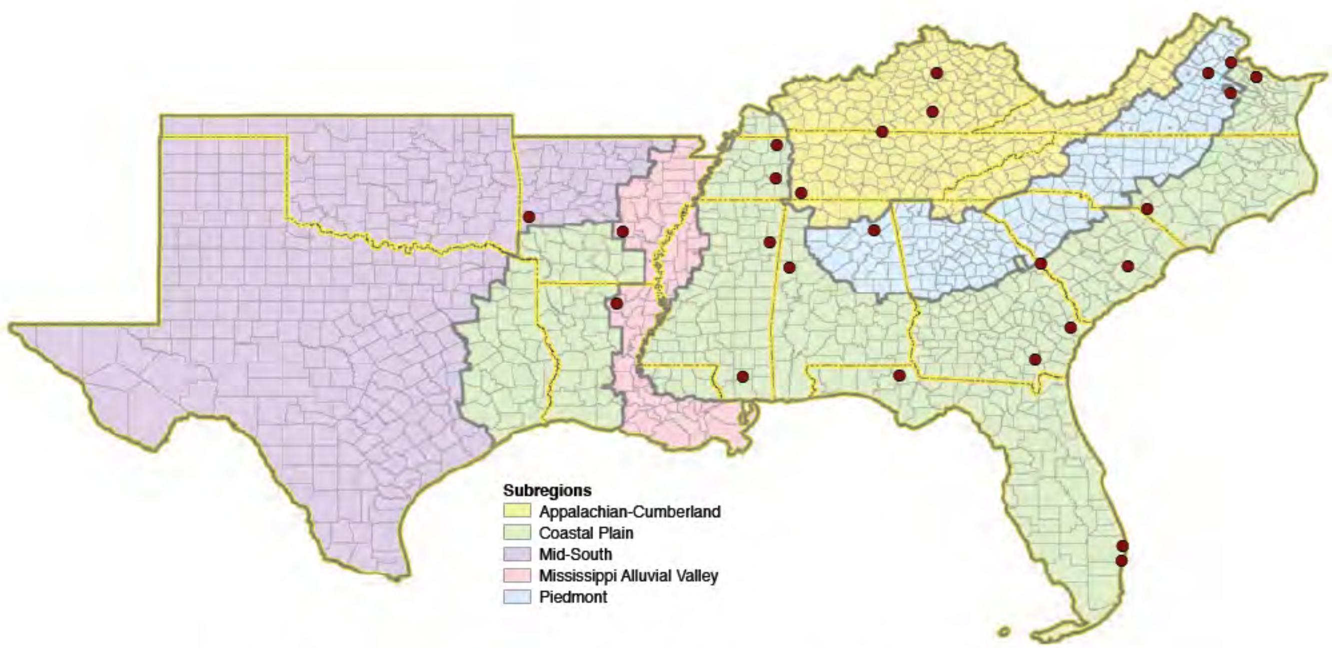


Figure 10.31—Wood pellet mills and locations in the South. (Source: Pellets Fuels Institute, 2010)

and Smith 2006b). Drawing from a study conducted in 15 Western States, the estimated costs for procuring biomass from forest fuel treatment thinnings range from $6.20 to $8.30 per Megawatt hour for cut and skid treatment, while this increases to cost $7.00 to $9.90 per Megawatt hour in cut/skid/chip method (USDA Forest Service 2005).

Other thermal technologies—Other thermal technologies (also known as advanced thermal technologies) are gasification and pyrolysis, both of which are technically feasible. Gasification is a high temperature process in which biomass is used to generate different bioproducts such as heat, electricity, methanol, ethanol, and syngas (hydrogen). If the gasification process includes a devolatization and conversion of biomass in a steam environment, it can produce a medium calorific gas that can be transformed into fuel for combined cycle power generation (Guo and others 2007). Otherwise, the syngas is converted to ethanol or hydrocarbon chemicals and fuels. Nexterra has commercial gasification units in British Columbia (Tolko and Kroger) using wood waste as a fuel source. A similar wood based gasifier is being set up in University South Carolina by Nexterra. Pyrolysis is a type of gasification technique that converts biomass at higher temperatures in the absence of oxygen to bio-oil (fast pyrolysis) and charcoal (slow pyrolisys). Bio-oil can be used as fuel in heating or electrical applications and for production of chemical commodities (Faaij and Domac 2006). Converting woody biomass to bio-oil increases energy density, which translates to improved transportability. Its main disadvantages are low heating value, poor ignition performance, and thermal instability (Jackson and others 2010). The pyrolysis plants are not yet commercially viable for large-scale production.

Biochemical—Processed biodiesel and ethanol (fig. 10.32) are the primary liquid fuels that can be derived from biochemical processes. Wood-based ethanol can be obtained through hydrolysis and fermentation. Cellulose and hemicellulose are broken down into sugars in hydrolysis, which are then fermented to generate ethanol.

Two hydrolysis stages are currently in practice: thermal, acid, alkaline, and biological pretreatments followed by an acid or enzymatic treatment. Hydrolysis and fermentation can be conducted separately or simultaneously. Separate processes

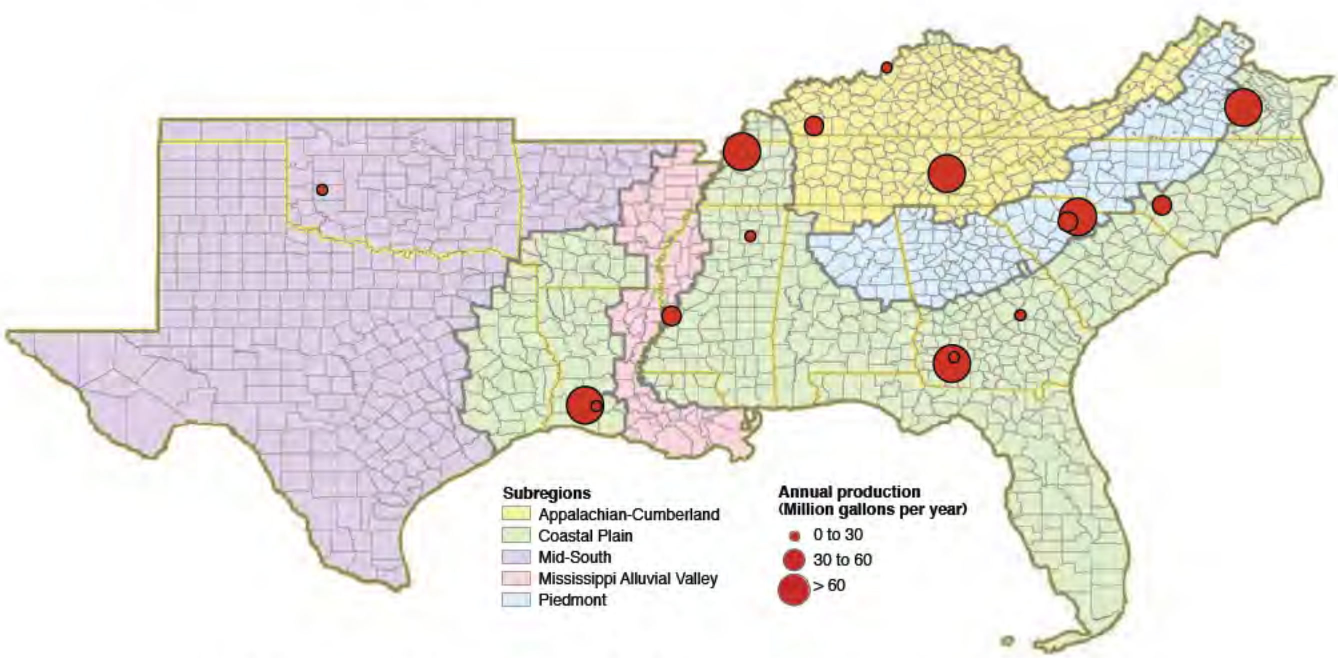


Figure 10.32—Producers of ethanol in the South, with locations and capacity. (Source: Renewable Fuels Association 2010)

are more expensive and have lower ethanol yields, but they allow each to be carried out at its optimal temperature (Jackson and others 2010).

Although several hydrolysis techniques have gained momentum in the last decade, efficiency and cost issues have hindered commercial viability. An integrated enzymatic process could contribute to cost reductions, but it has not yet moved out of the laboratory stage.

The Department of Energy set 2012 commercialization targets for research and development which included reducing the selling price of ethanol by 2012 to $1.07 rather than $1.61 per gallon, increasing ethanol yield per dry ton from 56 gallons in 2005 to 67 gallons in 2012, and reducing installed 2005 capital and operational costs by 35.5 percent and 65.3 percent respectively. For fermentation based ethanol production, the target is to increase yield from 65 gallons per ton in 2005 to 90 gallons per ton in 2012. The target also sets feedstock cost target for 2012 as $35 per dry ton. Efforts are ongoing to achieve these targets, but no technological breakthrough has yet achieved these large-scale production targets. The Range Fuel plant in Soperton, Georgia produced waste wood methanol in August 2010, and currently producing its first batch of cellulosic ethanol. However, the plant is shutting down operations after demonstrating its cellulosic production technology. The scale of bioenergy plant in terms of capital and biomass demands from the forest landscape are issues that need further attention. If a large plant is set up, then the transportation cost of procuring biomass from areas farther from the plant site might increase per unit cost and/or lead to procuring lower quality feedstock. The scale of the plant not only depends on cost issues, but also on the purpose for which it is being built. For example, Van Loo and Koppejan (2008) suggest that small combined heat and power plant facilities with lower conversion efficiency (10 percent) can be used where heat is the primary product with power as the secondary product, while facilities (more than ten megawatts) generally have higher efficiency (25 percent) as they produce electricity as the primary product.

The Policy Environment

A number of current and proposed policies and programs may influence the future of woody biomass-based energy markets in the South. Some of these policies are directed specifically at the expansion of woody biomass use for energy, and others influence indirectly by focusing on reductions of greenhouse gas emissions.

Incentive-based policies provide financial support such as cost-shares, tax reductions, subsidies or grants, and low- or no-interest loans for project financing. The Database of State Incentives for Renewables and Efficiency (2010) reports that policies for renewable energy (including woody biomass for energy) in the Southern States are generally in the form of tax rebates, grants, loans, industry support, bonds, and performance-based incentives.

Regulatory and support mechanisms include policies that set goals, targets, and limits; and compel certain types of behavior, as well as creating supportive infrastructure and facilitating public educational outreach. Rules, regulations, and policies (regulatory and support policies) are in the form of public benefit funds, renewable portfolio standards, net metering, interconnection standards, contractor licenses, equipment certification, access laws, construction and design rules, green power purchasing guidelines, and green power policies.

Incentive-based policies—In an effort to support market-based solutions, Federal and State governments have introduced a number of incentive-based policies. This generally results in altering prices by assigning a monetary value to something that was previously external to market forces (Shrum 2007). Subsidies are intended to encourage planting and management activities that might promote feedstock availability, and tax support encourages the use of renewables. Support in the form of grants and loans are also provided to encourage clean technology development and adoption.

Incentives for liquid biofuels were first instituted in the Energy Tax Act of 1978, which provided a $0.40 per gallon exemption from the gasoline excise tax for blends with at least 10 percent ethanol. Then it was increased to $0.51 per gallon by the 1998 Transportation Equity Act of the 21st Century. The American Jobs Creation Act of 2004 replaced the excise tax exemption with a volumetric ethanol excise tax credit of $0.51 per gallon until 2010 (reduced to $0.45 per gallon by the Farm Bill of 2008). The Energy Independence Security Act (2007) provided a production tax credit of $1.01 per gallon for cellulosic biofuels through 2012. The following section summarizes the current bioenergy policies in the South.

The 2008 U.S. Farm Bill created a new Biomass Crop Assistance Program (BCAP) to encourage development of large-scale energy crops that can support commercial-scale bioenergy production. BCAP provides incentives to farmers, ranchers, and forest landowners to establish, cultivate and harvest biomass for heat, power, bio-based products, and biofuels. The program shares the establishment cost and matches cost related to transportation and logistics up to $45 per ton to producers with user facilities contracts. The program reduces the financial risk to farmers and forest landowners to supply eligible biomass materials to qualifying facilities, and can reduce the cost of raw materials to the facility. These also promote conservation and stewardship by emphasizing that biomass is collected and harvested

Table 10.4—Number of financial incentives for renewable energy at Federal and State levels (blanks indicate no incentives): Number in the parentheses means whether incentives are State governments (S), utility companies (U), local governments (L), or nonprofit organizations (N)

State(s)	Personal tax	Corporate tax	Sales tax	Property tax	Rebates	Grants	Loans	Industry support	Performance-based incentive
All States (Federal incentives)	3	4				3	5	1	1
Alabama	1(1S)				3(3U)	1(1S)	3(1S,2U)		1(1U)
Arkansas					2(1S,1U)		1(1U)	1(1S)	
Florida		2(2S)	2(2S)		12(1S,10U,1L)		6(1S,5U)	1(1L)	2(2U)
Georgia	1(1S)	1(1S)	1(1S)		10(1S,9U)		1(1S)		2(2U)
Kentucky	1(1S)	2(2S)	1(1S)		11(1S,10U)	1(S)	4(1S,1U,1L,1N)		1(1S)
Louisiana	1(1S)	1(1S)		1(S)			2(2S)		
Mississippi					5(1S,4U)		4(1S,3U)		1(S)
North Carolina	1(1S)	1(1S)	1(1S)	2(2S)	6(6U)	1(1S)	4(3S,1U)		4(3S,1N)
Oklahoma		1(1S)			3(3U)		6(4S,2(U)	1(S)	
South Carolina	1(1S)	2(2S)	1(1S)		6(6U)		6(1S,5U)		4(1S,2U,1N)
Tennessee				1(S)	2(1S,1U)	2(2S)	3(2S,1U)	1(S)	1(S)
Texas		1(1S)		1(1S)	27(25U,2L)	2(2S)	2(2S)	1(1S)	2(2U)
Virginia				1(1S)	1(1S)		1(1S)	1(1S)	1(1U)
Total	**9**	**15**	**6**	**6**	**88**	**10**	**48**	**7**	**20**

Source: Database of State Incentives for Renewables and Efficiency (2010).

according to an approved conservation, or similar plan to protect soil and water quality and preserve future land productivity.

Rebates followed by loans are the most popular financial incentives in the South (table 10.4). Federal financial incentives are mainly comprised of corporate tax rebates, research and development grants, and loans. Loans and performance-based incentives are the policies most frequently used in the 76 State financial incentive programs in the South. North Carolina has the largest number of State financial incentives (eight), and Texas has the smallest (two).

Few State programs are specifically aimed at increasing woody biomass stock for energy use, partly because wood-for-energy markets have not yet been established. However, more often than not, improvement in forest biomass availability and sustainable use is an offshoot although not the overarching goal of these programs. Although the minimum acreage and stocking levels for property tax calculations vary across Southern States, the general objective of all these taxes is to provide an incentive for managing land on a sustained yield basis and a disincentive for converting forest land to other uses. The objectives of State cost-share programs are to reforest cutover land, plant open land, or improve woodlands; and many States offer to share the costs of other forest management activities. For example, South Carolina has forestry commission cost-share programs and North Carolina has forest agriculture cost-sharing programs. These programs lead to higher availability of feedstocks for energy conversion.

Several Federal programs provide incentives for conservation of forestlands and maintaining sustainable forest management practices. For example, the Environmental Quality Incentives Program (EQIP) provides cost shares for installing greenhouse gas mitigating technologies and the Landowners Incentive Program provides financial assistance to landowners for a variety of conservation goals including carbon sequestration. The Forest Land Enhancement Program promotes additional carbon sequestration and other ecosystem services through cost shares with landowners. These programs help to reduce land use change away from forests, in turn indirectly maintaining the forest stock that can be used for energy production at a later date. Incentive programs for reforestation have long been established in a number of States. For example, Mississippi provides tax credits for reforestation.

Regulations and support programs—At the Federal level, the Energy Policy Act of 2005 established Renewable Fuel Standards, which mandated that transportation fuels contain a minimum volume of renewable fuels, starting with 4 billion gallons in 2006 and 7.5 billion gallons by 2012. The Energy Independence Security Act (2007) called for production of 36 billion gallons of biofuels by 2022, of which 21 billion gallons must be cellulosic biofuel. The 2008 Farm Bill authorized mandatory funding of $1.1 billion for the 2008 to 2012, providing grants and loans to promote alternative feedstock resources including woody biomass. Interconnection standards and green power purchasing have also been formulated at the Federal level.

Construction and design support for establishment of bioenergy production facilities and net metering available to biomass based energy facilities so they can sell power back to the grid are the most employed State-level policies in the South and 10 Southern States have also formulated renewable portfolio standards as targets for using cleaner sources of energy in utilities and industries.

Extension and support activities have facilitated knowledge transfers, technology demonstrations, and information sharing sessions; and have developed multi-stakeholder partnerships to reduce greenhouse gas emissions. Extension agents and specialists at land-grant universities and government institutions transfer knowledge about natural resource management (including woody biomass-based energy) to client groups, such as forest owners, foresters and other natural resource managers, tree growers, loggers, and forest workers. Non-State efforts aimed at landowners include a State Tree Farm program that recognizes landowners who are doing a good job of managing their land with a certificate, subscription to Tree Farm magazine, and Tree Farm sign to display on their property. Regular interaction between landowners and professional foresters is facilitated through periodic visits by foresters.

There have been number of efforts by policymakers in the United States to create markets as a mechanism to regulate GHG emissions, although no bill has yet become law. For example, the House passed the American Clean Energy and Security Act (a.k.a. Waxman-Markey) on June 26, 2009, and three other bills were submitted to the Senate in 2009 and 2010: the Clean Energy Jobs and American Power Act (Kerry-Boxer), the American Power Act (Kerry-Lieberman), and the Carbon Limits and Energy for America's Renewal Act (Cantwell-Collins). Waxman-Markey, Kerry-Boxer, and Kerry-Lieberman would create markets for emitting and offsetting carbon dioxide and permit the purchase of up to 2 billion metric tons of carbon offsets annually (Mercer and others 2011). Gorte and Ramseur's (2008) estimate that at a CO_2e price of $50 per metric ton, more than 800 million metric ton of CO_2e could be sequestered through afforestation activities, and approximately 380 million metric ton through improved forest management activities. Since 2010, little congressional effort has focused on climate in general and carbon sequestration policies in particular.

Forestry offset projects including mitigation of green house gases through bioenergy production can potentially accrue carbon credits but the accounting is challenging. Assuming that energy crops do not lead to land use changes, life cycle analyses of different biofuels (including woody biomass) suggest overall green house gas reductions (Blottnitz and Curran 2006, Eriksson and others 2007, Gustavsson and others 2007). Searchinger and others (2008) argue that life cycle studies have failed to factor in indirect land use change effects, and suggest that using U.S. croplands or forestlands for biofuels results in adverse land use effects elsewhere, thus harming the environment rather than helping it. Indirect land use change effects are difficult to assess, and today there is no generally accepted methodology for determining such effects. Fritsche and others (2006) argue for assessing indirect influence of bioenergy on land use change through measures such as land prices and rents. However, conducting such assessments at the site level and translating these to operational indicators is quite costly. A satisfactory methodology for incorporating the effects of indirect land use changes into the lifecycle greenhouse gas emissions of fuels remains an important challenge.

There are also policies and regulations that could limit development of a bioenergy industry in the South. The Environmental Protection Agency's final Greenhouse Gas Tailoring Rule, does not exempt biomass power producers from greenhouse gas permitting requirements, and might act to limit the establishment of bioenergy conversion plants (Mendell and others 2010). This rule treats carbon emissions from biomass combustion identically to fossil fuels emissions and increases costs associated with obtaining permits and costs associated with technology requirements, such as Best Available Control Technology. Mendell and others (2010) suggest that regulatory uncertainty created due to this regulation could affect establishment of 130 renewable energy projects, and $18 billion in capital investment across the country. Similarly, the Environmental Protection Agency's air quality permitting for biomass boilers impacts biomass based electricity producers adversely.

Assessing efficacy of policies—A number of researchers suggest that private landowners are by and large unresponsive to property tax and capital gains provisions, and that forest property tax programs are only modestly successful in achieving their goals (Greene and others 2005, Jacobson and others 2009, Kilgore and others 2007). Many authors have found that landowners are largely unaware of the existence of incentives or do not understand how incentives might apply to them. For example, Butler (2008) based on landowner responses to the Forest Service's National Woodland Owner Survey, concluded that not all landowners are price-responsive. Factors such as maintaining forest land for aesthetics or wildlife conservation, as well a movement towards smaller ownerships, might be responsible for this price unresponsiveness. Nevertheless, at aggregate level, these incentive based policies result in increased welfare, as shown by Huang (2010) who found that when combined with investment in technology, they can result in overall positive outcomes for the South's economy and household welfare.

Beach and others (2005) and Greene and others (2005) found that nonindustrial private forest owners more often respond to targeted government programs than to market prices or other financial incentives. They also suggest that technical assistance, cost-share payments, and direct contact with professional foresters or natural resource specialists more often than not succeed in changing forest management decisions. Authors like Haines (2002) and Arnold (2000) have proposed integrating land use planning (and woody biomass-based energy use) into extension programs. Educating landowners and the general public about the benefits derived from cleaner energy sources such as woody biomass will improve and increase interest in forest biomass utilization. Mayfield and others (2008) indicated that education and community engagement play important roles in the development of cleaner technology like wood-based energy. Joshi and Arano (2009) agree that landowners are largely unaware of incentive programs available to them, and thus argue that much remains to be done to encourage private investment in forestry activities. In light of these findings, extension and outreach support programs become important for increasing the acceptability of wood-for-energy technology options and improving forest and land management practices.

Sustainability

The development of forest bioenergy systems presents new opportunities as well as risks. Many sustainability concerns are being raised about wood biomass utilization for energy. These concerns range from production processes to consumption processes—feedstock production, harvesting, transport, conversion, distribution, consumption, and waste disposal—and include issues of job creation and societal benefit distribution.

Forests provide not only wood for traditional uses but also several ecosystem services such as clean water and biodiversity (Amacher and others 2008, Neary 2002, Stupak and others 2007). These potential impacts—grouped into productivity, water quality, and biodiversity categories—are described in detail below.

Productivity—The forest floor accumulates nitrogen, phosphorus, calcium, and other nutrients that are essential for tree growth. Unlike traditional timber harvests, biomass harvests for energy production could impact regeneration and site productivity unless productivity reductions associated with site quality are offset by fertilization. Studies of forest biomass based energy production raise concerns regarding soil compaction and rutting (Reijnders 2006), decreased amounts of decaying wood on forested landscapes, changes in the chemical and physical environment of soils (Astrom and others 2005), increased use of agrochemicals (Fritsche and others 2006), increased soil erosion (Burger 2002), and nutrient loss (Burger 2002). These issues suggest a need for intensified site and off-site monitoring where forest management is intensified.

The machinery used to build roads and infrastructure for biomass harvesting biomass for energy might be different from what was used in traditional timber harvesting and harvesting might take place in areas where timber harvesting is traditionally not undertaken, resulting in new roads or pathways (Lal and others 2011, Smith and Lattimore 2008). Frequency of harvests for biomass removal could also be generally higher than for traditional harvests, and second operations or harvest residue collections might result in vehicle re-entry at the site (Lal and others 2009). Intensive removals of forest biomass for bioenergy might reduce soil carbon and organic matter to levels that are inadequate for sustaining forest productivity. Hope (2007) through their site experiments in British Columbia observed that stump removal decreases the soil stock of carbon by 53 percent, nitrogen by 60 percent, and phosphorus by 50 percent; and that the forest floor depth was decreased by 20 to 50 percent. Peng and others (2002) through their study in Central Canada reported that whole-tree harvesting produces an additional 32 percent loss of soil carbon compared to conventional tree harvesting. Smith and Lattimore (2008), while discussing potential environmental impacts of bioenergy harvesting on biodiversity list contributing activities such as mechanical damage to residual trees; expanded road networks; increased removals and land use changes that might impact productive and diverse ecosystems. Scott and Dean's (2006) Long Term Site Productivity Study found that whole-tree harvesting reduced productivity on over 75 percent of the study blocks in South by an average of 18 percent. However, they also found that a one-time application of nitrogen and phosphorus fertilizer maintained productivity and increased productivity by an additional 47 percent above the stem-only harvest level.

Harvesting slash remaining after conventional harvesting of loblolly pine (*Pinus taeda*) in the Coastal Plain along the Gulf of Mexico reduced site productivity, decreasing soil organic matter and associated nutrients by 18 percent (Scott and Dean 2006). Reductions of jack pine (*P. banksiana*) height growth of 18 percent on whole-tree harvested plots in sites of Quebec region of Canada were attributed to lower soil moisture and nutrient availability (Thiffault and others 2006). To avoid decreased productivity from soil compaction during biomass harvesting, Janowiak and Webster (2010), after reviewing the state of knowledge regarding the impacts of intensive forestry with respect to issues relevant to bioenergy production, recommended using machinery that is similar to what is used in conventional harvesting.

Water quality—Increased biomass harvesting activities for a wood-to-energy market might have adverse impacts on water quality in streams, rivers, and lakes. Increased road construction required for woody biomass harvesting might lead to soil erosion, high soil moisture, and increased runoff and sediments from forest roads and landings (Janowiak and Webster 2010). Increased machinery use might also impact the water table at the harvest site, leading to impermeable soils from compaction. Removal of younger trees and lopping and topping during biomass harvests might decrease leaf surface area, resulting in decreased transpiration and interception (Lal and others 2009).

Machine re-entry at harvest sites might increase sedimentation and flow levels in waterways, increasing the chances of sediment movement into wetlands through damaged erosion control features. Frequent harvests might increase suspended solids and aluminum levels in water, raising acidification levels and negatively impacting fish and other aquatic organisms (Grigal 2000). In addition, woody biomass harvesting adjacent to waterways might increase the probability of higher water temperatures, disturbed chemistry, and reduced clarity that would damage biological communities and alter ecological processes (Janowiak and Webster 2010). Aust and Blinn (2004) reviewed best management practices for timber harvesting and site preparation in the eastern United States in terms of water quality and productivity research during for the time period between 1982 and 2002, and concluded that effects of harvesting on forest hydrology are highly variable across sites and time periods. However, harvesting impacts on forest hydrology are likely to be greater immediately following harvest, with the recovery to preharvest conditions taking up to 5 years

Biodiversity—The extraction of additional biomass for bioenergy could degrade habitats beyond the range of natural variability and produce negative effects on some species (Janowiak and Webster 2010). Increased access and intensity of harvest can also fragment habitats and adversely impact wildlife corridors (Fletcher and others 2011, Lal and others 2009). Natural disturbances such as fire, wind, and pest outbreaks permit a continuous supply of deadwood in unmanaged forests. Intensive forest management leading to removal of stumps might reduce the amount of deadwood that is considered essential to forest ecosystems and provides habitats for different organisms (Humphrey and others 2002).

The removal of residues and stumps might negatively alter the entire soil fauna community and structure of the food web, harming small mammals, and reducing ecological niches, thereby lowering diversity and numbers of invertebrates such as spiders and predatory insects (Ecke and others 2002). There is also a chance of insects or other wood-colonizing species getting trapped in wood burnt for fuel.

However, intensive forest management practices controlling pests and disease can also improve forest habitats. For example, certain fungi species cause root and butt rot disease to conifers worldwide. Stump removal associated with whole-tree harvesting generally leads to significant reductions in the area of the stump colonized by these fungi, reducing the risk of attack (Thor and Stenlid 2005). Conversely, the harvesting of forest residues and stumps would also favor pioneering species of flora that are also more tolerant of exposure and soil moisture levels. When all biomass is removed, growth these species is more vigorous, particularly the invasive nonforest field vegetation, which—if it is not managed—might lead to a reduction in timber productivity (Walmsley and Godbold 2010). Scott and Dean (2006) also suggest that in the Gulf Coastal Plain, soil analyses could be used to identify harvesting sites at risk of harvesting-induced productivity loss, and fertilization treatment could be used to avoid productivity loss caused by whole-tree harvesting.

Meta-analysis by Fletcher and others (2011) of studies on crops being used or considered in the United States, found that vertebrate diversity and abundance are generally lower in biofuel crop habitats relative to the non-crop habitats. They found diversity effects are lower for pine and poplar than for corn, and birds of conservation concern experience lower negative effects. However, for minimizing impacts of biofuel crops on biodiversity, they suggest practices that reduce chemical inputs, increase heterogeneity within fields, and delay harvests until after bird breeding. Many of these practices might already be incorporated under intensive management regimes in South and could be incorporated into biomass production systems and management planning used to avoid adverse impact on forested landscapes.

Results of direct and indirect land use change to agricultural row systems can also cause habitat loss (Jonsell 2007). The land use change from natural forests to forest plantations, including short rotation woody crops, is of the greatest concern from an ecological point of view (Wear and others 2010). Interventions focused on ecological restoration or fuel reduction activities associated with woody biomass would also benefit wildlife habitat (Janowiak and Webster 2010).

However, biomass production might also have negative consequences unless coordinated with breeding and nesting seasons and maintaining cover for overwintering small mammal species (Bies 2006).

Just as important to southerners, but less quantifiable, are the potential impacts of increased woody biomass removals on quality-of-life issues: aesthetics, community relationships, and appreciation of forest land as an integral part of the social and physical landscape (Wear and others 2010).

DISCUSSION AND CONCLUSIONS

Markets

Our demand analysis shows that the consumption requirements for wood from bioenergy markets would not likely be met by urban wood waste alone, and that demands for woody biomass would require harvesting residues or biomass from timber markets by 2013 (fig. 10.2). Prices for all forest products would likely increase, resulting in increased returns to forest landowners. Price changes are greater than changes in removals or inventory, consistent with an inelastic market response. Although removals are responsive to price changes (higher removals at higher prices), forest inventories will also depend on factors like forest growth, afforestation of agricultural or pasture lands, intensive management of forest land, and increased plantations of fast growing species. The models used for our analysis attempt to account for these factors, but future conditions are clouded by large uncertainties about demand and supply factors. Consistent with chapter 4, the market model indicates that increased prices under bioenergy futures would mitigate the loss of forest land in the future. Planted pine forest area is the most responsive to these price trends. Bioenergy demands would result in declining use of timber by forest industry, with impacts more pronounced for pulp-based industries than for sawtimber industries.

With high demand for woody biomass, sawtimber industries could also be impacted, although at lower levels. This projection is consistent with studies by Aulisi and others (2007) and Galik and others (2009), who found that pulpwood markets are more likely to be impacted by an emerging wood-based energy industry. Furthermore, Aulisi and others (2007) suggest that sawmills might benefit from the higher prices paid by bioenergy markets for secondary products such as sawdust and chips. Our simulation indicates that at high levels of bioenergy demands, the softwood sawtimber industry would eventually be adversely impacted.

Forest industry might also face increased feedstock prices for their pulp and sawtimber operations. In the long run, price increases for softwood nonsawtimber are less severe than for hardwood nonsawtimber because pine plantation area can respond quickly, and hardwood plantations are not common in the South.

Increased forest productivity could moderate price growth and result in higher rates of removals and inventories. Although productivity has grown substantially in the South as a response to intensive management and genetic improvements, productivity effects are not limited to softwoods. Price increases are smallest with productivity growth strategies that extend to all management types along with an increase in short rotation plantations. Expanding demands for bioenergy would not necessarily reduce the levels of forest inventories. Our simulations show that an increase in demand from the energy industry, coupled with productivity increases, could lead to higher levels of both removals and inventory.

With management and technological advancements, woody bioenergy markets could result in increases in inventory, removals, forest acreage, and returns to landowners. Southern forests could be managed to produce substantially more timber for bioenergy and other forest products consistent with the projections shown in chapter 9.

These results indicate that the future trajectory of southern forests will depend on the state of wood-based energy markets as influenced by technological developments and cost considerations. Markets will also be shaped by other unknowns, including the amount of renewable energy that will come from solar, wind, and other sources of renewable energy. Similar to any nascent industry, the future of wood-based energy will depend on a number of uncertainties, including the costs of production, technological breakthroughs, the government policies that support renewable technologies, forest productivity decisions, and the expansion of short rotation woody crops. Along these lines, if carbon markets emerge and carbon credits for displacing fossil fuels with woody bioenergy are considered, more changes in forest management and short rotation woody crops might be expected, but inclusion of these details is beyond the scope of this chapter.

Technologies

On the woody biomass-based energy technology front, there is no emergent favorite. Even supposedly “low-hanging fruits” such as co-firing face significant challenges, such as boiler ash deposition, corrosion, and feedstock selection. Federal and State governments, along with forest industry, are investing research dollars into these technologies with hopes of commercial success. Different types of woody bioenergy occupy different places on the cost feasibility spectrum. Wood pellets are already feasible under current markets, while biofuels are not economically competitive at the current level of technology.

Advantages of wood pelletization include high energy-to-weight ratio, lower capital requirements, ability to operate production facilities at a variety of scales based on demand or wood supply, lower costs of shipping the final product, easier handling, and, most of all, high demand in European countries. Conversely, preferred conversion technologies for wood-based fuels remain largely uncertain because of the high cost of production, project-specific factors, and environmental standards (McKendry 2002). The high unit cost of woody biomass-based energy is largely attributed to high harvesting and transport costs; for example, making woody biomass-based ethanol competitive with starch-based ethanol or gasoline would require reduced capital costs through technology improvements, reduced feedstock costs (primarily from yield improvement), and densification of wood at the harvest site to lower harvesting costs (Alavalapati and Lal 2009, Dwivedi and others 2009, Jackson and others 2010). The cost of transport from the supply source (for example, the forest) to the conversion plant also determines the viability of the manufactured product (electricity, heat, or liquid fuels). Overcoming this significant challenge requires that plants have easy access to the wood supply and to distribution markets.

No species group has emerged as a favorite for woody bioenergy. Both softwoods and hardwoods can be co-fired with coal, used in combined heating and power plants, and compressed for wood pellet production (Spelter and Toth 2009). Evidence supporting a clear preference for hardwood or softwood species for wood-based liquid fuel is lacking as well. Zhu and Pan (2010) suggest that sulfite pretreatment to overcome lignocelluloses recalcitrance process holds promise for woody biomass conversion, especially for softwood species. However, softwoods contain more lignin than hardwoods (Galbe and Zacchi 2002), meaning that the conversion to liquid fuels might be less efficient in softwoods because lignin needs to be removed during the pretreatment process. Even Zhu and Pan (2010) noted that in one of the most common pretreatment processes (acid catalyzed steam explosion) sugar was successfully recovered from hardwoods (for example, 65 to 80 percent recovery from poplars) compared to less encouraging results for softwood species.

Regardless of the conversion technology employed, a continuous long-term flow of wood would be needed as raw material. Because many Southern States are emphasizing renewable technologies, new co-firing and combined heat and power plants and ethanol biorefineries are likely to be established in the future. Expansion of this sector—more woody biomass-based energy plants or expansion of existing facilities to achieve economies of scale—will be associated with an increase in the demand for wood fiber. To meet the burgeoning demand for woody biomass for energy estimated by SRTS simulation runs, merchantable timber and small-diameter wood would be required in addition to logging residues or wood waste such as sawdust, shavings, and chips from other wood product manufacturing processes.

Technological advancements are essential for making wood energy competitive with other sources such as gasoline and coal. Policy support for woody biomass-based energy, a nascent industry, might help in attaining commercial viability and developing a mature market.

Policies

Available policy instruments have advantages and disadvantages (Aguilar and Saunders 2010, Alavalapati and others 2009). Financial incentives allow directly measurements of their impact on prices. Moreover, they can promote sustained demand for and supply of energy feedstocks, and can lower the capital costs of investments. However, funding for these programs is vulnerable during hard economic times. Regulations such as renewable portfolio standards are easy to adopt, and producers generally bear incurred costs. However, these types of policies might suffer from inflexibility, and information needed for effective targeting can be elusive. A better option might be to develop a suite of policy options geared towards woody biomass-based energy. For example, an Environmental and Energy Study Institute proposal (2010) suggests that in uncertain times, an integrated policy approach for bioenergy might include: inventorying bioenergy resources and markets and developing a long range bioenergy plan; developing sustainable feedstock production guidelines; developing locally appropriate feedstocks and conversion technologies; creating easement programs for sustainable feedstock production; establishing minimum renewable fuel standards; enacting a low carbon fuel standard; promoting interagency cooperation and cooperation with other States; providing tax incentives for producers and retail distributors; and leveraging State resources through Federal and private partnerships.

Given current logistical and technological challenges, developing a mature woody biomass-based energy market would likely depend on some level of government support that includes financial incentives and other regulatory and support policies. Indeed, such policies have emerged in various forms, including research and development, consumption incentives (such as fuel tax reductions), production incentives (such as tax incentives, direct subsidies, and loan guarantees), and mandatory consumption requirements. These and future policies for production, conversion technologies, and markets and distribution can potentially impact the production and commercialization of woody biomass for energy, but might also alter the ecosystem services provided by forests.

Financial incentives might facilitate the increased production and diversion of woody biomass, likely increasing wood demand and adding to the profitability of landowners and those engaged in wood-to-energy conversion. Stand improvement and restoration activities prioritized by States, such as land recovery and cost share programs, might help landowners make the long-term investments. Support for weed and pest management, such as the pine bark beetle prevention program in Virginia, might also increase biomass availability. Best management practices and harvesting guidelines developed especially for bioenergy could restrict wood availability by reducing harvesting impacts through minimum tillage and reduced applications of fertilizers and pesticides; protecting wildlife corridors, riparian zones, and other sensitive areas; and adopting wildlife habitat enhancement measures such as leaving patches of undisturbed areas, promoting certain species mixtures and crop rotations, and retaining quantities of harvest residues, litter, deadwood, snags, and den trees.

Research and technology grants, coupled with subsidies, could help develop current and future wood-for-energy markets. Other financial incentives targeting energy producers might also favor the progress of new conversion technologies and the integration of new technologies with existing ones. Policy efforts geared towards development of gasification techniques or an integrated process with biomass-based electricity generation would likely increase the production of woody biomass-based energy. Technological innovations channeled towards reducing feedstock production costs are significant, as they are likely to spike the demand of wood, luring away some share from traditional forest industries.

A wide array of policy instruments geared towards improving the marketing and distribution of woody biomass-based bioenergy—such as appliance efficiency standards, mandatory utility green power options, and renewable portfolio standards—could play a pivotal role in deciding where the wood–to-energy conversion plants and distribution centers are set up. Because location of infrastructure translates to increased demand for forest biomass, the conditions of nearby forests might change.

Economic and technological uncertainties might influence the impacts that current and future policies have on southern forests. However, the great variety of policies—and the multitude of ways in which the can interact—confounds efforts to predict their potential effects. Policies addressing other environmental and societal benefits associated with forests and wood-to-energy markets might also alter the impacts of bioenergy policies. In particular, emergence of carbon markets could spur further growth in the wood-to-energy industry, but formulating a policy mechanism to realize carbon payments is a huge challenge. For example, under the Carbon Cap and Trade Bill currently in the U.S. Congress, many forest landowners would not qualify for carbon market benefits because they would not get credit for existing levels of carbon sequestration, nor could they meet sequestration permanence standards.

Sustainability Issues

Production of woody biomass for bioenergy can help meet energy goals, but can also stimulate accelerated harvesting, with potentially negative implications for forest ecosystems. Reduction of soil nutrients as well as soil compaction would likely decrease forest productivity. Intensive biomass removal might affect aquatic communities by increasing erosion, runoff, and waterway sedimentation. Intensive forest management might also degrade forest habitat conditions, negatively affecting flora and fauna and reducing biodiversity. Land use changes from natural forest to managed plantations might adversely affect imperiled species in certain locations (see chapter 14). However, changes from agricultural systems to forests might improve habitat conditions. Further, the highgrading of stands generally observed during some timber harvesting might be eliminated with biomass harvesting.

Intensive woody biomass removal might also have some negative implications for community relationships, aesthetics, and public perceptions about forest land as an integral component of southern ecosystems. Potential impacts on forest ecosystems at local and regional levels is most likely to challenge the forestry community to consult new research findings like those summarized below and update existing certification systems with guidelines on how, when, and where woody biomass removals should be conducted:

Janowiak and Webster (2010) provide a framework that includes adapting management to site conditions, increasing forested land where feasible, using biomass harvests as a restoration tool, evaluating the possibility of fertilization and wood ash recycling, and retaining deadwood and structural heterogeneity for biodiversity.

Hennenberg and others (2009) suggest creating protected areas that can be used to conserve relevant portions of biodiversity.

Lal and others (2011) similarly report a set of nine criteria that are necessary to the pursuit of sustainable woody biomass extraction: reforestation and productive capacity, land use change, biodiversity conservation, soil quality and erosion prevention, hydrologic processes, profitability, community benefits, stakeholder participation, and community and human rights.

Fletcher and others (2011) recommend the following strategies to ensure habitat for biodiversity: reducing harvesting impacts through minimum tillage and reduced fertilizers and pesticides; protecting wildlife corridors, riparian zones, and other sensitive areas; and adopting wildlife habitat enhancement measures such as leaving patches of undisturbed areas, promoting certain species mixtures and crop rotations, and retaining quantities of harvest residues, litter, deadwood, snags, and den trees.

Multi-stakeholder efforts such as the Roundtable on Sustainable Biofuels and the Global Bioenergy Partnership for biomass harvesting are already underway. The Roundtable on Sustainable Biofuels and Global Bioenergy Partnership are in the process of developing global principles and criteria for developing a set of global, science-based criteria and indicators coupled with field examples and best practices (including benchmarks) for bioenergy sustainability.

In addition to the overall scale of biomass production, the location and methods of woody biomass harvests would affect the health, vitality, and ecological function of southern forests. Existing certification systems such as the Forest Stewardship Council, American Tree Farm System, and Sustainable Forestry Initiative have criteria and indicators to safeguard site productivity, water quality, and biodiversity but some additional indicators may be required for woody biomass harvests. For example, an indicator might be needed to address harvest residues left on site to maintain habitat for small mammals, insects, reptiles, and amphibians. Levels of necessary residues would depend on site-specific conditions, although general guidelines could be formulated at State or Southwide levels. Similarly, erosion-preventing indicators (such as those prohibiting harvests on shallow and nutrient-poor soils) would need to consider specific soil conditions such as depth of soils, nutrient conditions, and regeneration potential.

Biomass harvesting at the levels explored in this chapter could have negative implications for future forest conditions and ecosystem services flowing from southern forests including water (chapter 13) and wildlife/biodiversity (chapter 14). These outcomes depend on the amount and location of harvesting, but perhaps more critically on the management strategies used. The research described above indicates that management systems can be designed to mitigate damages to various ecosystem services. Of course, this requires management planning that addresses management objectives in the context of local conditions.

The need for additional best management practices or other guidelines will depend on the rate of development of the bioenergy sector, which is highly uncertain. The acceptability of these approaches would depend on the process of updating best management practices, which would ideally combine public involvement with a science-based process at appropriate scales (Alavalapati and Lal 2009).

SUMMARY

Wood-based energy markets have been proposed as a means to ensure sustainable forests, enhance energy security, promote environmental quality, and realize social benefits. However, several complex issues are influencing the ability to develop these markets in economically efficient, environmentally benign, and socially desirable ways. These issues include biomass availability or supply, market competitiveness and technology development, supportive Federal and State policies, tradeoffs with traditional forest product industries, sustainability, and ecosystem integrity.

This chapter has focused on four interrelated dimensions of bioenergy futures related to southern forests: markets, technologies, policies, and sustainability. Across the various bioenergy scenarios, these new demands would affect the markets for all wood products and lead to price increases for timber products and higher returns to private landowners. The degree to which other wood consumers are impacted would depend on expansion in supply, which in turn depends on intensification of forest management and changes in land use (primarily from agricultural to forestry).

New demands for bioenergy will be determined by expansion of existing technologies—for example, pellets and co-firing with coal—but more critically on the emergence of new technologies that are not yet economically viable. Accelerated technological developments and reduced production costs might be achieved through various policies at Federal and State levels. The sustainability issues surrounding bioenergy are defined by the negative externalities associated with accelerated harvesting in the South. Research indicates that management systems and standards can be designed to protect these values, defining another interface with future policy.

All of these dimensions are fraught with uncertainty. Market futures depend on demands for traditional wood products and on energy prices. Technology development depends on research funding but also on unknowable limits to technical feasibility and the prospect of economic returns. Policy development is highly uncertain and fundamentally engages tradeoffs among energy, environment, community, and other societal objectives. The relationship between harvesting at unprecedented levels and forest ecosystem services is not fully known.

This chapter lays out a broad range of potential developments and management options. Clearly the path to sustainable bioenergy futures will involve enhancing knowledge, monitoring changes, updating expectations, and narrowing the overall uncertainty about future prospects. These issues will likely be the focus of forest assessments for years to come.

KNOWLEDGE AND INFORMATION GAPS

The future of woody bioenergy markets depends on a multitude of factors such as supply and availability of wood biomass; advancements in conversion technologies; improvements in harvesting, collection, storage, densification, preprocessing, and transportation; product prices and elasticities; infrastructure; and productivity increases.

Determining many such factors with confidence was difficult, and our analysis tools were limited. The bioeconomic model that we employed for market analysis calculates harvest levels, related prices, inventory, and acreage as functions of input demands, productivity increases, and various assumed parameters. These relationships are not known with high precision, and the market analysis cannot account for every economic variable and strategic response to the impacts on energy markets. Applying the models to a large number of scenarios provides insights into the range of potential market responses in the future. Improved estimates of the various supply, demand, and production relationships would enhance forecasts of future market developments. What's more, high-demand bioenergy futures imply important trades between wood products sectors with implications for employment, income, and rural economies that warrant additional study.

Our stylized approach to constructing consumption projections for the region leaves certain aspects of bioenergy futures unaddressed. Importantly, questions regarding interregional and international trade in wood products that could affect the ultimate expression of regional demands were not directly addressed. Trade modeling was beyond the scope of the Futures Project and explains why a broad range of futures was evaluated—i.e., to capture a reasonable range of futures regardless of the mechanisms leading to demand outcomes. The national assessment of timber and wood products markets contained in the 2010 RPA Assessment (Ince and others 2011) explores trade under similar scenarios and serves as a useful reference.

Woody bioenergy production might be more cost competitive under a greenhouse gas reduction strategy that assigns a market value to carbon emissions, in effect allowing social and environmental benefits to be accrued to woody bioenergy. This approach could monetize the benefits gained through greenhouse gas reduction, and those gains could be traded in a carbon market. Although likely to spur further growth in a bioenergy industry, the carbon market approach has yet to formulate a viable mechanism for realizing carbon payments to forest landowners.

The legal definitions of what qualifies as 'forest biomass' under different policy descriptions would generate large variations in forest biomass utilization and therefore require research attention. For example, the Energy Independence Security Act (2007) provides a restricted definition by excluding biomass from public forests and naturally regenerated private forests. Conversely, the 2008 Farm Bill provides a comprehensive definition for forest biomass.

Estimates of the volume of woody material that can used for energy production at secondary wood products manufacturing facilities are imprecise and based on varying assumptions about production facilities and per-unit production potential. Also needing research attention is comprehensive analyses of short rotation woody crops that can be made available for energy use; land use tradeoffs of short rotation woody crops with agriculture, pastures, and forest land; and potential for pine-switchgrass and other agroforestry systems to expand. Productivity gains from changing the geographic range of agriculture and woody biomass feedstocks and improving management is another research area that warrants further attention, as is documenting landowner willingness to participate in forest biomass markets and incorporating this information into woody biomass supply functions.

Additional research is needed to identify sustainability issues surrounding woody biomass utilization for energy. The focus of these concerns ranges from production processes to consumption processes (feedstock production, harvesting, transport, conversion, distribution, consumption, and waste disposal) to job creation and societal benefit distribution. Future research would necessarily focus on the tradeoffs arising from woody biomass diversion for energy use, and the level at which woody bioenergy might become ecologically, economically, and socially undesirable.

ACKNOWLEDGMENTS

The authors wish to thank Robert J. Huggett, Jr., and Karen L. Abt, U.S. Department of Agriculture, Forest Service, Southern Research Station; and Frederick J. Rossi, School of

Forest Resources and Conservation, University of Florida, for their support and insights. Thanks are also due to Carol Whitlock and Shawna Reid from the U.S. Department of Agriculture Forest Service, Southern Research Station, for technical edits and help in preparing GIS maps respectively.

LITERATURE CITED

Abt, R.C.; Abt, K.L. 2013. Potential impact of bioenergy demand on the sustainability of the southern forest resource. Journal of Sustainable Forestry. 32(1-2): 175-194.

Abt, R.; Abt, K.; Cubbage, F.; Henderson, J. 2010. Effect of policy-based bioenergy demand on southern timber markets: a case study of North Carolina. Biomass and Bioenergy. 34(12): 1679–1686.

Abt, R.C.; Cubbage, F.W.; Abt, K.L. 2009. Projecting southern timber supply for multiple products by subregion. Forest Products Journal. 59(7–8): 7–16.

Abt, R.; Cubbage, F.; Pacheco, G. 2000. Southern forest resource assessment using the Subregional Timber Supply (SRTS) model. Forest Products Journal. 50(4): 25–33.

Adams, D.M.; Alig, R.; Callaway, J.M. [and others]. 1996. The Forest and Agricultural Sector Optimization Model (FASOM): model structure and applications. Res. Pap. PNW–RP–495. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 60 p.

Aguilar, F.X.; Saunders, A. 2010. Policy instruments promoting wood-to-energy uses in the continental United States. Journal of Forestry. 108(3): 132–140.

Alavalapati, J.; Lal, P. 2009. Woody biomass for energy: an overview of key emerging issues. Virginia Forests. Fall: 4–8.

Alavalapati, J.R.R.; Hodges, A.W.; Lal, P. [and others]. 2009. Southern bioenergy roadmap. Research Triangle Park, NC: Southeast Agriculture and Forestry Energy Resources Alliance (SAFER), Southern Growth Polices Board. 127 p.

Amacher, A.J.; Barrett, R.H.; Moghaddas, J.J.; Stephens, S.L. 2008. Preliminary effects of fire and mechanical fuel treatments on the abundance of small mammals in the mixed-conifer forest of the Sierra Nevada. Forest Ecology and Management. 255(8–9): 3193–3202.

Arnold, C.L. 2000. Land use is the issue, but is land grant the answer? Journal of Extension. 38(6). http://www.joe.org/joe/2000december/comm1.html. [Date accessed: June 15, 2010].

Astrom, M.; Dynesius, M.; Hylander, K.; Nilsson, C. 2005. Effects of slash harvest on bryophytes and vascular plants in southern boreal forest clear-cuts. Journal of Applied Ecology. 42: 1194–1202.

Aulisi, A.; Sauer, A.; Wellington, F. 2007. Trees in the greenhouse: why climate change is transforming the forest products business. World Resources Institute Report. 74 p.

Aust, W.; Blinn, C. 2004. Forestry best management practices for timber harvesting and site preparation in the Eastern United States: an overview of water quality and productivity research during the past 20 years (1982-2002). Water, Air, and Soil Pollution Focus. 4: 5–36.

Beach, R.; Pattanayak, S.; Yang, J. [and others]. 2005. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Economics and Policy. 7: 261–281.

Belanger, R.; Hedden, R.; Lorio, P. 1993. Management strategies to reduce losses from the southern pine beetle. Southern Journal of Applied Forestry. 17: 150–154.

Bies, L. 2006. The biofuels explosion: is green energy good for wildlife? Wildlife Society Bulletin. 34: 1203–1205.

Bingham, M.F.; Prestemon, J.P.; MacNair, D.A.; Abt, R.C. 2003. Market structure in U.S. southern pine roundwood. Journal of Forest Economics. 9: 97–117.

Blottnitz, V.H.; Curran, M.A. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life-cycle perspectives. Journal of Cleaner Production. 15(7): 607-619.

Burger, J.A. 2002. Soil and long-term site productivity values. In: Richardson, J.; Bjorheden, R.; Hakkila, P. [and others], eds. Bioenergy from sustainable forestry: guiding principles and practice. Dordrecht, The Netherlands: Kluwer Academic Publishers: 165–189.

Butler, B.J. 2008. Family forest owners of the United States, 2006. Gen. Tech. Rep. NRS–27. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 72 p.

Carter, D.; Langholtz, M.; Schroeder, R. 2007. Biomass resource assessment part I: availability and cost analysis of woody biomass for Gainesville regional utilities. Gainesville, FL: University of Florida, School of Forest Resources and Conservation. 122 p.

Database of State Incentives for Renewables and Efficiency. 2010. summary Tables: Financial incentives for renewable energy/energy efficiency and rules, regulations and policies for renewable energy/energy efficiency. http://www.dsireusa.org/summarytables/index.cfm?EE=1&RE=1. [Date accessed: June 12, 2010].

De La Torre Ugarte, D.; English, B.; Jensen, K. [and others]. 2006. Economic and agricultural impacts of ethanol and biodiesel expansion. Study report by University of Tennessee, Agricultural Economics. http://beag.ag.utk.edu/pub/Ethanolagimpacts.pdf. [Date accessed: July 14, 2010].

De La Torre Ugarte, D.G.; Ray, D.E. 2000. Biomass and bioenergy applications of the POLYSYS modeling framework. Biomass and Bioenergy. 18(14): 291–308.

De La Torre Ugarte, D.G.; Ray, D.E.; Tiller, K.H. 1998. Using the POLYSYS modeling framework to evaluate environmental impacts in agriculture. In: Robertson, T.; English, B.C.; Alexander, R.R., eds. Evaluating natural resource use in agriculture. Ames, IA: Iowa State University Press: 151–172.

Dwivedi, P.; Alavalapati, J. 2009. Stakeholders' perceptions on forest biomass-based bioenergy development in the Southern U.S. Energy Policy. 37: 1999–2007.

Dwivedi, P.; Alavalapati, J.R.R.; Lal, P. 2009. Cellulosic ethanol production in the United States: conversion technologies, current production status, economics, and emerging developments. Energy for Sustainable Development. 13(3): 174–182.

Dwivedi, P.; Bailis, R.; Bush, T.; Marinescu, M. 2011. Quantifying GWI of wood pellet production in the Southern United States and its subsequent utilization for electricity production in the Netherlands/Florida. Bioenergy Research: 1-13.

Ecke, F.; Löfgren, O.; Sörlin, D. 2002. Population dynamics of small mammals in relation to forest age and structural habitat factors in northern Sweden. Journal of Applied Ecology. 39: 781–792.

Energy Independence and Security Act. 2007. H.R. 6. 110th U.S. Congress. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname= 110_cong_bills&docid= f:h6enr.txt.pdf. [Date accessed: June 16, 2010].

Energy Information Administration. 2007. Energy and economic impacts of implementing both a 25-percent renewable portfolio standard and a 25-percent renewable fuel standard by 2025. Report SR/OIAF/2007–05. http://www.eia.doe.gov/oiaf/servicerpt/eeim/index.html. [Date accessed: July 14, 2010].

Energy Information Administration. 2009. Annual energy outlook. Report DOE/EIA–0383(2009). http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2009).pdf . [Date accessed: January 12, 2010].

Energy Information Administration. 2010a. Annual energy outlook. Report DOE/EIA–0383(2010). http://www.eia.doe.gov/oiaf/aeo/index.html. [Date accessed: June 12, 2010].

Energy Information Administration. 2010b. Annual energy outlook. Year-by-year reference case tables (2007-2035). Report DOE/EIA–0383(2010). http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html. [Date accessed: June 14, 2010].

Energy Information Administration. 2010c. Net summer capacity of plants cofiring biomass and coal, 2007 and 2008. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1_9.pdf. [Date accessed: June 15].

Energy Information Administration. 2010d. Electric power generation and fuel consumption and stocks monthly time series file. Form EIA–923. http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html. [Date accessed: June 12, 2010].

Environmental and Energy Study Institute. 2010. Developing and advanced biofuels industry: State policy options and uncertain times. http://www.eesi.org/021610_state_biofuel_paper. [Date accessed: June 15].

Eriksson, E.; Gillespie, A.; Gustavsson, L. [and others]. 2007. Integrated carbon analysis of forest management practices and wood substitution. Canadian Journal of Forest Research. 37(3): 671-681.

Faaij, A.; Domac, J. 2006. Emerging international bioenergy markets and opportunities for socio-economic development. Energy for Sustainable Development. 1: 7–19.

Fletcher, R.; Robertson, B.A.; Evans, J. [and others]. 2011. Biodiversity conservation in the era of biofuels: risks and opportunities. Frontiers in Ecology and the Environment. 9: 161–168.

Fox, T.; Jokela, E.; Allen, H. 2007. The development of pine plantation silviculture in the Southern United States. Journal of Forestry: 337–347.

Fritsche, U.R.; Hunecke, K.; Schulze, F.; Wiegman. K. 2006. Sustainability standards for bioenergy. Darmstadt, Germany: WWF Germany, Oeko-Institut. www.wwf.de/fileadmin/fm-wwf/pdf_neu/Sustainability_Standards_for_Bioenergy.pdf. [Date accessed: July 6, 2010].

Galbe, M.; Zacchi, G. 2002. A review of the production of ethanol from softwood. Applied Microbiolgy Biotechnology. 59: 618–628.

Galik, C.; Abt, R.; Wu, Y. 2009. Forest biomass supply in the Southeastern United States—implications for industrial roundwood and bioenergy production. Journal of Forestry. 107(2): 69–77.

Gan, J.; Mayfield, C. 2007a. Benefits to landowners from forest biomass/bioenergy production. In: Hubbard, W.; Biles, L.; Mayfield, C.; Ashton, S., eds. 2007. Sustainable forestry for bioenergy and bio-based products: trainers curriculum notebook. Athens, GA: Southern Forest Research Partnership, Inc: 225-228.

Gan, J.; Mayfield, C. 2007b. The economics of forest biomass production and use. In: Hubbard, W.; Biles, L.; Mayfield, C.; Ashton, S., eds. 2007. Sustainable forestry for bioenergy and bio-based products: trainers curriculum notebook. Athens, GA: Southern Forest Research Partnership, Inc: 213-216.

Gan, J.; Smith, C.T. 2006a. A comparative analysis of woody biomass and coal for electricity generation under various CO_2 emissions reductions and taxes. Biomass and Bioenergy. 30(4): 296-303.

Gan, J.; Smith, C.T. 2006b. Availability of logging residues and potential for electricity production and carbon displacement in the USA. Biomass and Bioenergy. 30(12): 1011–1020.

Gorte, R.W.; Ramseur, J.L. 2008. Forest carbon markets: potential and drawbacks. Report prepared by CRS for Congress. Washington, DC: CRS RL34560. http://www.nationalaglawcenter.org/assets/crs/RL34560.pdf. [Date accessed: July 16, 2010].

Greene, J.L.; Daniels, S.; Kilgore, M.A. [and others]. 2005. Existing and potential incentives for practicing sustainable forestry on nonindustrial private forest lands. Final report to the National Commission on Science for Sustainable Forestry. http://www.srs.fs.usda.gov/econ/data/forestincentives/ncssf-c2-final-report.pdf. [Date accessed: July 15, 2010].

Grigal, D. 2000. Effects of extensive forest management on soil productivity. Forest Ecology and Management. 138: 167–185.

Guo, Z.; Sun, C.; Grebner, D.Q. 2007. Utilization of forest derived biomass for energy production in the U.S.A.: status, challenges, and public policies. International Forestry Review. 9(3): 748–758.

Gustavsson, L.; Holmberg, J.; Dornburg, V. [and others]. 2007. Using biomass for climate change mitigation and oil reduction. Energy Policy. 35(11): 5671-5691.

Haines, A.L. 2002. Blended teaching: land use planning education in Wisconsin and lessons learned. Journal of Extension. 40(5): 5IAW2. http://www.joe.org/joe/2002october/iw2.shtml. [Date accessed: June 12, 2010].

Hanson, C.; Yonavjak, L.; Clarke, C. [and others]. 2010. Southern Forests for the Future. Issue Brief 2. Washington, DC: World Resources Institute: 1-16.

Hardie, W.; Narayan, T.A.; Gardner, B.L. 2001. The joint influence of agricultural and nonfarm factors on real estate values: an application to the mid-Atlantic region. American Journal of Agricultural Economics. 83 (1): 120–132.

Hennenberg, K.; Dragisic, C.; Hewson, J. [and others]. 2009. The power of bioenergy-related standards to protect biodiversity. Conservation Biology. 24(2): 412–423.

Hill, J.; Nelson, E.; Tilman, D. [and others]. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences. 103(30): 11,206–11,210.

Hope, G. 2007. Changes in soil properties, tree growth, and nutrition over a period of 10 years after stump removal and scarification on moderately coarse soils in interior British Columbia. Forest Ecology Management. 242(2–3): 625–635.

Huang, M.Y. 2010. Regional impacts of bioenergy policies in the Southeastern United States: a computable general equilibrium analysis. University of Florida. 134 p. Ph.D. dissertation. http://purl.fcla.edu/fcla/etd/UFE0041091. [Date accessed: June 26, 2011].

Hughes, E. 2000. Biomass co-firing: economics, policy and opportunities. Biomass and Bioenergy. 19: 457–465.

Humphrey, J.; Davey, S.; Peace, A. [and others]. 2002. Lichens and bryophyte communities of planted and seminatural forests in Britain: the influence of site type, stand structure and deadwood. Biology Conservation. 107(2): 165–180.

Ince, P.J.; Kramp, A.D.; Skog, K.E. [and others]. 2011. U.S. forest products module: a technical document supporting the Forest Service 2010 RPA Assessment. Research Paper FPL-RP-662. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 61 p.

Jackson, S.; Rials, T.; Taylor, A.M. [and others]. 2010. Wood to energy: a state of the science and technology report. University of Tennessee and U.S. Endowment for Forestry and Communities Report. Knoxville, TN: University of Tennessee. 56 p.

Jacobson, M.G.; Greene, J.L.; Straka, T.J. [and others]. 2009. Influence and effectiveness of financial incentive programs in promoting sustainable forestry in the South. Northern Journal of Applied Forestry. 33(1): 35–41.

Janowiak, M.; Webster, C. 2010. Promoting ecological sustainability in woody biomass harvesting. Journal of Forestry. 108(1): 16–23.

Johnson, T.G.; Bentley, J.W.; Howell, M. 2009. The South's timber industry—an assessment of timber product output and use, 2007. Resour. Bull. SRS–164. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 52 p.

Jonsell, M. 2007. Effects on biodiversity of forest fuel extraction, governed by processes working on a large scale. Biomass and Bioenergy. 31(10): 726–732.

Joshi, S.; Arano, K.G. 2009. Determinants of private forest management decisions: a study on West Virginia NIPF landowners. Forest Policy and Economics. 11(2): 118–125.

Kilgore, M.A.; Greene, J.L.; Jacobson, M.G. [and others]. 2007. The influence of financial incentive programs in promoting sustainable forestry on the nation's family forests. Journal of Forestry: 184–191.

Kumarappan, S.; Joshi, S.; MacLean, H. 2009. Biomass supply for biofuel production: estimates for the United States and Canada. BioResources. 4(3): 1070–1087.

Lal, P.; Alavalapati, J.; Marinescu, M. [and others]. 2009. Sustainability indicators for woody biomass harvesting. The future of wood bioenergy in the United States: defining sustainability, status, trends and outlooks for regional development volume by Pinchot Institute for Conservation. http://www.pinchot.org/bioenergy_paper. [Date accessed: July 12, 2010].

Lal, P.; Alavalapati, J.; Marinescu, M. [and others]. 2011. Developing sustainability indicators for woody biomass harvesting in the United States. Journal of Sustainable Forestry. 30(8): 736–755.

Liao, X.; Zhang, Y. 2008. An econometric analysis of softwood production in the U.S. South: a comparison of industrial and nonindustrial forest ownerships. Forest Products Journal. 58(11): 69–74.

Lucier, A. 2010. Fatal flaw in Manomet's biomass study. The Forestry Source. September 2010: 4 p.

Manomet Center for Conservation Sciences. 2010. Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Walker, T., ed. Natural Capital Initiative Report NCI-2010- 03. Brunswick, ME: Manomet Center for Conservation Sciences. 182 p.

Mayfield, C.A.; Foster, C.D.; Smith, C.T. [and others]. 2008. Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States. Biomass and Bioenergy. 31(9): 631–637.

Mckendry, P. 2002. Energy production from biomass (part 2): conversion technologies. Bioresource Technology. 83(1): 47–54.

Mendell, B.; Lang, A.H.; Tydor, T. 2010. Economic and regional impact analysis of the treatment of biomass energy under the EPA greenhouse gas tailoring rule. Commissioned by National Alliance of Forest Owners. Athens, GA: Forisk Consulting. 32 p.

Mercer, E.; Lal, P.; Alavalapati, J. 2011. Competitiveness of carbon offset projects on nonindustrial private forest lands in the United States. In: Alig, R.J., ed. Economic modeling of effects of climate change on the forest sector and mitigation options: a compendium of briefing papers. Gen. Tech. Rep. PNW-GTR 837. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station: 119–160.

Milbrandt, A. 2005. A geographic perspective on the current biomass resource availability in the United States. Tech. Rep. NREL/TP–560–39181. http://www.nrel.gov/docs/fy06osti/39181.pdf. [Date accessed: June 16, 2010].

Neary, D.G. 2002. Hydrologic values. In: Richardson, J.; Bjorheden, R.; Hakkila, P. [and others], eds. Bioenergy from sustainable forestry: guiding principles and practice. Dordrecht, The Netherlands: Kluwer Academic Publishers: 190–215.

Neary, D.; Zieroth, E. 2007. Forest bioenergy system to reduce the hazard of wildfires: White Mountains, AZ: Biomass and Bioenergy. 31: 638–645.

Nesbit, T.; Alavalapati, J.R.R.; Dwivedi, P.; Marinescu, M. 2011. Economics of ethanol production using feedstock from slash pine (*Pinus elliottii*) plantations in the Southern United States. Southern Journal of Applied Forestry. 35(2): 61-66.

Oak Ridge National Laboratory. 2008. Bioenergy conversion factors. bioenergy.ornl.gov/papers/misc/energy_conv.html. [Date accessed: June 10, 2010].

O'Laughlin, J. 2010. Accounting for greenhouse gas emissions from wood bioenergy: response to the U.S. Environmental Protection Agency's call for information, including partial review of the Manomet Center for Conservation Sciences' biomass sustainability and carbon policy study. Report No. 31. Moscow, ID: Policy Analysis Group, College of Natural Resources. University of Idaho. 58 p.

Oklahoma Department of Agriculture, Food, and Forestry. 2008. Southern pine beetle threat draws cost-share funds. http://www.ok.gov/~okag/forms/forestry/pinebeetle.pdf. [Date accessed: April 16, 2011].

Pattanayak, S.; Murray, B.; Abt, R. 2002. How joint is joint forest production? An econometric analysis of timber supply conditional on endogenous amenity values. Forest Science. 48(3): 479–491.

Pattanayak, S.K.; Abt, R.C.; Sommer, A.J. [and others]. 2005. Forest forecasts: does individual heterogeneity matter for market and forest landscape outcomes? Forest Policy and Economics. 6(3–4): 243–260.

Pellet Fuels Institute. 2010. Fuel availability. http://pelletheat.org/pellets/fuel-availability/. [Date accessed: June 16, 2010].

Peng, C.; Jiang, H.; Apps, M.J.; Zhang, Y. 2002. Effects of harvesting regimes on carbon and nitrogen dynamics of boreal forests in central Canada: A process model simulation. Ecological Modeling. 155: 177–189.

Perlack, R.D.; Wright, L.L.; Turhollow, A.F. [and others]. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. DOE/GO–102995–2135. Joint report by U.S. Department of Agriculture and Department of Energy. Oak Ridge, TN: Oak Ridge National Laboratory. 58 p.

Prestemon, J.P.; Abt, R.C. 2002. Timber products supply and demand. In: Wear, D.; Greis, J., eds. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 299–326.

Reijnders, L. 2006. Conditions for the sustainability of biomass based fuel use. Energy Policy. 34(7): 863–876.

Renewable Fuels Association. 2010. Biorefinery Locations. http://www.ethanolrfa.org/bio-refinery-locations/. [Date accessed accessed: January 7, 2010].

Rossi, F.J.; Carter, D.R.; Abt, R.C. 2010. Woody biomass for electricity generation in Florida: bioeconomic impacts under a proposed Renewable Portfolio Standard (RPS) mandate. Final report prepared for Florida Department of Agriculture and Consumer Services, Division of Forestry. Gainesville, FL: School of Forest Resources and Conservation. 98 p.

Sample, V.A. 2009. Ensuring sustainability in the development of wood-based bioenergy in the U.S. South. http://www.pinchot.org/gp/SouthRegionalMeeting. [Date accessed: July 25, 2010].

Schaberg, R.H.; Aruna, P.B.; Cubbage, F.W. [and others]. 2005. Economic and ecological impacts of wood chip production in North Carolina: an integrated assessment and subsequent applications. Journal of Forest Policy and Economics. 7(2): 157–174.

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C. [and others]. 2002. Development of coarse-scale spatial data for wildland fire and fuel managment. RMRS-GTR 87. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 41 p.

Scott, D.; Dean. T. 2006. Energy trade-offs between intensive biomass utilization, site productivity loss, and ameliorative treatments in loblolly pine plantations. Biomass and Bioenergy. 30: 1001–1010.

Searchinger, T.; Heimlich, R.; Houghton, R.A. [and others]. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. Science. 319(5867): 1238-1240.

Sendek, P.E.; Abt, R.C.; Turner, R.J. 2003. Timber supply projections for northern New England and New York: integrating a market perspective. Northern Journal of Applied Forestry. 20(4): 175–185.

Shrum, T. 2007. Greenhouse gas emissions: policy and economics. Report prepared for the Kansas Energy Council. Topeka, KS: Kansas Energy Council. 78 p. http://kec.kansas.gov/reports/GHG_Review_FINAL.pdf. [Date accessed: July 22, 2010].

Siry, J.P.; Cubbage, F.; Malmquist, A. 2001. Potential impact of increased management intensities on planted pine growth and yield and timber supply modeling in the South. Forest Products Journal. 51(3): 42–48.

Siry, J.P.; Robison, D.J.; Cubbage, F.W. 2004. Economic returns model for silvicultural investments in young hardwood stands. Southern Journal of Applied Forestry. 28: 179–184.

Smith, T.; Lattimore, B. 2008. Potential environmental impacts of bioenergy harvesting on biodiversity. Forest Encyclopedia Network. http://www.threats.forestencyclopedia.net/t/t450/?searchterm=mitigating. [Date accessed: April 22, 2011].

Speight, M. 1997. Forest pests in the tropics: current status and future threats. In: Watt, A.; Stork, N.; Hunter, M., eds. Forests and insects. London: Chapman and Hall. 406 p.

Spelter, H.; Toth, D. 2009. North America's wood pellet sector. Res. Pap. FPL–RP–656. Madison, WI: U.S. Department of Agriculture Forest Service, Forest Products Laboratory. 21 p.

Stupak, I.; Asikainen, A.; Jonsell, M. [and others]. 2007. Sustainable utilization of forest biomass for energy—possibilities and problems: policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. Biomass and Bioenergy. 31(10): 666–684.

Susaeta, A.; Alavalapati J.; Carter, D. 2009. Modeling impacts of bioenergy markets on nonindustrial private forest management in the Southeastern United States. Natural Resource Modeling. 22(3): 345–369.

Susaeta, A.; Alavalapati, J.; Lal, P.; Matta, J. 2010. Assessing public preferences for forest biomass based energy in the Southern United States. Environmental Management. 45(4): 697–710.

Thiffault, E.; Paré, D.; Bélanger, N. [and others]. 2006. Harvesting intensity at clear-felling in the boreal forest: impact on soil and foliar nutrient status. Soil Science Society of American Journal. 70: 691–701.

Thiffault, E.; Pare, D.; Brais, S.; Titus, B. 2010. Intensive biomass removals and site productivity in Canada: a review of relevant issues. Forestry Chronicle. 86(1): 36–42.

Thor, M.; Stenlid, J. 2005. *Heterobasidion annosum* infection of *Picea abies* following manual or mechanized stump treatment. Scandinavian Journal of Forest Research. 20: 154–164.

United States Department of Agriculture (USDA) Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western States. RMRS-GTR-149. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 17 p.

Van Loo, S.; Koppejan, J. 2008. The handbook of biomass combustion and cofiring. London, UK: Earthscan. 442 p.

Walmsley, J.; Godbold, D. 2010. Stump harvesting for bioenergy—a review of the environmental impacts. Forestry. 83(1): 17–38.

Walsh, M.E. 2008. U.S. cellulosic biomass feedstock supplies and distribution. http://ageconsearch.umn.edu/bitstream/7625/2/U.S.%20Biomass%20Supplies.pdf. [Date accessed: July 5, 2010].

Wear, D.; Abt, R.; Alavalapati, J. [and others]. 2010. The South's outlook for sustainable forest bioenergy and biofuels production. The Pinchot Institute Report. 20 p.

Wear, D.; Greis, J.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS–115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Zhu, J.Y.; Pan, X.J. 2010. Woody biomass pretreatment for cellulosic ethanol production: technology and energy consumption evaluation. Bioresource Technology. 100(13): 4992–5002.

APPENDIX B. Total Wood Demand for Energy Estimation

This appendix accompanies chapter 10. Estimation of the woody biomass required for electricity production began with Energy Information Administration (2010) data on electricity generation, in billion kilowatt hours (kWh), for the electricity grids that supply customers in the Southern United States. The grid-based sales data is available only until 2035, but we extrapolated it to 2050 by applying the average growth rate calculated over the five preceding years. Determining the amount of electricity consumed in the 13 Southern States is challenging because the electric grid networks do not track the volume of power flowing to or from individual areas, nor do they break out the electricity sales information by States.[1]

We assumed that a fixed percentage of individual grid electricity caters to the South (Galik and others 2009, Rossi and others 2010) and based estimates of that percentage on expert opinions. Our underlying assumption was that the electricity demand storyline will not drastically change, with little alterations in percentages.

The Florida Reliability Coordinating Council and Electric Reliability Council of Texas grids only serve customers in the South, so we assumed that all of their sales are within the South. Other electric grids cater to customers outside the South as well:

The Southeast Reliability Corporation serves customers throughout Missouri, Alabama, Tennessee, North Carolina, South Carolina, Georgia, and Mississippi; as well as portions of Iowa, Illinois, Kentucky, Virginia, Oklahoma, Arkansas, Louisiana, Texas, and Florida. To account for supplies going outside the South—most of Missouri and portions of Iowa and Illinois—we subtracted 16 percent of the grid total electricity.

The Southwest Power Pool serves customers throughout Kansas as well as portions of New Mexico, Texas, Oklahoma, Arkansas, Louisiana, Missouri, and Nebraska. We assigned 36 percent of the grid's output to the Southern States—Texas, Oklahoma, Arkansas, and Louisiana.

An East Central Area Reliability Coordination Agreement state, now merged into Reliability First Corporation, serves portions of Kentucky and Virginia. We assigned 18 percent of the grid's output to those States.

Western Texas also receives some electricity from the Western Electricity Grid. Rather than apportioning part of the Western Grid supply, we inflated the electricity supply of the major supplier in the State (Electric Reliability Council of Texas) by 6 percent.

Using the percentage apportioning described above, we scaled data on the total U.S. annual electricity sales outlined in Energy Information Administration (2010) reference case scenario to the Southern States.

We estimated the share of woody biomass-based electricity, using the same data source (Energy Information Administration 2010) for the electricity grids. These data are broken down by the type of renewable energy—including conventional hydroelectric, geothermal, wood and other biomass, biogenic municipal waste, wind, photovoltaic, and solar thermal sources; but excluding ethanol, net electricity imports, and nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters—and scaled down according to the percentage factors used to derive total output for the South. Using total electricity demanded, total renewable electricity, and total woody and other biomass-based electricity data, we derived the share of renewables in the total electricity portfolio of the region, as well as the share of wood-based biomass electricity within the renewables. Following Galik and others (2009), we assumed that all energy from wood and other biomass sources outlined by the Energy Information Administration (2010) is completely composed of wood. The woody biomass demand specified as electricity in billion kWh was converted to woody biomass in thermal energy terms of trillion Btu. Following Rossi and others (2010), we used a conversion factor of 13,648 Btu per kWh, which is the standard electricity to thermal energy conversion factor (3,412 Btu per

[1] Personal communication, 2010. R.J. Robertson, Manager, Customer Relations. Southwest Power Pool, 415 North McKinley, #140 Plaza West, Little Rock, AR 72205; and Teresa Glaze, Data Analyst, SERC Reliability Corporation, 2815 Coliseum Centre Drive, Suite 500, Charlotte, NC 28217.

kWh) at a 25 percent level of efficiency. This is congruent with the Wiltsee (2000) study of biomass-fuelled power plants, which reported the typical higher heating value to be approximately 14,000 Btu per kWh (24.4 percent efficiency).

To account for conversion efficiency increases resulting from factors such as increased use of co-firing with coal in the future, replacing older combustion steam turbines with gasification combined cycle plants, and technological advances to all types of biomass power plants, we assumed a gradual increase in thermal efficiency after 2020 to a maximum of 40 percent in 2050. We converted Btu values to mass in green tons by applying a conversion factor of 8.6 million green tons per Btu outlined by the Forest Service (2004) for green wood (50 percent moisture content). Next we needed to allocate how much of the total biomass used for energy is sourced from softwoods versus hardwoods. This is challenging as weight-to-volume conversion factors vary with stem size and specific gravity of species. Galik and others (2009) estimated conversion factors for trees of average diameters based on Timber Mart-South 2007 data. We followed their conversion factors—34.44 green tons per thousand cubic feet for softwoods and 35.98 green tons per thousand cubic feet for hardwoods.

ESTIMATING DEMAND

Wood-Based Liquid Fuels

Estimation of the woody biomass required for liquid fuels production began with Energy Information Administration (2010) projections of energy consumption by sector and source. We used this information to determine the share of cellulosic ethanol with respect to the total domestic ethanol production. While extrapolating ethanol production from 2036 to 2050, we pegged the corn and starch ethanol production value at the 2035 level and assumed that increased ethanol production will come from cellulosic sources alone. This is in sync with current Renewable Fuel Standard target of pegging corn and starch ethanol production at a fixed level and allows for increase in ethanol production through cellulosic sources alone, although the Energy Information Administration (2010) projections assume that the Renewable Fuel Standard target of cellulosic ethanol will not be met by 2022.

We estimated total domestic cellulosic ethanol production (in million barrels per day) based on percentage share data on estimates of liquid fuels supply and disposition, and added data for other biomass-derived liquids such as pyrolysis oils, biomass-derived Fischer-Tropsch liquids, and renewable feedstocks used for the production of green diesel and gasoline, gathered from the same source, to get total liquid fuels that can be produced from wood or other cellulosic sources (Energy Information Administration 2010).

We scaled cellulosic liquid fuels demand at the national level down to southern levels based on the assumption that 55 percent of the national demand will be met by the 13 Southern States. Because wood is a high-volume low-value product, transportation costs limit its transport to conversion plants far from harvesting areas. In this light, 55 percent is conservative, as 57 percent of wood harvesting occurs in the South (Hanson and others 2010).

A suite of feedstocks (including wood, paper and pulp liquors, algae, switch grass, and agricultural residue) can be used to produce cellulosic ethanol or other bio-oils. Because the future of liquid fuel from biomass sources is uncertain and we do not know how much cellulosic ethanol and other bio-oils will come from wood sources, we assumed that 30 percent of the total cellulosic fuels and bio-oils are from wood. We converted barrel-per-day demand to gallons per day according to Oak Ridge National Laboratory (2010) protocols, which defined 1 barrel as 42 gallons. We converted daily consumption data to annual levels by multiplying by a factor of 365.242 and converted gallons of ethanol and bio-oils to green tons of wood using an ethanol yield calculator (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html), establishing that a green ton of softwoods produces 40.75 gallons, 50.4 gallons for hardwoods. We further converted the wood demand in thousand cubic feet by applying the volume-to-weight conversion factors developed by Galik and others (2009).

Wood Pellets

The U.S. wood pellet industry is already established, in contrast to the wood electricity and wood fuels industries (Alavalapati and Lal 2009, Spelter and Toth 2009). However, to a large extent, it is being driven by European demand (Gold 2009). This along with the use of wood pellets for domestic heating rather than grid electricity might result in incomplete accounting by the Energy Information Administration (2010), where renewable electricity production estimates are based solely on electricity grid sales. This prompted us to account for wood pellet demand separate from wood based electricity demand. Spelter and Toth (2009) estimated southern pellet plant capacity to be 1.85 million tons in 2009; based on their assessment that U.S. plants operate at an average efficiency of 66 percent, we estimated the demand for wood for pellets in the southern region to be 1.22 million tons. Because many States are encouraging the use of renewables, domestic demand is likely to increase in future. To account for expected demand increase in future, we assumed a 0.5-percent annual increase in the capacity of pellet plants from 2011 onwards. The current capacity utilization of U.S. pellet plants is lower than countries like Canada, which have utilization efficiency of 81 percent. Spelter and Toth (2009) attributed this to reasons such as newer plants, normal startup problems, and limits on fiber availability. However, they also say that as pellet plants become older, the U.S. capacity utilization is expected to increase. To account for technological advancements, we assumed that overall capacity utilization increases by 1 percent per year from 2015 until it reaches 85 percent.

Harvesting Residues and Urban Wood Waste

Current literature (Perlack and others 2005, Galik and others 2009, Energy Information Administration 2010) indicates that harvesting residues—discarded tree tops and limbs generated during the harvesting process—currently being left on the ground can be used as woody biomass-based energy feedstocks. Recent analyses (Galik and others 2009, Rossi and others 2010) suggest that harvesting residues could be used to avoid diverting some merchantable timber for energy production. Rossi and others (2010) also argue that the projections of woody biomass demand for energy production need to be scaled down further to account for urban wood waste. For this reason, we dropped urban wood waste from the total amount of woody biomass consumption. This essentially gives us the merchantable timber that will be required for energy production (total woody biomass minus urban wood waste). Note that the residue from additional harvesting was handled endogenously. The model calculates softwood and hardwood harvesting residues along with the merchantable timber that can be harvested in a particular year. For each year, the amount of harvesting residues that can be made available is estimated along with the harvest levels of softwood and hardwood pulpwood and sawtimber. Because it ignores urban wood waste, we netted out urban wood waste from total woody biomass consumption and fed the remainder into the model.

The harvest residue that can be used for energy production depends on total harvest as well as the residue utilization factor (the percentage of harvest residue that can be converted to energy). Increased harvesting efficiency can reduce the availability of forest residues (Grushecky and others 2007). Rather than having a constant harvesting residue utilization factor—40 percent for Walsh and others (2008), 45 percent for Rossi and others (2010), and 50 percent for Galik and others (2009)—we assume 45 percent in 2010, increasing to 67 percent in 2025, and remaining pegged at this level until 2050. We believe that this trend characterizes the effects of current harvest efficiencies and technology improvements along with potential developments of the forest residues market. Because forest residue removal also has the potential for adverse impacts on site productivity and biodiversity (Lal and others 2009), some State biomass harvesting guidelines are aimed at retaining of 10 to 33 percent forest residues on harvesting sites (Lal and others 2011). Consequently, we assume that not more than 67 percent of harvest residues are removed and utilized for energy production.

Total harvest information for different time periods is estimated through an auxiliary Subregional Timber Supply model, (Abt and others 2000), which calculates gross harvest residues. The modified model uses residual factors (Johnson and others 2009) to estimate softwood and hardwood harvesting residues produced for different woody biomass consumption scenarios. For the forest survey units in this study, the harvesting residual factors for softwood ranges from 0.049 to 0.161 (per cubic foot of removals) for growing stock, and 0.091 and 0.357 for nongrowing stock, compared to 0.106 to 0.247 for growing stock and 0.1945 and 0.3783 for nongrowing stock for hardwoods.

The subregional supply model run allocates harvest residues based on species (hardwood versus softwood) rather than to hardwood and softwood products (sawtimber versus nonsawtimber). To distribute residues to the four products, we used average product shares of these products as initial parameter values and calculated the average product shares based on the Timber Product Outputs data (Bentley 2003; Johnson and others 2006, 2008, 2009). We estimated the residues at 55.51 percent for softwood sawtimber, 44.48 percent for softwood nonsawtimber, 39.74 percent for hardwood sawtimber, and 60.25 percent for hardwood nonsawtimber.

Wiltsee (1998) estimated per capita urban wood waste at 0.203 green tons per year, which we used—along with the yearly estimates of future population of the Southern States through 2050 from the U.S. Census Bureau States Interim Population Projections by Age and Sex data sets (http://www.census.gov/population/www/projections/projectionsagesex.html)—to calculate the annual amount of urban wood waste generated in the region. Because some urban wood waste will not be diverted for energy use, we scaled the per capita urban wood waste estimation by a utilization factor of 60 percent (Carter and others 2007).

ALLOCATING MERCHANTABLE TIMBER INTO FOUR PRODUCTS

To determine the percentage share within a species group, we allocated woody biomass requirement (minus harvesting residues) only to the pulpwood market, as sawtimber and other higher value forest resources might be too expensive to be used for bioenergy production. The nonsawtimber-based feedstock preference can also be observed in a recent study by Rossi and others (2010) in Florida, which assumed that 88 percent of the total timber diverted for energy comes from nonsawtimber sources. However, Perlack and others (2005) outline the possibility that high oil prices and low timber prices may create conditions whereby pulpwood or even small sawtimber resources could be used for bioenergy. We assumed that nonsawtimber will be used for energy production earlier than high value sawtimber. However, at higher level of woody biomass consumption, we determined how much of the woody biomass requirement exceeds what can be met by nonsawtimber. We posit that this extra requirement of biomass (over and above the harvest levels depicted by the model runs) is sourced by displacing softwoods and hardwoods sawtimber from forest industries.

The subregional supply model utilizes diameter distributions for each subregion, owner, management type, and age class to calculate product removals and inventory volumes by age class. We modified age class in the subregional supply model from a five-year period to annual levels so that the supply response could be consistent with consumption data. Furthermore, the model requires a specific cull factor and a diameter range that determines how much volume (in each product category) contributes to nonsawtimber. We used the cull factor outlined in Abt and others (2009, 2010) and demarcated sawtimber versus nonsawtimber based on diameter at breast height (d.b.h.) definitions from the Forest Service Forest Inventory and Analysis program: 5–8.9 inches for softwood nonsawtimber, 5–10.9 inches for hardwood nonsawtimber, >9.0 inches for softwood sawtimber, and ≥11.0 inches for hardwood sawtimber. Trees <5 inches d.b.h. are considered to be saplings.

The modified subregional supply model requires that consumption be input according to the softwood and hardwood categories specified by the user. We apportioned total woody biomass consumed (both for energy and for traditional forest industry requirements) for a particular scenario among the hardwood and softwoods as the starting point. Looking at roundwood output data for the past decade (Bentley 2003; Johnson and others 2006, 2008, 2009), we observed that the softwoods comprise approximately 70 percent of the total timber output, compared to 30 percent for hardwoods.

As most of the technology for woody bioenergy production is in nascent stage and no species group has been established as favored, we followed this generic timber output trend and parameterized the initial model run by assuming that 70 percent of wood used for energy or by industry is sourced from softwood, and the remaining 30 percent is from hardwoods.

CHAPTER 11.
Effect of Taxes and Financial Incentives on Family-Owned Forest Land

John L. Greene, Thomas J. Straka, and Tamara L. Cushing[1]

KEY FINDINGS

- Federal and State taxes reduce the pre-tax value of family-owned forest land in the South by amounts ranging from little more than one-quarter to nearly half, with the greatest share of the reduction attributable to the Federal income tax and State property taxes.
- Most family forest owners are aware of some general business provisions of the Federal income tax, but half or fewer are aware of provisions specifically for forests and other working lands, such as the reforestation incentives and special treatment of qualifying cost-share payments.
- For family forest owners who do not grow timber for sale, State property taxes are of greater concern than any other tax, because they occur annually and are perceived as being high in relation to the value of the land.
- State-to-State variability in property taxes produces relative disadvantages to holding forest land and likely contributes to conversion of family-owned forest land in States that tax property at higher rates.
- Owners of family forests and other working lands are many times more likely than U.S. taxpayers in general to incur the Federal estate tax. Of the forest estates that owe estate tax, 40 percent sell timber or land to pay part or all of the tax, with roughly one-quarter of the acres sold converted to other uses.
- Financial incentive programs are generally successful in promoting sustainable practices among the family forest owners who participate in them, but funding levels and owner confusion about the requirements to apply for and participate in the programs limit the number of acres that are treated.

[1]John L. Greene is an Emeritus Scientist, Forest Economics and Policy Research Work Unit, Southern Research Station, U.S. Department of Agriculture Forest Service, Research Triangle Park, NC 27709; Thomas J. Straka is a Professor of Forestry and Natural Resources and Tamara L. Cushing an Assistant Professor and Extension Forestry Specialist, Department of Forestry and Natural Resources, Clemson University, Clemson, SC 29634.

INTRODUCTION

Taxes on forest-related income, forest land, and forest products can encourage or inhibit private investment in forest resource management. In financial analyses, taxes rank with harvest returns and rotation length as a key determinant of the viability of forest management investments. As such, they constitute an important part of the operating environment for owners and managers of private forest land, and a critical factor in determining the level of stewardship practiced and the types of products and services provided. For units of government, taxes represent a significant source of funding and a powerful tool for pursuing societal goals. These characteristics combine to make effective integration of tax considerations both problematic and essential for forest owners, managers, investors, elected officials, and natural resource policymakers.

Of the 751 million acres of forest land in the United States, 35 percent (264 million acres) is owned by families—defined to include individuals, married couples, estates, trusts, and other unincorporated groups of individuals—and 18 percent (138 million acres) is owned by forest industry (Butler 2009). Private forest ownership is even more prevalent in the South, with 59 percent of forest land (128 million acres) held by families (Butler and Leatherberry 2004) and 27 percent (57 million acres) held by forest industry (Smith and others 2009).

This chapter addresses the effect of Federal, State, and local taxes on family-owned forests in the South. The effect of taxes on land owned by forest industry and the comparative advantages of different business organizational models are discussed in chapter 6.

The Federal Income Tax

The Federal income tax was established in 1913, under the 16th amendment to the U.S. Constitution. The earliest provisions that recognize the unique character of forest management date to 1918 (Dana and Fairfax 1980). The Federal income tax has the greatest potential of any tax to affect family forest owners, because it applies to income from all sources and the rates are high compared with other taxes. The economic effect of an income tax is to increase the variable cost of owning or managing forests. It therefore influences how intensively owners manage their holdings (Gregory 1972).

Since its institution, a number of provisions have been added to the Federal income tax that help family forest owners keep their land in forest and manage it sustainably. Some are general business provisions, while others are specifically for owners of forests and other working lands. Among the most important of the general provisions are (Greene and others 2013):

Long-term capital gain treatment of qualifying income—Income from the sale of timber held for more than 12 months generally qualifies as a "long-term capital gain." Long-term capital gains currently are taxed to individuals at a maximum rate of 20 percent (compared with 39.6 percent for ordinary income) and a minimum rate of 0 percent (compared with 10 or 15 percent for ordinary income; CCH 2013). Capital gains enjoy other advantages over ordinary income: they are not subject to self-employment taxes, at rates up to 15.3 percent, and they do not count toward the amount of income retired persons may earn before their Social Security benefits are reduced. Further, large losses in capital investments may only be applied against $3,000 of ordinary income per year, but against any amount of capital gains.

Depletion deduction—Owners who sell or dispose of timber or such other natural resources as oil or minerals can recover their investment in the resource sold through a depletion deduction. The deduction is equal to the owner's "basis" (a measure of investment in a capital asset) in each unit of the resource sold. This deduction is available to all owners who hold their forest for the production of income, whether as an investment or part of a trade or business.

Annual deduction of management costs—Owners may deduct the cost of forest management practices annually, as they occur. This deduction does not apply to reforestation, which has its own provisions (see below), but does apply to fees paid to a consulting forester or the cost of brush control, thinning, mid-rotation fertilization, timber stand improvement, control of insects and diseases, maintenance of roads and firebreaks, and similar practices, as long as they are ordinary and necessary for timber management and related to the income potential of the forest. This deduction also is available to all owners who hold their forest for the production of income. Investors, however, must take it as a "miscellaneous itemized deduction," which combined with other such expenses is deductible only to the extent it exceeds 2 percent of their "adjusted gross income."

Depreciation deductions—Owners can recover investments in qualifying income-producing property—including machinery, buildings, equipment, fences, culverts, and bridges—as it loses value over time due to wear and tear, age, deterioration, or obsolescence. Depreciation deductions are available to all owners who hold their forests to produce income, although investors again must report them as miscellaneous itemized deductions subject to the 2 percent of adjusted gross income floor. Under current law, owners also may elect to take a first-year "bonus" depreciation deduction equal to 100 percent of the cost of new property "placed in service" (available and ready for use) between Sep. 9, 2009, and the end of 2011. The bonus depreciation deduction for new property placed in service before Sep. 9, 2009, or during 2012 or 2013, is 50 percent of its cost (CCH 2010, CCH 2013).

The section 179 deduction—Owners who hold their forest as part of a trade or business may elect to deduct part or all of the cost of certain types of property instead of capitalizing and depreciating it. This deduction is not available to investors, trusts, or estates. Qualifying property includes tangible personal property, but not improvements to land, buildings, or components of buildings. For 2010 through the end of 2013, the maximum amount of the deduction is $500,000, reduced by $1 for each dollar over $2 million of section 179 property placed in service during the year (CCH 2010, CCH 2013).

Loss deductions—All owners who hold their forest land to produce income may recover the amount of their basis in timber or other property lost in a casualty event, theft, or condemnation. Owners who hold their forest as part of a trade or business also may recover their basis in property lost in a noncasualty event. (Owners who hold their forest for personal use, without a profit motive, can recover their basis in timber or other property lost in a casualty event, theft, or condemnation only to the extent that all losses in a year, minus $100 per event, exceed 10 percent of their adjusted gross income.) If income-producing property is damaged rather than destroyed, the owner must make an effort to salvage it. Since owners' basis in their timber typically is lower than its actual value, a salvage harvest of damaged timber often results in a taxable gain rather than a loss. But the owner can postpone recognition of the gain, and the tax on it, by using the gain to restore or replace the damaged property within the allowable replacement period, usually 2 years.

The provisions for owners of forests and other working lands include (Greene and others 2013):

Reforestation incentives—All owners who hold forest land for the production of income may deduct outright qualifying reforestation costs up to $10,000 per year and "amortize" (write off over a set period) any additional amount over 8 tax years.

Special treatment of qualifying cost-share payments—Landowners may elect to exclude a calculated portion of qualifying public cost-share payments from their gross income. Currently, cost-share payments from nine Federal programs—the Conservation Reserve Program, Emergency Forest Restoration Program, Emergency Watershed Protection Program, Environmental Quality Incentives Program, Forest Health Protection Program, Longleaf Pine Initiative, State Acres for Wildlife Enhancement, Wetlands Reserve Program, and Wildlife Habitat Incentives Program (table 11.1)—as well as a number of State programs are approved for exclusion. Because of the way the excludable portion is calculated, it is likely that the full amount of a cost-share payment will be excludable if the affected area has been harvested in the past 3 years, but only a fraction will be excludable it if has not.

Enhanced charitable deduction for a qualifying donation of interest in land—Landowners may take a charitable contribution deduction for donation of an interest in land. To qualify for a deduction, the donation must consist of a qualified real property interest, made to a government agency or qualified publicly-supported organization, for one of four conservation purposes (see "Incentives for Conservation Easements"). Under current law, the annual limit for this deduction is 100 percent of adjusted gross income for owners who earn more than half of their gross income from farming (defined to include forest land) or ranching, and 50 percent of adjusted gross income for other owners (Land Trust Alliance Web site 2011).

The tax rates and deduction limits for four of the above provisions are temporary, and were originally put in place by laws enacted between 2001 and 2008, collectively called the Bush tax cuts:

- The reduced tax rates for long-term capital gains were put in place by the Jobs and Growth Tax Relief Reconciliation Act of 2003 (P.L. 108-27), and were scheduled to sunset at the end of 2010.
- Bonus depreciation, previously available only to taxpayers affected by a Presidentially-declared disaster, was made generally available by the Economic Stimulus Act of 2008 (P.L. 110-185) and extended through the end of 2009 (through the end of 2010 for certain property with a long production period) by the American Recovery and Reinvestment Act of 2009 (P.L. 111-5).
- The increased section 179 deduction was put in place by The Economic Stimulus Act of 2008 (P.L. 110-185), then increased further and extended through the end of 2011 by the Hiring Incentives to Restore Employment and Small Business Jobs Acts of 2010 (P.L. 111-147 and 111-240, respectively).
- The enhanced charitable deduction for a qualifying donation of interest in land was put in place by the Pension Preservation Act of 2006 (P.L. 109-280) and extended through the end of 2009 by the 2008 Farm Bill (P.L. 110-246).

As a result, the provisions either expired at the end of 2009 or were set to expire at the end of 2010 or 2011. The Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act (2010 Tax Relief Act, P.L. 111-312), signed into law Dec. 17, 2010, reinstated all four provisions and extended them through the end of 2012 (CCH 2010). The American Taxpayer Relief Act of 2012 (P.L. 112-249), signed into law Jan. 2, 2013, replaced the first three temporary provisions with permanent ones and extended the enhanced charitable deducation for donation of an interest in land through the end of 2013, preventing all four provisions from returning to pre-2002 law (CCH 2013).

State Income Taxes

All but three of the Southern States tax income to individuals. The exceptions are Florida and Texas, which do not levy an individual income tax, and Tennessee, which taxes only dividend and interest income (table 11.2). Most States that tax income to individuals use Federal adjusted gross income or Federal taxable income as the starting point for calculating the State tax (Cushing 2006); however, they differ widely in how they set tax rate schedules, incorporate personal exemptions and itemized deductions, and treat retirement income and capital gains (Butler and others 2010). Because of the close link between Federal and State income taxes, most Federal tax provisions that benefit family forest owners flow through to the State income tax (Siegel and others 1996).

State income tax rate schedules generally ramp up quickly. In all Southern States except Kentucky and Georgia, the threshold for the top tax rate is below the ceiling for the 15-percent Federal tax bracket, the second-lowest bracket (Bankrate.com 2011). But the top marginal State tax rates range only from 5 percent to 8 percent, well below the top Federal rates for either capital gains (20 percent) or ordinary income (39.6 percent). For this reason, although State income taxes have the same economic effect as the Federal tax, their qualitative impact is smaller.

State Property and Harvest Taxes

State and local governments have levied taxes on land and other forms of property since the colonial period, with provisions which recognize that taxing land and timber together encourages deforestation dating to the 1860s (Dana and Fairfax 1980). Property taxes have the greatest impact of any State tax on family forest owners, because they occur annually and are based on the value of the land. The economic effect of a property tax is to increase the fixed cost of owning land. It therefore influences forest owners' decisions about whether to continue holding their land (Gregory 1972).

All of the Southern States assess or tax family-owned forest land in its current use rather than its highest and best use

Table 11.1—Federal incentive programs of interest to family forest owners

Biomass Crop Assistance Program (BCAP)—Authorized in 2008 to provide financial incentives for the collection, harvest, storage, and transportation of biomass material by qualified conversion facilities and the establishment and production of biomass crops. Payments to landowners under the biomass material provisions were suspended early in 2010 pending issuance of final rules and the biomass crop provisions are to be implemented in the future. All program payments must be included in adjusted gross income. BCAP is administered by the Farm Service Agency.[a,b]
Conservation Reserve Program (CRP)—Established in 1985 to help safeguard environmentally sensitive agricultural land by converting it to a long-term, resource-conserving cover. Participants receive annual rental payments under a 10 to 15 year contract. They also may receive incentive payments, and cost-share payments to cover up to 50 percent of the cost of establishing a suitable long-term cover. A calculated portion of cost-share payments may be excluded from adjusted gross income, but all other program payments must be included. CRP is administered by the Farm Service Agency.[c]
Conservation Stewardship Program (CSP)—Authorized in 2008 to assist owners of agricultural and forest land to adopt and maintain practices to conserve soil, water, air, and related resources. Participating owners receive annual payments under a 5-year contract to install and maintain new conservation practices; they also may receive supplemental payments to adopt a resource-conserving crop rotation. All program payments must be included in adjusted gross income. CSP is administered by the Natural Resources Conservation Service.[d]
Emergency Forest Restoration Program (EFRP)—Created in 2008 as a new part of the Emergency Conservation Program. EFRP provides participating forest owners a cost-share of up to 75 percent of the cost of restoring land damaged by a natural disaster, such as a flood, hurricane, tornado, or wildfire. A calculated portion of EFRP cost-share payments may be excluded from adjusted gross income. EFRP is administered by the Farm Service Agency.[e]
Emergency Watershed Protection Program (EWP)—Established to assist in implementing emergency recovery measures from natural disasters that impair or damage watersheds. Affected landowners may receive technical assistance and a cost-share of up to 75 percent (90 percent in limited resource areas) of the cost of clearing or restoring the damage; the administering agency also may elect to purchase perpetual floodplain easements from willing owners. A calculated portion of EWP cost-share payments have been excludable from adjusted gross income since 1978. EWP is administered by the Farm Service Agency.[d]
Environmental Quality Incentives Program (EQIP)—Established in 1996 to help farm, ranch, and forest-landowners address management practices that pose a significant threat to soil or water resources. Participating landowners receive technical assistance, incentive payments, and cost-share payments for 1 to 10 years that cover up to 75 percent (90 pecent for new, limited resource, or socially disadvantaged owners) of the cost of implementing conservation practices. A calculated portion of EQIP cost-share payments may be excluded from adjusted gross income. EQIP is administered by the Farm Service Agency.[d]
Forest Land Enhancement Program (FLEP)—Established in 2002, FLEP combined aspects of two earlier programs. It promoted sustainable management of family forest land by providing technical, educational, and cost-share assistance to owners. A written forest management plan was required to participate. A calculated portion of FLEP cost-share payments could be excluded from adjusted gross income. Administered by the U.S. Forest Service in cooperation with State forestry agencies, the program was not reauthorized in the 2008 Farm Bill.
Forest Legacy Program (FLP)—Created in 1990 to protect environmentally important private forest land threatened with conversion to non-forest uses. FLP is not a cost-share program. It operates primarily through the purchase of permanent conservation easements. Up to 75 percent of the total cost of protecting forest land may be Federally funded. FLP is administered by the Forest Service in partnership with the individual States.[f]
Forest Stewardship Program (FSP)—Established in 1990 to encourage and enable active long-term management of family-owned forest land and increase the economic and environmental benefits it provides. FSP is not a cost-share program. State forestry agency partners use the program to promote forest owner adoption of stewardship practices, for example, by offering a State Forest Stewards program or providing technical assistance to develop Forest Stewardship plans. FSP is administered by the U.S. Forest Service in partnership with the individual States.[g]
Healthy Forest Reserve Program (HFRP)—Authorized in 2003 to restore and enhance forest ecosystems to promote the recovery of at-risk species, improve biodiversity, and enhance carbon sequestration. Participating owners receive assistance to develop a Forest Stewardship Plan, then may elect either a 10-year agreement, which pays 50 percent of the cost of the conservation practices, or a permanent easement, which pays the easement value of the land plus 100 percent of the cost of the practices. All payments must be included in adjusted gross income. HFRP is administered by the Natural Resources Conservation Service.[d]
Landowner Incentive Program (LIP)—Established in 2003 to help private landowners protect and restore habitat for at-risk plant and animal species. LIP provides funding for States to offer technical assistance and grants to participating landowners to develop and implement habitat management plans. All LIP payments must be included in adjusted gross income. LIP is administered by the U.S. Fish and Wildlife Service in cooperation with the individual States. To participate, States must provide a minimum 25 percent match for Federal funding.[h]

(Continued)

Table 11.1—(continued) Federal incentive programs of interest to family forest owners

Longleaf Pine Initiative (LPI)—Initiated in 2006 as a conservation practice under CRP, with the goal of restoring up to 250,000 acres of longleaf pine forest in nine Southern States. Participating landowners receive annual rental payments under a 10 to 15 year contract. They also may receive incentive payments, and cost-share payments to cover up to 50 percent of the cost to plant, protect, and manage longleaf pine stands on suitable sites. A calculated portion of LPI cost-share payments may be excluded from adjusted gross income, but all other payments must be included. LPI is administered by the Farm Service Agency.[i]
Partners for Fish and Wildlife (PFW)—Established in 1987 to help restore wetlands and other important fish and wildlife habitats on private lands. Participating owners receive technical assistance and a cost-share of up to 100 percent of the cost of implementing conservation practices. Funds for cost-share payments come from Federal, State, and local units of government, soil and water conservation districts, and private conservation organizations. All program payments must be included in adjusted gross income. PFW is administered by the U.S. Fish and Wildlife Service in cooperation with the individual States.[j]
Red-Cockaded Woodpecker (RCW) Recovery Program—Created under the Endangered Species Act of 1973 to help public and private landowners in 11 Southern States conserve red-cockaded woodpeckers and the habitat upon which they depend. Program specifics for private landowners vary by State. In most States, participants receive technical assistance in habitat improvement, but in some States cost-share funding also is available. Any program payments must be included in adjusted gross income. RCW is administered by the Fish and Wildlife Service in cooperation with the individual States.[k]
Southern Pine Beetle Prevention Program (SPBP)—Established in 2003 to help public and private forest-landowners in the Southern States reduce the susceptibility of their holdings, restore affected areas, and fund research. Program specifics vary by State, but private landowners can receive technical assistance and cost-share payments to cover part of the cost of such treatments as thinning and hazard fuel reduction. A calculated portion of SPBP cost-share payments may be excluded from adjusted gross income. SPBP is administered by the U.S. Forest Service in cooperation with the individual States.[l]
State Acres for Wildlife Enhancement (SAFE)—Initiated in 2008 as a conservation practice under CRP to protect and restore habitat for high-priority wildlife species. Participating landowners receive annual rental payments under a 10 to 15 year contract. They also may receive incentive payments, and cost-share payments to cover up to 50 percent of the cost to establish habitat-enhancing natural covers on suitable land. A calculated portion of program cost-share payments may be excluded from adjusted gross income, but all other payments must be included. SAFE is administered by the Farm Service Agency.[m]
Wetlands Reserve Program (WRP)—Established in 1985 to encourage conservation of wetlands on privately owned lands. Participating owners elect one of three program options: a permanent easement, which pays 100 percent of the easement value of the land and the cost of wetland restoration practices; a 30-year easement, which pays 75 percent of the easement value and the cost of restoration practices; or a cost-share option, which pays 75 percent of the cost of restoration practices. A calculated portion of WRP cost-share payments may be excluded from adjusted gross income, but all other payments must be included. WRP is administered by the Farm Service Agency.[d]
Wildlife Habitat Incentives Program (WHIP)—Established in 1996 to encourage development and improvement of wildlife habitat on private land. Participating landowners receive technical assistance, incentive payments, and cost-share payments under an agreement lasting 1 to 10 years that cover up to 75 percent (90 percent for new, limited resource, socially disadvantaged owners, or Indian tribes) of the cost of implementing conservation practices. A calculated portion of program cost-share payments may be excluded from adjusted gross income. WHIP is administered by the Farm Service Agency.[d]

[a]FSA BCAP Fact Sheet: http://www.fsa.usda.gov/Internet/FSA_File/bcap09.pdf.
[b]Biomass Magazine: http://biomassmagazine.com/article.jsp?article_id=3793.
[c]FSA CRP Fact Sheet: http://www.fsa.usda.gov/Internet/FSA_File/crpcont06.pdf.
[d]NRCS Conservation Programs Web page: http://www.nrcs.usda.gov/PROGRAMS/.
[e]FSA EFRP Fact Sheet: http://www.fsa.usda.gov/Internet/FSA_File/2008fbemergencyforestsummary.pdf.
[f]USFS FLP Web page: http://www.fs.fed.us/spf/coop/programs/loa/flp.shtml.
[g]USFS FSP Web page: http://www.fs.fed.us/spf/coop/programs/loa/fsp.shtml.
[h]USFWS LIP Web page: http://wsfrprograms.fws.gov/Subpages/GrantPrograms/LIP/LIP.htm.
[i]FSA LPI Fact Sheet: http://www.fsa.usda.gov/Internet/FSA_File/crplongleaf06.pdf.
[j]USFWS PFW Southeast Region Web page: http://www.fws.gov/southeast/es/partners/.
[k]USFWS Red-Cockaded Woodpecker Recovery Web page: http://www.fws.gov/rcwrecovery/.,
[l]USFS SPBP Web page: http://www.fs.fed.us/r8/foresthealth/programs/spb_prevention/spb_prevention.shtml.
[m]FSA SAFE Fact Sheet: http://www.fsa.usda.gov/Internet/FSA_File/safe08.pdf.

Table 11.2—State income tax provisions applicable to family forest owners in the South, 2010

State	State-level income tax	Preferential treatment of long-term capital gains	Deduction or credit for conservation
Alabama	Yes	–	–
Arkansas	Yes	Yes	Credit
Florida	–	–	–
Georgia	Yes	–	Credit
Kentucky	Yes	–	–[a]
Louisiana	Yes	–	–
Mississippi	Yes	–	Deduction
North Carolina	Yes	–	Credit
Oklahoma	Yes	–	–
South Carolina	Yes	Yes	Credit[b]
Tennessee	–	–	–
Texas	–	–	–
Virginia	Yes	–	Credit[b]

– = indicates no applicable provision.
[a]Some family forest owners may qualify for an income tax deduction Kentucky provides for donation of a conservation easement on farmland or open space land for agricultural use.
[b]The credit is transferrable; that is, any unused portion may be sold to others.
Sources: Butler and others 2010, Private Landowner Network Web site 2011.

(table 11.3). The States vary substantially, however, in the approaches they use and the methods by which they apply them. Some States determine the current use value of land using soil type and productivity, which involves using a specified capitalization rate to discount prospective future returns from the land back to the present; others use fair market value in the land's current use, which emphasizes recent sales of comparable properties. The States also vary in the goals for their preferential property tax programs, and the requirements to participate in or withdraw from the program (table 11.3).

Three States—Alabama, North Carolina, and Tennessee—expressly exempt standing timber from property taxes (National Timber Tax Website 2011a). Another three states restrict deduction of property taxes on State income tax returns: Louisiana does not permit deduction of property taxes, Virginia does not allow individual taxpayers to deduct property taxes, and Tennessee does not allow corporations to deduct property taxes (Cushing 2006).

Property taxes are set and levied at the county level, making them the most diverse of the taxes that family forest owners face and the most difficult to track. Some county officials in the Southern States have expressed interest in developing property tax provisions that discourage urban sprawl and encourage provision of ecosystem services from rural land, but little is known about how many such provisions have been put in place or the level of their success.

Seven Southern States also impose a severance tax on timber when it is harvested. Three of the States—Georgia, Louisiana, and Mississippi—levy the tax on forest owners, while the other four—Alabama, Arkansas, North Carolina, and Virginia—levy it on timber processors. All seven States use at least part of their severance tax receipts to support a forestry incentive program or another forest-related purpose (Cushing 2006, National Timber Tax Website 2011a). The economic effect of a severance tax mirrors that of an income tax, but at the rates used its impact is minor, having little effect on an owner's management decisions.

The Federal Estate and Gift Taxes

The Federal government has taxed transfers of estates since 1916 and lifetime gifts since 1932 (Siegel and others 2009). The U.S. Congress periodically redefines what constitutes a taxable transfer of wealth; the most recent changes came with passage of the Economic Growth and Tax Relief Reconciliation Act of 2001 (EGTRRA, P.L. 107-16) and the Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010 (2010 Tax Relief Act, P.L. 111-312). The economic effect of estate and gift taxes is difficult to quantify because they occur at irregular intervals. They do, however, increase risk and put a premium on keeping planning options open.

The Federal tax code includes numerous provisions that reduce or eliminate the impact of the Federal estate and gift taxes. These provisions help family forest owners keep their holdings intact through a transfer from one generation to another and reduce the likelihood that heirs will need to liquidate timber or fragment the holding. As with the Federal income tax, some are general provisions available to all taxpayers, while others are specifically for owners of forests and other working lands. Among the most important general provisions are (Siegel and others 2009):

Gifting—Individuals may make lifetime gifts up to the annual exclusion amount, currently $14,000 (Internal Revenue Service 2012), to as many different recipients each year as they wish without using the effective exemption amount for gifts (see below) or incurring a gift tax. Married couples may make "split gifts" of double the annual exclusion amount. In addition, there is an unlimited exclusion for gifts to qualifying charitable organizations and qualifying gift payments of educational or medical costs. There is no "step-up" in basis (see below) for gifts, but gifting enables

Table 11.3—Property tax provisions applicable to family-owned forest land in the South, by State, 2010

State	Property tax type of program[a]	Primary goals[b]	Minimum acreage to enroll[c]	Requires a management plan[c]	Enrollment period in years[c]	Withdrawal penalty
Alabama	PT	AG	5	Varies	Varies	No
Arkansas	PA	–	–	–	–	–
Florida	PT	AG/OS	Varies	Varies	Continuous	No
Georgia	PT	OS	Varies	No	10	Yes
Kentucky	PA	–	–	–	–	–
Louisiana	PA	–	–	–	–	–
Mississippi	PA	–	–	–	–	–
North Carolina	PT	HAB	20	Yes	Continuous	Yes
Oklahoma	PA	–	–	–	–	–
South Carolina	PT	AG/FOR	5	Varies	Continuous	Yes
Tennessee	PT	OS	15	Yes	Continuous	Yes
Texas	PT	FOR	Varies	Varies	Continuous	Yes
Virginia	PT	FOR/OS	20	No	Continuous	Yes

– = indicates no applicable provision.
[a]PA=Preferential assessment; PT=Preferential tax.
[b]AG=Sustain agriculture; FOR=Sustain forestry; HAB=Habitat conservation; OS=Maintain open space.
[c]Varies=Varies from county to county.
Source: Butler and others 2010.

owners to remove from their estate assets that are rapidly appreciating in value.

“Step-up” in basis for bequests—A recipient’s basis in an asset received through a bequest generally is its fair market value on the valuation date, either the date of the decedent’s death or the earlier of 6 months after death or the date any estate asset is sold. This usually results in a “step-up” in the basis compared with what it was in the decedent’s hands. EGTRRA repealed the Federal estate tax for 2010, and placed limits on the value of estate assets that could receive a step-up in basis. The 2010 Tax Relief Act extended and enhanced the Federal estate tax provisions for decedents dying in 2011 or 2012 (see below), with all estate assets eligible for a step-up in basis. For decedents dying in 2010, the executor could elect to use either the provisions of EGTRRA or the 2010 Tax Relief Act (CCH 2010, CCH 2013).

The marital deduction—The Federal tax code allows an unlimited deduction for the value of all property passed from one spouse to the other through a lifetime gift or bequest. This provision recognizes the role of both spouses in building up a family’s assets. It does not eliminate or reduce the estate tax, however, but merely postpones it to the time of the surviving spouse’s death. This can be a considerable disadvantage if the assets—land or standing timber, for example—appreciate greatly in value during the time between the deaths.

Effective exemption amount for gifts—This is a credit against the tentative gift tax due, which shields part or all of gifts over the annual exclusion amount from tax. The 2010 Tax Relief Act extended the $1 million exemption amount for gifts made in 2010; for gifts made in 2011 or 2012, the Act established a $5 million unified exemption amount for gifts and estates (CCH 2010). Under a unified exemption, an owner can transfer assets up to the exemption amount to recipients other than their spouse, either as lifetime gifts or bequests, without incurring a tax.

Effective exemption amount for estates—This is a credit against the tentative estate tax due, which shields part or all of an owner’s estate from tax. As just described, the 2010 Tax Relief Act combined the effective exemption amounts for gifts and estates into a $5 million unified exemption amount. It applied to the estates of decedents dying in 2011, and where the executor elected to use the provisions of the 2010 Tax Relief Act rather than EGTRRA, to the estates of decedents dying in 2010 (CCH 2010). The American Tax Relief Act of 2012 indexed the unified exemption amount for inflation after Dec. 31, 2011, so that it increased to $5.12 million for decedents dying in 2012 and $5.25 million for decedents dying in 2013 (CCH 2013). The 2010 Tax Relief

Act further made the unified exemption amount "portable" between spouses. This means that in families led by a married couple, any part of the unified exemption amount not used by the estate of the first spouse to die may be added to the unified exemption amount for the estate of the second spouse. Portability effectively doubles the unified exemption amount, allowing family assets of $10 million or more in value to pass untaxed from one generation to another (CCH 2010, CCH 2013).

Deferral and extension of estate tax—If an interest in a closely-held business accounts for more than 35 percent of a decedent's estate, the Federal estate tax on the business portion of the estate may be deferred for 4 years after the estate tax return is filed, with only interest payments due, then paid in up to 10 annual installments. Although this provision does not reduce the amount of estate tax due, it can reduce the need to disrupt an established forest management plan in order to pay tax.

The provisions for owners of forests and other working lands include (Siegel and others 2009):

Special use valuation—Under specific conditions, an executor may elect to reduce the taxable value of an estate by valuing assets used for farming (defined to include forest land) or a trade or business according to their value in actual use rather than their fair market value. The maximum amount of the reduction has been indexed for inflation since 1998 and reached $1.07 million in 2013 (Internal Revenue Service 2012). There are, however, stringent requirements to qualify for and remain under the provision, including a restriction against harvesting special use-valued timber for 10 years.

Exclusion for land in a qualified conservation easement—An executor may elect to exclude from the taxable value of an estate up to 40 percent of the value of land subject to a qualified conservation easement (see below). The benefit is capped at $500,000 and the 40 percent maximum exclusion is reduced if the value of the easement is less than 30 percent of the value of the land. As with the charitable deduction for donation of an interest in land, the easement must consist of a qualified real property interest, made to a government agency or qualified publicly-supported organization, for one of four conservation purposes (see "Incentives for Conservation Easements"). This provision offers many of the benefits of special use valuation with fewer restrictions. There is, however, no step-up in basis for the excluded land.

Estate planning professionals have developed additional strategies, not specifically provided in the Federal tax code, to facilitate intergenerational transfers of family assets. These include (Siegel and others 2009):

Forms of business—Two forms of business organization, the Family Limited Partnership (FLP) and Limited Liability Company (LLC), are popular among family forest owners as means to transfer ownership of a forest enterprise to other family members and engage them in its management. The FLP is a type of limited partnership. In an FLP, the general partners (typically the parents) retain management rights but can transfer ownership to the limited partners (typically the children) through gifts, which can be discounted for minority interest and/or lack of control. The LLC is a hybrid between a partnership and a corporation. Like a partnership, an LLC is a pass-through entity for tax purposes, but like a corporation, individual members' liability is limited to the amount of their investment in the business. Forest owners should be aware that these forms of business have two drawbacks: first, there is no step-up in basis for land or timber transferred to others through the business, and second, both FLPs and LLCs are under scrutiny by the Internal Revenue Service as potential tax avoidance devices that lack economic substance. To help avoid difficulties, owners should ensure that their FLP or LLC has a clear business purpose, is held completely separate from personal assets, and is set up and run entirely as a business.

Trusts—A trust is an arrangement in which a person or institution called the trustee holds legal title to designated property and manages it for the benefit of one or more beneficiaries. A trust is a separate legal entity from its donor. A "lifetime trust" is created during the donor's life and may be revocable or irrevocable. Only an irrevocable lifetime trust removes the trust property from the donor's estate. A "testamentary trust" is created at the donor's death, according to instructions in his or her will. The full value of the trust property is included in the donor's estate, but the trust then can provide income to successive generations of beneficiaries while shielding the trust property from further estate tax. Trusts may be used for a variety of purposes. For example, an "irrevocable life insurance trust" removes a life insurance policy from the donor's ownership and prevents its full face value from entering his or her estate at death. A "qualified terminal interest property trust" is a type of marital deduction trust that may be useful with "blended" families; it provides for the needs of the surviving spouse while controlling disposition of the trust property remaining after his or her death.

Conservation easements—This is the donation or sale of one or more attributes of land ownership, for example, the right to subdivide the land. The easement removes the attribute(s) of ownership from the land. This typically lowers the value of the land and reduces the tax consequences of transferring it to heirs; however, the easement passes with the land and is binding on future owners. To qualify for either of the tax provisions discussed above, an easement must involve the transfer in perpetuity, by means of an outright gift or "bargain sale" (a sale at a price below the property's fair market value), of a qualified real property interest, to a government agency or qualified publicly-supported organization, for one of four conservation purposes (see "Incentives for Conservation Easements").

The Bush tax cuts temporarily set separate effective exemption amounts for gifts and estates. Between 2001 and 2009 they increased the effective exemption amounts for estates from $1 million to $3.5 million and decreased the top rate for gift and estate taxes from 55 percent to 45 percent. For 2010, they repealed the Federal estate tax, placing limits on the value of estate assets that could receive a step-up in basis and setting the top gift tax rate at 35 percent, equal to the top Federal income tax rate. These provisions were set to sunset at the end of 2010 (Siegel and others 2009). But as noted above, the 2010 Tax Relief Act extended and enhanced the estate tax, with all estate assets eligible for a step-up in basis. As well, it reunified the effective exemption amounts for gifts and estates, with the maximum exemption increased to $5 million and portability between married spouses, and reduced the top estate tax rate to 35 percent (CCH 2013). The American Taxpayer Relief Act of 2012 further enhanced the Federal estate and gift tax provisions and made them permanent, preventing them from returning to pre-2002 law after the end of 2012 (CCH 2013).

State Estate, Inheritance, and Gift Taxes

The States again vary widely in how they tax intergenerational transfers of assets. Some States tax the right to transfer property through an estate tax, while others tax the right of heirs to receive property through an inheritance tax. A handful of States tax gifts over specified annual or lifetime exemption amounts. As well, State transfer taxes differ in their filing requirements, exclusion amounts, and rate schedules; whether they are stand-alone taxes or tied to the Federal tax code; whether they are "flat-rate" (one tax rate applies regardless of the amount transferred), "graduated" (the tax rate increases in steps with the amount transferred) or "layered" (the tax rate varies with the heir's relation to the decedent); and whether certain closely-related heirs are exempt (Siegel and others 2009).

Before the enactment of EGTRRA, every State had on its books at least one tax that was a "pick-up" or "piggy-back" tax designed to use the full available amount of the Federal credit for State transfer taxes. This approach apportioned part of what would have been the Federal estate or gift tax to the State, with no additional tax burden on the estate or the beneficiaries. EGTRRA phased out the Federal credit for State transfer taxes between 2002 and 2005, replacing it with a deduction. This eliminated State transfer taxes that were tied to the Federal credit, throwing State tax law and tax planning into turmoil. Individual States responded very differently to the change. Many "decoupled" their transfer taxes from current Federal law, tying them to the Federal tax code as it existed before EGTRRA. Others made no change, allowing their estate, inheritance, and gift taxes to phase out with the Federal credit. A few States took EGTRRA as an opportunity to repeal transfer taxes or to craft stand-alone taxes on transfers of assets (Siegel and others 2009).

Only five Southern States currently levy transfer taxes: Kentucky and Louisiana each have a stand-alone inheritance tax, North Carolina has a stand-alone gift tax and an estate tax that is decoupled from current law and tied to the Federal tax code as of the end of 2001, Oklahoma has a stand-alone estate tax, and Tennessee has stand-alone inheritance and gift taxes (table 11.4). Virginia repealed its estate tax effective during 2007.

Except for North Carolina and Virginia, however, all of the Southern States still have pick-up or piggy-back taxes on their books which will come back into effect if the Federal credit for State transfer taxes is reinstated (table 11.4). If that occurs, seven additional Southern States—Alabama, Arkansas, Florida, Georgia, Mississippi, South Carolina, and Texas—will have an estate tax; Kentucky and Louisiana will have an estate tax as well as an inheritance tax; Oklahoma will have a second estate tax; and Tennessee will have estate, inheritance, and gift taxes (Siegel and others 2009).

Incentives for Conservation Easements

Conservation easements are one of the most powerful tools available to family forest owners who wish to preserve the conservation value of their land over time. A conservation easement involves the donation or sale of one or more attributes of land ownership—the right to build additional structures on the land, for example, or develop it for commercial or industrial use—to a government agency or organization that shares the owner's vision for the land. The easement removes those attributes of ownership from the land and helps ensure that it remains in forest (Greene and others 2013).

A conservation easement does not involve the donation or sale of an owner's entire interest in the land. The owner can retain the right to live on the land, manage it for timber or other forest products, and use it for other benefits. The easement also can apply only to part of the property, with the owner retaining all attributes of ownership for the rest. The owner can pass the full remaining interest in the land to heirs or sell it to others, although the easement passes with the land and is binding on future owners (Greene and others 2013).

The terms for conservation easements are not standardized, but can be tailored to reflect the values of the owner and

Table 11.4—State estate, inheritance, and gift tax provisions applicable to family forest owners in the South

State	Currently has a State-level estate tax	Currently has a State-level inheritance tax	Currently has a State-level gift tax	Special use valuation for estate tax	Phased-out tax still on the books
Alabama	–	–	–	–	Estate tax
Arkansas	–	–	–	–	Estate tax
Florida	–	–	–	–	Estate tax
Georgia	–	–	–	–	Estate tax
Kentucky	–	Yes	–	–	Estate tax
Louisiana	–	Yes	–	–	Estate tax
Mississippi	–	–	–	–	Estate tax
North Carolina	Yes	–	Yes	No	No
Oklahoma	Yes	–	–	No	Estate tax
South Carolina	–	–	–	–	Estate tax
Tennessee	–	Yes	Yes	–	Estate tax
Texas	–	–	–	–	Estate tax
Virginia	–	–	–	–	No

– = indicates no applicable provision.
Sources: Butler and others 2010, Siegel and others 2009.

the receiving organization, as well as the characteristics of the land itself. For example, an easement on property that contains habitat for rare plant or wildlife species might prohibit any development, while an easement on working forest land might permit continued management for forest products and the construction of roads and improvements consistent with that use. The purchaser or recipient of the easement is responsible for ensuring the easement's terms are followed (Land Trust Alliance Web site 2011).

Federal provisions—Income from the sale of a conservation easement is taxable at the Federal level. The donation or bargain sale of an easement, however, can provide a charitable contribution deduction on the donor's income tax and a future estate tax deduction (Greene and others 2013). These deductions are discussed above, but generally require the transfer in perpetuity, by means of an outright gift or bargain sale, of a qualified real property interest, to a government agency or qualified publicly-supported organization, for one of four conservation purposes. The qualified real property interest may be the owner's entire interest (but not solely a mineral interest), a remainder interest, or a perpetual restriction on how the property may be used, as with a conservation easement. The four conservation purposes are: outdoor recreation by or education of the general public; protection of a relatively natural habitat for fish, wildlife, or plants; preservation of open space for scenic enjoyment by the general public or pursuant to a clear conservation policy of the Federal, State, or local government; and conservation of an historically important land area or certified historic structure.

Four of the Federal incentive programs available to family forest owners involve conservation easements. The Forest Legacy Program funds up to 75 percent of the cost of placing forest land under an easement. Under the Healthy Forest Reserve and Wetlands Reserve Programs, owners may elect to receive payments for the easement value of their land as well as the cost of conservation practices they implement. Under the Emergency Watershed Protection Program, the administering agency may elect to address impairment or damage to watersheds caused by a natural disaster through the purchase of floodplain easements from willing owners (SRS Forest Economics and Policy Web site 2011). The provisions of these programs are summarized in table 11.1.

State provisions—Because of the close link between Federal and State income taxes, most Federal tax provisions that benefit family forest owners flow through to the State income tax (Siegel and others 1996). Individual States, however, offer their own incentives for conservation easements. Property tax relief proportional to the decrease in value of land placed in an easement generally is available in every State, but is required by law in Florida, Georgia, Kentucky (for land dedicated to the State Nature Preserves System), South Carolina, Tennessee, and Virginia. Arkansas, Georgia, North

Carolina, South Carolina, and Virginia each have enacted an income tax credit for donation of a qualifying conservation easement. In Virginia, sales of easements over 30 years in duration are exempt from the State capital gain tax. As well, Alabama, Florida, Georgia, and Texas operate conservation trusts to preserve working agricultural and forest land (Private Landowner Network Web site 2011).

Incentives for Forest Sustainability

Forest sustainability is one aspect of sustainable development (USDA Forest Service 2004). In a broad sense, forest sustainability can be described as involving:

> *"... the continued existence and use of forests to meet human physical, economic, and social needs; the desire to preserve the health of forest ecosystems in perpetuity; and the ethical choice of preserving options for future generations while meeting the needs of the present."* (USDA Forest Service 2002)

At a more specific level, it can be defined as:

> *"The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and potential to fulfill, now and in the future, relevant ecological, economic, and social functions at local, national, and global levels, and that does not cause damage to other ecosystems."* (Helms 1998)

Federal programs—The Federal government sponsors a wide range of incentive programs to encourage sustainable management of family-owned forests and other rural lands. Most are administered by agencies of the Department of Agriculture—the Farm Service Agency, Forest Service, or Natural Resources Conservation Service. Three programs are administered by the Fish and Wildlife Service within the Department of Interior. Virtually all of the programs provide technical assistance to help owners select and implement conservation practices that will be effective on their land. Many also provide financial incentives, such as cost-share payments to cover part or all of the cost of conservation practices, land rental payments over a term of years, or other types of payments.

Table 11.1 provides a brief description of the Federal incentive programs of particular interest to family forest owners. As noted above, owners can elect to exclude a calculated portion of cost-share payments from nine programs from their adjusted gross income, making the payments tax-free (Greene and others 2013), and four programs involve use of conservation easements.

State programs—State agencies participate in the on-the-ground management of six Federal incentive programs: the Forest Legacy, Forest Stewardship, and Southern Pine Beetle Prevention Programs administered by the Forest Service and the Landowner Incentive, Partners for Fish and Wildlife, and Red-cockaded Woodpecker Recovery Programs administered by the Fish and Wildlife Service. As well, educational and technical assistance for forest management generally is available in every Southern State, through State forestry and cooperative extension personnel.

In addition, many States offer their own incentive programs for family forest owners. Louisiana, Mississippi, North Carolina, South Carolina, and Virginia offer reforestation cost-share programs, while Texas offers technical assistance and cost-share payments for practices to suppress oak wilt. Owners may exclude a calculated portion of payments from all six programs from adjusted gross income in calculating their Federal income tax. Mississippi and Texas also provide tax incentives for reforestation, Mississippi through a reforestation tax credit and Texas through a 50 percent property tax reduction for reforesting following a harvest. And through its Forest Health Program, Mississippi informs forest owners if they have pest damage on their property and provides technical assistance on how to salvage damaged timber and reduce or prevent further damage (Private Landowner Network Web site 2011, SRS Forest Economics and Policy Web site 2011).

Provision of Ecosystem Services

Ecosystem services are commonly defined as the benefits people obtain from ecosystems. Ecosystem services include basic services—provisioning services like delivery of food, fresh water, wood and fiber, and medicine—as well as services that are equally critical but less tangible and harder to measure: regulating services like carbon sequestration, erosion control, and pollination; cultural services like recreation, ecotourism, and educational and spiritual values; and supporting services like nutrient cycling, soil formation, and primary productivity (USDA Forest Service Valuing Ecosystem Services Web site 2011).

Federal programs—To ensure that the full range of ecological, social, and economic benefits from family-owned lands is maintained in quantity and quality over time, all of the Federal-sponsored incentive programs summarized in table 11.1 have at least one objective that focuses on conservation of natural resources, protection of natural systems, enhanced stewardship, or sustainable management. Consequently, all of the programs, as well as most of the Federal income and estate tax provisions summarized above, promote the provision of ecosystem services.

State programs—It is the States, however, that most directly address provision of ecosystem services. Educational and technical assistance for management of wildlife habitat or riparian areas, water quality, resource conservation, and protection from invasive species generally is available in all States, through their forestry, wildlife, and cooperative extension personnel. Additionally, individual States offer a wide range of programs that directly address ecosystem services (Private Landowner Network Web site 2011, SRS Forest Economics and Policy Web site 2011):

- Alabama sponsors TREASURE Forest, a voluntary program promoting sound and sustainable multiple-use forest management, and the Alabama Agricultural and Conservation Development Commission Program, which provides cost-share payments for soil conservation, water quality improvement, reforestation, and forest improvement practices.
- Arkansas has enacted an income tax credit for creating or restoring wetland or riparian zones.
- Through its Rural and Family Lands Protection Program, Florida purchases perpetual easements on working agricultural or forested lands that contain significant natural areas or water resources.
- Georgia sponsors Georgia GROWS, a recognition program promoting sound management and stewardship of family-owned forest land.
- The Kentucky Soil Erosion and Water Quality Cost Share and Soil Stewardship Programs help farm and forest owners address soil erosion, water quality, and other environmental issues.
- Louisiana provides relief from State, parish, and district property taxes for owners who enter a contract over 25 years in duration that allows the State to use their land as a wildlife management area.
- Mississippi offers a property tax exemption for owners of coastal wetlands.
- The North Carolina Agricultural Cost-Share Program reimburses up to 75 percent of the cost of controlling runoff of sediment, nutrients, animal wastes, and pesticides from working lands.
- The Oklahoma Conservation Cost-Share Program reimburses the cost of applying soil and water conservation practices.
- The Tennessee Farm Wildlife Habitat Program reimburses up to 75 percent of the cost of improving habitat for declining grassland and shrubland wildlife species, including bobwhite quail, cottontail rabbits, and songbirds.
- Texas sponsors the East Texas Wetlands Project, which reimburses up to 50 percent of the cost of restoring, enhancing, or creating wetlands on land subject to a 30-year or perpetual easement; the Lone Star Land Steward Award Program, a recognition program that promotes wildlife conservation and habitat management; the Wildlife Grant Program for habitat improvement projects closely tied to the Texas Wildlife Action Plan; and property tax reductions for aesthetic timber management, protection of critical wildlife habitat, and streamside management.
- Virginia has enacted tax credits for a portion of the value of timber retained in a riparian buffer and the cost of approved equipment used to implement Best Management Practices (BMPs); as well, the Virginia BMP Cost-Share Program reimburses up to $50,000 of the cost of implementing practices to address nonpoint source pollution.

Privately sponsored programs available in the Southern States include State Tree Farm programs coordinated by the American Forest Foundation (American Tree Farm System Web site 2011) and the Longleaf Restoration Program sponsored by The Longleaf Alliance (The Longleaf Alliance Web site 2011).

METHODS AND DATA SOURCES

From the time private forest owners first became interested in long-term management, researchers have been suggesting ways to improve the management and sustainability of family forest holdings: financial incentives for owners who demonstrate interest in managing their forest (Folweiler and Vaux 1944); technical assistance, leveraged through coordinated management of neighboring forest ownerships (Cloud 1966); reduced property, estate and inheritance taxes, more favorable tax credits and deductions, more favorable capital gain tax treatment of timber income, and cost-sharing of forest management expenses (Fecso and others 1982); incentives linked to specific management practices, such as reforestation (Greene 1998); and incentive programs for ecosystem services, such as wildlife habitat or protection of water quality (Greene and Blatner 1986, Koontz 1999).

Family Forest Owner Awareness and Use of Federal Income Tax Provisions

Most of the literature on income taxes concerns Federal taxation of forest-related income and focuses on the tax law itself. It consists of tax guides for forest owners (see Greene and others 2013, Hoover and Koontz 2010), popularized descriptions of how particular income tax provisions affect forest owners (see Haney 2011, Wang and Greene 2011), or background papers prepared for policymakers (see Dialog Group on Forested Lands and Taxation 2001, Granskog and others 2002). A small number of studies have analyzed the effect of current or proposed income tax provisions on returns to hypothetical family forest owners (Bailey and others 1999; Klemperer 1989; Smith and others 2007, 2008; Straka and Greene 2007).

In a 2001 study conducted in South Carolina, researchers with the Clemson University Department of Forest

Resources and the Forest Service Southern Research Station investigated whether family forest owners were aware of Federal income tax provisions that provide incentives for following sound management practices, whether they had used provisions they were aware of, and their reasons for using or not using each one. The provisions examined were: long-term capital gain treatment of qualifying income, annual deduction of management costs, depreciation and the section 179 deduction, loss deductions, special treatment of qualifying cost-share payments, and the reforestation incentives. At the time the study was conducted, the reforestation incentives consisted of a 10 percent investment tax credit on up to $10,000 per year of qualifying expenses to establish or reestablish trees, plus the ability to amortize up to $10,000 per year of qualifying costs over 8 tax years (the amount an owner could amortize was reduced by half of any reforestation tax credit taken).

Data for the study were collected by means of a mailed questionnaire sent to family forest owners randomly selected from a list of current, past, and prospective members maintained by the State chapter of a national forest owner organization, using the Dillman (2000) tailored design method. In addition to knowledge and use of each income tax provision, several demographic characteristics were surveyed: total acres owned; forested acres owned; primary reason for owning forest land; whether the owner belonged to a forest owner organization; whether the owner had a written forest management plan; owner occupation; and owner education, age, and household income, by level. The response categories for primary reason for owning forest land and for owner occupation, education, and age corresponded closely to those used by Birch (1996).

State Property Taxes

As with income taxes, most of the literature on State property taxes consists of landowner guides (see Baughman and Reichenbach 2009, Kays and Schultz 2002) and summaries of State tax provisions (see Chang 1996, Rodenberg and others 2004). State property tax studies by Hickman and others in Tennessee, Virginia, and Texas are distinguished by their inclusion of economic analyses as well as summaries of the law (Gayer and others 1987, Hickman 1982, Hickman and Crowther 1991).

Hibbard and others conducted a study that examined the use, structure, and effectiveness of forest property taxes throughout the U.S. In a survey of State program administrators conducted as part of the study, the researchers found that State property tax programs only marginally conformed to accepted attributes of a "good" tax (equity, efficiency, simplicity, stability, adequacy, and visibility), and only modestly accomplished program objectives (Hibbard and others 2003).

Other researchers have found that property tax program requirements can be at odds with family forest owner objectives for their land. One example, identified in studies in Pennsylvania (Jacobson and McDill 2003) and New York (Kernan 2004), is an overemphasis on timber management and production.

In a national study completed in 2010, researchers from six institutions documented the Federal, State, and local tax policies that affect family forest owners and evaluated their impact on owners' decisions regarding their land. The collaborating institutions were the Forest Service Northern and Southern Research Stations, the University of Massachusetts Amherst Family Forest Research Center, University of Minnesota Department of Forest Resources, Utah State University Department of Environment and Society, and Yale School of Forestry and Environmental Studies. Data for the study were collected using several methods: a review of the existing literature; systematic documentation and verification of the Federal, State, and local tax provisions that affect family forest owners; a survey of State property tax program administrators; and focus groups of family forest owners and natural resource professionals in selected States. The data were quantitatively analyzed, then synthesized with the assistance of a panel of forestry, conservation, and tax professionals and family forest owners.

The literature review initially focused on peer-reviewed publications from the past 10 to 15 years, but was expanded to include earlier, seminal works and non-peer reviewed publications. Federal tax provisions affecting family forest owners were documented using sources from the National Timber Tax Website (2011b). The web site also was the starting point for documenting State tax provisions; gaps were filled in using State government web sites and other sources, then verified using a key informant in each State, an employee of either the State forestry agency or department of revenue.

The survey of State property tax administrators focused on preferential property tax programs, defined as voluntary programs that reduce the property tax burden on owners in return for requiring them to restrict use of their land, have a written forest management plan, or pay a penalty for removing land from the program. The survey was conducted using a mailed questionnaire sent to a selected department of revenue employee in each State. The questionnaire asked the respondents to use a 5-point Likert scale to rate their State's preferential property tax program according to the eight policy effectiveness criteria used by Hibbard and others (2003):

- The program has clearly articulated goals;
- The magnitude of the tax break is significant;
- The program complements other State forestry incentive programs;
- The forest land valuation mechanisms, eligibility

requirements, withdrawal penalties, and minimum enrollment periods reflect program goals;
- The program is administered consistently from county to county;
- Funding for the program has been stable and predictable;
- The program is periodically reviewed to ensure that objectives are being met; and
- Guidance through the application process is available to forest owners.

The respondents also were asked to estimate the average savings for enrollees in the preferential property tax program, the percentage of eligible forest owners enrolled, and the overall effectiveness of the program in protecting forest resources in areas highly susceptible to development. Administrators from 33 of the 38 States that have a preferential property tax program applicable to family forest owners returned a completed questionnaire, for a response rate of 87 percent.

Ten 2-hour focus groups of 8 to 10 family forest owners were held, two each in New Hampshire, Wisconsin, South Carolina, Alabama, and Washington. The States were selected to represent a broad range of property, income, and estate or inheritance tax policies. Participants were selected from local property tax rolls. Owners who held between 10 and 999 acres of forest land were screened to provide a mix of holding sizes, harvesting experience, acquisition history (inherited or non-inherited), estate planning status (formal plan or no formal plan), and demographics (gender, age, and formal education).

Parallel focus groups of 6 to 10 forestry and conservation professionals also were held in New Hampshire, Wisconsin, South Carolina, and Washington (logistical problems precluded a professionals focus group in Alabama). Participants included members of State forestry agencies, university extension systems, and nongovernmental organizations as well as private consulting foresters. These groups covered the same topics as the forest owner focus groups.

Combined Impact of Federal and State Taxes

Family forest owners face combinations of Federal and State taxes on their forest-related income and forest land, yet with few exceptions researchers have studied taxes in isolation from one another. Only two studies were identified in the past 25 years that considered Federal and State taxes in combination. Following passage of the Tax Reform Act of 1986 (P.L. 99-514), Bettinger and others calculated the effect of Federal and State income taxes on hypothetical family forest owners in the South (Bettinger and others 1989) and West (Bettinger and others 1991). Smith and others updated this work following passage of the Economic Growth and Tax Relief Reconciliation Act of 2001 and Jobs and Growth Tax Relief Reconciliation Act of 2003, the first Bush tax cuts, calculating the effect of Federal and State income taxes for family forest owners In the North (Smith and others 2007) and West (Smith and others 2008).

In a study initiated in 2003, researchers with the University of Georgia Warnell School of Forest Resources and the Forest Service Southern Research Station quantified the effect of Federal and State taxes on private forest owners by calculating land expectation value (LEV) for typical forest management regimes in 22 timber-producing States in the South, North, and Northwest. The calculations were made pre-tax and again after each Federal or State tax was applied. Using this approach, it was possible to determine the relative effect of each type of tax as well as the combined effect. Separate calculations were made for family, corporate, and institutional forest owners.

The study was framed by several assumptions: that forest owners of all types are profit-oriented and employ timber management practices appropriate to that objective and “typical” for their region; the owners meet the requirements for current use property tax valuation; they deduct property taxes annually against both the Federal, and as allowed, State income taxes; and they capitalize reforestation expenditures and offset them against harvest returns. The last assumption was based on studies such as Greene and others (2004) and Smith and others (2007, 2008), which found that many forest owners are unaware of Federal income tax provisions developed for owners of forests and other working lands.

Spreadsheets were developed to perform the LEV calculations based on user input for State, management expenses, timber prices, property tax per acre, Federal income tax rate, State income tax rate, harvest tax per unit of timber, and discount rate. Following Klemperer (1988) and Chang (1996), pre-tax LEV was used as the base reference, and reduction in LEV as each tax was added as the measure of the economic effect of that tax. A discount rate of 5 percent, real (with no adjustment for inflation), was used for all LEV calculations. Because it is uniform across the nation, the effect of the Federal income tax was calculated first, followed by the State property tax, harvest tax, and income tax.

For each study State, data were collected on typical timber management practices, including species or species mix, rotation length, and harvest volumes; typical costs for stand establishment and timber management; average stumpage prices for the products obtained; applicable property tax per acre; harvest taxes per unit of timber; and applicable Federal and State income tax rates.

The data were gathered from numerous sources, including published price reports; State tax web sites; and correspondence with consulting foresters, State agency and cooperative extension foresters, and university faculty. For the Coastal Plain States of the South, management practices and harvest volumes were determined using the SiMS 2003 growth and yield model (ForesTech International 2003). Timber product prices were taken from Timber Mart-South (2003), using the regional pine sawtimber and pulpwood market segments defined by Yin and others (2002). The Federal income tax rates and the income, property, and harvest tax rates used for each State were those in effect in 2003.

Effect of the Federal Estate Tax

Most of the literature on the effect of taxes on transfers of assets from one generation to another relates to the Federal estate tax and concerns the tax law itself. It consists of estate planning guides for forest owners (see Becker and Jacobson 2008, Siegel and others 2009) and popularized descriptions of how particular estate tax provisions affect forest owners (see Siegel 2010; Tufts and others 2003a, 2003b). A handful of case studies have used hypothetical family forest owners to analyze aspects of intergenerational transfers of forest land, including the effect of form of forest ownership and assets used to pay the estate tax on net returns from the forest (Howard 1985) and the interaction between Federal and State death taxes (Peters and others 1998; Walden and others 1987, 1988).

With the many strategies available to reduce or eliminate the impact of the estate tax, one might expect that only owners who fail to plan would owe tax. Many owners, however, fail to take advantage of the estate planning tools available to them because they are unaware of the full value of their holdings, overwhelmed by the complexity and ever-changing nature of estate tax law, unable to confront their personal mortality, or unwilling to accept the loss of control that most estate planning strategies entail. Further, the stringent requirements for special use valuation make it difficult for managed forest land to qualify for or remain under that provision (Peters and others 1998, Siegel and others 2009).

In a study initiated in 1999, researchers with the Mississippi State University College of Forest Resources and the Forest Service Southern Research Station investigated the effect of the Federal estate tax on owners of family forests and other working lands. The study represented the first attempt to quantify the effect of the Federal estate tax on family forests.

Data for the study were collected by means of a mailed questionnaire, using the Dillman (1978) total design method. A draft version of the questionnaire was pretested using members of the Mississippi Forest Association. The revised questionnaire was sent to landowners randomly selected from the membership lists of the National Woodland Owners Association and American Tree Farm System and a nationwide database of farm and ranch owners maintained by J.D. Esseks at Northern Illinois University. Questionnaire recipients were first asked whether they had been involved in the transfer of an estate between 1987 and 1997, a period when the unified exemption amount shielded a constant $600,000 of estate value from tax. Those who responded affirmatively were asked a series of questions about the characteristics of the estate, whether special use valuation had been used, and what assets were used to pay any Federal estate tax due.

The number of family forest holdings affected was estimated by multiplying the percent of positive responses by Birch's (1996) estimate of the number of "individual" and "other" private forest ownership units in the United States. The number of acres affected was estimated by multiplying that figure by the mean acreage response for the question. Chi-square tests at the 5 percent level of significance were used to test for differences between the responses from forest owners and other owners of working lands.

Effectiveness of Financial Incentive Programs in Promoting Sustainable Practices

Research has shown that a large percentage of family forest owners are unaware that financial and tax incentive programs exist or what the programs can do for them (Anderson 1960, Christensen and Grafton 1966, Farrell 1964, Greene and others 2004, Perry and Guttenberg 1959); that many owners who participate in an incentive would have done the supported practice anyway (Brockett and Gerhard 1999, James and others 1951), although the incentive generally enables the owners to treat additional acres (Bliss and Martin 1990, Royer 1987); and that favorable property and capital gain tax provisions have little short-term effect on forest owner behavior (Brockett and Gerhard 1999, Kluender and others 1999, Stoddard 1961).

Three approaches, however, have consistently been found to influence family forest owners to apply sustainable practices on their land: technical assistance, cost-share payments, and programs that put owners in direct contact with a forester or other natural resource professional. James and others (1951) found that owners prefer technical assistance to financial or tax incentives. Greene and Blatner (1986) further found that direct contact with a professional is associated with owners becoming forest managers. Egan and others (2001) found that the aspects of the Forest Stewardship Program that involve contact with a professional—getting a management plan and technical assistance—were the things owners liked best about the program.

In a nationwide study conducted in 2005, researchers from five institutions identified and assessed the success of public and private incentive programs in encouraging family forest owners to use sustainable practices on their lands. The collaborating institutions were the Forest Service Southern Research Station, the Clemson University Department of Forestry and Natural Resources, Pennsylvania State University School of Forest Resources, University of Minnesota Department of Forest Resources, and Utah State University Department of Sociology, Social Work, and Anthropology.

The study was conducted in three phases: a systematic review of the research literature on the tax, cost-share, and other financial incentives available to family forest owners; a nationwide survey of selected forestry officials; and focus groups with family forest owners in the South, North, and West.

Publications for the literature review were identified through a search of databases including the University of Minnesota Social Sciences in Forestry web site and CABI Publishing's Forestry Abstracts. The identified publications were summarized and analyzed for their conclusions about the effectiveness of the various incentive programs and their apparent effect on forest owner motivations and practices.

The survey of forestry officials was done by means of a mailed questionnaire, using the Dillman (2000) tailored design method. One official in each State was selected to receive the questionnaire, based on their overall knowledge of financial incentive programs. The appropriate person in each State was identified using peer recommendations; in most cases it was the individual in the State forestry agency who managed the Forest Stewardship Program. The draft questionnaire was pre-tested with the identified official in each of the researchers' home state and refined using their feedback.

The questionnaire asked the officials to name and describe the public and private financial incentive programs available to family forest owners in their State. In follow-up questions they were asked to use a 4-point Likert scale to assess forest owners' awareness of each program they had identified, its overall appeal among the owners aware of it, and its effectiveness in encouraging sustainable forestry and enabling owners to meet their objectives of forest ownership. The officials also were asked to estimate the percent of program practices that remained in place and enrolled acres that remained in forest over time, and to suggest ways to improve owner participation in the program and its administrative effectiveness.

Nine Federal financial incentive programs were examined: the Forest Stewardship Program, Conservation Reserve Program, Environmental Quality Incentives Program, Forest Land Enhancement Program, Forest Legacy Program, Landowner Incentive Program, Southern Pine Beetle Prevention Program, Wetlands Reserve Program, and Wildlife Habitat Incentives Program (table 11.1). Three types of non-Federal financial incentive programs also were examined: preferential property tax programs for forest land, other State-sponsored incentive programs, and programs sponsored by private entities.

Although the questionnaire was extensive—89 questions on 30 pages—follow-up e-mails and telephone calls produced a 100 percent useable response. The Likert scale ratings and the officials' written comments were compiled and summarized. Tukey tests at the 5 percent level of significance were used to identify statistically significant differences between the officials' ratings for each program attribute.

The final study phase consisted of focus groups with family forest owners in South Carolina, Pennsylvania, Minnesota, and Oregon. Two focus groups were conducted in each State, one with members of forest owner organizations and one with other family forest owners. The participants in each group were identified through an approach similar to that used for the survey of forestry officials. The number of participants in the focus groups ranged from 7 to 17 and averaged 11.

The focus group sessions were conducted using the protocol described by Daniels and Walker (2001), with a moderator guiding discussion by means of a chart mounted on the meeting room wall and verbal prompts from a prepared guideline. Data were collected by recording the sessions and by taking notes. The recordings and notes for each session were qualitatively analyzed, again following Daniels and Walker (2001), first by a single researcher, then in discussion among the entire research team. The results for each region were coded in terms of themes without consideration for what might be themes in other regions. Once the region-specific themes were identified, they were compared across regions to identify emergent patterns. The data were then re-analyzed to look specifically for the presence or absence of the emergent patterns in each region.

RESULTS

Family Forest Owner Awareness and Use of Federal Income Tax Provisions

In the study of South Carolina family forest owners, 87 percent of the survey respondents were aware of at least one Federal income tax provision. Nearly 80 percent were aware of two provisions available to taxpayers in general: treatment of qualifying income as a long-term capital gain and annual deduction of management costs. In contrast, just over 40 percent were aware of special treatment of qualifying cost-share payments, one of the provisions available to owners of working lands (Greene and others 2004).

Long-term capital gain treatment of qualifying income—Some 78 percent of the respondents were aware that income from the sale or disposal of timber can qualify as a long-term capital gain. Of those who were aware of the provision, 85 percent had used it (table 11.5). Respondents who were aware of the provision tended to own more acres of land and more forested acres than those who were not; they also were more likely to belong to a forest owner organization and to have a written forest management plan, and tended to have higher levels of formal education and household income. As shown in Table 11.6, most respondents who were aware of the provision but had not used it believed it did not apply to their situation (36 percent) or that the benefit was too small to bother with (21 percent).

Annual deduction of management expenses—Overall, 78 percent of the respondents were aware they could deduct ordinary and necessary forest management expenses annually, and of those who were aware of the provision, 85 percent had used it (table 11.5). Respondents who were aware of the provision differed from those who were not in the same ways as above: they tended to own more acres of land and more forested acres, were more likely to belong to a forest owner organization and to have a written forest management plan, and tended to have higher levels of formal education and household income. Most respondents who were aware of the provision but had not used it believed it did not apply to their situation (35 percent) or that the benefit was too small to bother with (33 percent; table 11.6).

Depreciation and the section 179 deduction—About half of the respondents (51 percent) were aware they could recover the cost of equipment and other property purchased for the production of income on their forests through depreciation or the section 179 deduction. Of those who were aware of the provisions, 66 percent had used one or both (table 11.5). Respondents who were aware of the provisions differed from those who were not in that they tended to own more acres of land and more forested acres, were more likely to own their forest land primarily for timber production, were more likely to belong to a forest owner organization and to have a written forest management plan, were more likely to be salaried professionals, and tended to have higher levels of formal education and household income. Most respondents who were aware of the provisions but had not used them believed the provisions did not apply to their situation (57 percent) or that the benefit was too small to bother with (21 percent; table 11.3).

Loss deductions—Only 60 percent of the respondents were aware they could take a deduction for timber or other income-producing assets lost in a casualty, theft, condemnation, or for owners who held their forest as a trade or business, in a noncasualty event. Further, only 23 percent of those who were aware of the provision had used it (table 11.5). Respondents who were aware of the provision differed from those who were not on nearly all of the demographic characteristics tested: they tended to own more acres of land and more forested acres, were more likely to own their

Table 11.5—Number and percent of forest owner reporting awareness and use of beneficial Federal income tax provisions

Response to survey	Long-term capital gains treatment		Management expense deduction		Depreciation, Section 179[a] deduction		Loss deductions		Reforestation incentives: Tax credit		Reforestation incentives: Amortization		Cost-share payment exclusion	
Aware of the provision	364	77.8%	363	77.6%	235	51.4%	277	60.2%	255	54.8%	260	56.4%	194	42.1%
Had used the provision	308	84.6%	308	84.8%	155	66.0%	64	23.1%	199	78.0%	207	79.6%	137	70.6%
Had not used the provision	56	15.4%	53	14.6%	80	34.0%	213	76.9%	56	22.0%	53	20.4%	57	29.4%
Not aware of the provision	104	22.2%	105	22.4%	222	48.6%	183	39.8%	210	45.2%	201	43.6%	267	57.9%

[a] Allows a taxpayer to deduct the cost of certain types of property as an expense, rather than requiring the cost to be capitalized and depreciated.
Source: Greene and others 2004.

Table 11.6—Reasons forest owners who were aware of beneficial Federal income tax provisions cited for not using the provisions

Response to survey	Long-term capital gains treatment		Management expense deduction		Depreciation, Section 179[a] deduction		Loss deductions		Reforestation incentives				Cost-share payment exclusion	
									Tax credit		Amortization			
It's too complicated	2	3.8%	3	5.5%	3	3.9%	11	5.8%	1	2.0%	0	0.0%	5	10.2%
Benefit is too small to bother with	11	20.8%	18	32.7%	16	21.1%	31	16.2%	16	31.4%	10	23.3%	14	28.6%
It doesn't apply to my situation	19	35.8%	19	34.5%	43	56.6%	93	48.7%	20	39.2%	22	51.2%	11	22.4%
I don't want to use it	1	1.9%	1	1.8%	2	2.6%	5	2.6%	2	3.9%	0	0.0%	7	14.3%
Other	20	37.7%	14	25.5%	12	15.8%	51	26.7%	12	2.35%	11	25.6%	12	24.5%

[a] Allows a taxpayer to deduct the cost of certain types of property as an expense, rather than requiring the cost to be capitalized and depreciated.
Source: Greene and others 2004.

forestland primarily for recreation or timber production, were more likely to belong to a forest owner organization and to have a written forest management plan, were more likely to be salaried professionals, and tended to have higher levels of formal education and household income. Most respondents who were aware of the provision but had not used it believed it did not apply to their situation (49 percent) or that the benefit was too small to bother with (16 percent; table 11.6).

Reforestation incentives—Just over half of the respondents (55 percent) were aware of the reforestation tax incentives, but among those who were aware, 80 percent had used one or both incentives (table 11.5). Respondents who were aware of the reforestation tax credit tended to own more acres of land and more forested acres, were more likely to belong to a forest owner organization and to have a written forest management plan, and tended to have a higher level of household income. Respondents who were aware of the reforestation amortization deduction tended to own more acres of land and more forested acres, were more likely to own their forest land primarily for recreation or timber production, were more likely to belong to a forest owner organization and to have a written forest management plan, were more likely to be a salaried professional or a farmer, and tended to have higher levels of formal education and household income. Most respondents who were aware of the provisions but had not used them believed they did not apply to their situation (51 percent) or that the benefit was too small to bother with (31 percent; table 11.6).

Special treatment of qualifying cost-share payments—Only 42 percent of the respondents were aware they could exclude a calculated portion of qualifying public cost-share payments from their gross income (table 11.5), making it the least-known provision surveyed. Of those who were aware of the provision, 71 percent had used it. Respondents who were aware of the provision were more likely than those who were not to belong to a forest owner organization and to have a written forest management plan, and tended to have a higher level of household income. Most respondents who were aware of the provision but had not used it believed the benefit was too small to bother with (29 percent) or that it did not apply to their situation (22 percent; table 11.6).

State Property Taxes

Survey of State property tax administrators—Estimates of family forest owner participation in State preferential property tax programs varied widely. Just 48 percent of the administrators who responded to the survey estimated that half or more of eligible family forest owners were enrolled in their State's program. Administrators who indicated the greatest percent of eligible forest land enrolled generally were from States in the West or South.

Of the administrators who provided a response, 83 percent estimated that participating in their State's program reduced the annual property tax burden by half or more. On the one hand, some administrators expressed regret that forest owners could not qualify for their State's agricultural preferential property tax program, which typically provides greater tax relief, while others expressed frustration at "tax dodgers" and "loopholes" that allowed their State's program to be misused.

Only a third of the administrators responded that their State's program had all of the attributes of an effective property tax policy. The most commonly noted shortcomings were lack of consistency from county to county and lack of stable funding, followed by lack of complementarity with other programs (Butler and others 2010).

Family forest owner focus groups—Property taxes were by far the tax of greatest concern to the family forest owners in this study, coming up unprompted as a concern in all 10 focus groups. This is not a surprise, since property taxes occur on an annual basis as opposed to being a rare event, as with taxes on timber income, or once-in-a-lifetime, as with an estate or inheritance tax. Particularly outside the South, owners perceived their property taxes as high, out of sync with what their land was worth, and inevitably increasing.

Some forest owners had never heard about their State's preferential property tax program, while others were uncertain about whether they were enrolled in a program. The latter was particularly the case in the South, where program requirements are the least restrictive; owners in States with more rigorous programs were more likely to know what program they were enrolled in and its requirements. The primary means for finding out about tax programs was conversations with neighbors, friends, and relatives, followed by county assessors, foresters or loggers working on the land, and community meetings.

At the same time, many owners who were enrolled their State's program were highly positive about it and recommended it to those who were not enrolled. They cited benefits including that the reduced property taxes were helping them keep their land, and the program promoted open space and sustainability, encouraged tree planting and growth, and improved forest management. Some owners became interested at this point, while others remained wary.

Reasons for wariness about participating in a preferential property tax program included uncertainty about penalties for withdrawing land and what happened if the land was sold or passed to heirs. Privacy and freedom of action were major objectives for many owners, with the result that some opted not to enroll in their State's program due to fear of losing managerial control to the government or being required to allow public access on their land (Butler and others 2010).

Combined Impact of Federal and State Taxes

The full study reported here estimated the effect of Federal and State taxes on privately-owned forest land in 22 States in the South, North, and Northwest, by calculating pre- and after-tax land expectation value (LEV) under typical management regimes for family, corporate, and institutional forest owners (Cushing 2006). This section, however, summarizes only the results for family forest owners in the Southern States.

Pre-tax LEV—Among the Coastal Plain States, pre-tax LEV ranged from $373 per acre for Texas to $796 per acre for Alabama, with a mean of $585 per acre and a median of $539 per acre (table 11.7). Oklahoma was not included in the analysis. The spreadsheets for all 10 included States were built around the same loblolly pine management plan and assumed the same costs for stand establishment and timber management. The only source for differences in pre-tax LEV was variation in the stumpage prices for the pulpwood, chip-n-saw, and sawtimber produced.

In the States of the Appalachian-Cumberland highlands, pre-tax LEV was just $271 per acre for Kentucky, due primarily to long rotation lengths and low harvest yields for mixed upland hardwood timber. Pre-tax LEV for Tennessee was comparable to that for the Coastal Plain States, at $579 per acre for uneven-age management of mixed oak-hickory timber (table 11.7). There was no statistically significant difference in the results for the two subregions (Cushing 2006).

Effect of the Federal income tax—Although family forest owners in every State paid the same 15 percent Federal capital gain tax on their net harvest returns, the economic effect of the tax varied with the size and frequency of harvest returns and the amount of capitalized reforestation expenses. In the Coastal Plain States, LEV decreased by amounts ranging from $91 per acre for Texas to $153 per acre for Alabama, in roughly the same order as pre-tax LEV (table 11.6). The absolute and relative changes were inversely related to one another, however, with the $91 per acre change for Texas equating to a 24 percent reduction in LEV and the $153 per acre change for Alabama equating to a 19 percent reduction.

In the Appalachian-Cumberland highlands, the Federal income tax had a similar but smaller effect, decreasing LEV by $48 per acre (18 percent) in Kentucky and $87 per acre (15 percent) in Tennessee (table 11.6). The difference in the results for the two subregions was statistically significant (Cushing 2006).

Table 11.7—Comparison of pre- and after-tax land expectation values (LEV) in the South using a 5-percent discount rate, by State

State	Pre-tax LEV (Dollars)	Federal income tax			Property tax			Harvest tax			State income tax		
		New LEV	Decrease		New LEV	Decrease		New LEV	Decrease		New LEV	Decrease	
			Dollars	Percent		Dollars	Percent		Dollars	Percent		Dollars	Percent
Coastal Plain													
Alabama	796	643	153	19.2	616	27	3.4	616	0	0.0	567	49	6.2
Arkansas	497	388	109	21.9	370	18	3.6	370	0	0.0	324	46	9.3
Florida	608	484	124	20.4	419	65	10.7	419	0	0.0	419	0	0.0
Georgia	682	546	136	19.9	475	71	10.4	448	27	4.0	400	48	7.0
Louisiana	523	412	111	21.2	371	41	7.8	336	35	6.7	291	45	8.6
Mississippi	787	636	151	19.2	579	57	7.2	573	6	0.8	527	46	5.8
North Carolina	538	423	115	21.4	371	52	9.7	371	0	0.0	314	57	10.6
South Carolina	540	426	114	21.1	379	47	8.7	379	0	0.0	330	49	9.1
Texas	373	282	91	24.4	231	51	13.7	231	0	0.0	231	0	0.0
Virginia	503	396	107	21.3	366	30	6.0	366	0	0.0	325	41	8.2
Appalachian-Cumberland highlands													
Kentucky	271	223	48	17.7	206	17	6.3	206	0	0.0	189	17	6.3
Tennessee	579	492	87	15.0	468	24	4.1	468	0	0.0	468	0	0.0

Source: Cushing 2006.

Effect of property tax—Property tax rates on family-owned forest land varied widely across the Coastal Plain States, from just over $1 per acre per year in Arkansas to nearly $5 per acre per year in Georgia. As a result, the amount by which property tax decreased LEV also varied widely, from $18 per acre (4 percent) for Arkansas to $71 per acre (10 percent) for Georgia and $51 per acre (14 percent) for Texas. The results for the States of the Appalachian-Cumberland highlands were at the low end of the same range (table 11.6). There was no statistically significant difference in the results for the two subregions (Cushing 2006).

Effect of harvest tax—Only harvest taxes levied on forest owners were included in the study; taxes levied on timber processors were excluded. Of the three Southern States that levy a harvest tax on forest owners, Louisiana and Georgia expressed the tax as a percentage of timber stumpage price, while Mississippi expressed it as a flat rate per unit harvested. In all three States the tax rate was quite low, resulting in a decrease in LEV ranging from $6 per acre (1 percent) for Mississippi to $35 per acre (7 percent) for Louisiana (table 11.6).

Effect of State income tax—As discussed above, Florida and Texas do not tax income to individuals and Tennessee taxes only dividend and interest income. In most of the Southern States that tax income to individuals the top marginal tax rate for 2003 fell between 5 and 6 percent; the exceptions were North and South Carolina, with top marginal tax rates of 8.25 percent and 7 percent, respectively. In the Coastal Plain States, State income tax decreased LEV by amounts ranging from $41 per acre (8 percent) for Virginia to $57 per acre (11 percent) for North Carolina. In the Appalachian-Cumberland highlands, State income tax decreased LEV by $17 per acre (6 percent) in Kentucky (table 11.6). There was no statistically significant difference in the results for the two subregions (Cushing 2006).

Effect of the Federal Estate Tax

The research results summarized in this section are from a national survey (Greene and others 2006). The sample size precludes segmenting the findings into regional estimates; however, it is known that the Southern States account for about two-fifths (41 percent) of family forest holdings and half (51 percent) of family-owned forest land in the United States (Butler and Leatherberry 2004).

Family forest land transferred—During the survey period, 9 percent of the forest owner respondents had been involved in the transfer of an estate. Among these respondents, 84 percent were family members of the decedent; the remaining 16 percent were friends, business associates, or professionals who had served the decedent. Roughly half of the estates (49 percent) had been held in individual ownership by the decedent, with another 27 percent held jointly with other individuals, and the remaining 24 percent held by partnerships, corporations, or such other forms of business as Family Limited Partnerships or Limited Liability Companies. Some 64 percent of the decedent owners had used a financial or legal professional to help them plan their estate (table 11.8).

The value of the decedents' gross taxable estates ranged from below the $600,000 unified credit amount to over $3 million. The total area of the forest estates ranged from 10 to 20,000 acres, with a mean of 1,225 acres and a median of 200 acres; the forest area ranged from 8 to 20,000 acres, with a mean of 1,024 acres and a median of 156 acres (table 11.8). Expanded to family-owned forest lands throughout the United States, these findings mean an estimated 77,200 forest estates, with 79.1 million acres of forest land, were transferred each year at the death of their owners (Greene and others 2006).

Special use valuation—With forest land, special use valuation (see above) can be applied to the land only or to both the land and timber. Just 33 percent of forest estates qualified for and 26 percent elected to use special use valuation. Of the estates that used special use valuation, 26 percent applied it to the land only and 74 percent applied it to both the land and timber.

Applying special use valuation reduced the taxable value of forest estates by amounts ranging from $0 to $750,000, with a mean of $325,000 and a median of $250,000, both well under the $750,000 maximum for the provision during the study period. Expanded nationally, these findings mean an estimated 20,000 forest estates elected to use special use valuation each year, resulting in a combined total reduction in their taxable estate values on the order of $6.5 billion (Greene and others 2006).

Assets used to pay the Federal estate tax—A substantial majority of survey respondents (62 percent) reported that no Federal estate tax was due in the transfers they were involved with. In most instances where estate tax was due, insurance or other assets were used to pay it. But in 42 percent of the transfers, timber or land was sold to pay part or all of the tax.

In 22 percent of all transfers, timber was sold to pay estate tax, with 75 percent of the sales necessary because other assets were not sufficient to pay the tax. The forest size of ownerships that needed to sell timber ranged from 79 to 10,000 acres, with a mean of 3,035 acres and a median of 670 acres. The area harvested ranged from 5 to 1,100 acres, with a mean of 498 acres and a median of 430 acres. Expanded nationally, these findings mean an estimated

Table 11.8—Characteristics of the estates of forest owners and other owners of working lands

Survey question	Response	Forest owners Number	Forest owners Percent	Other rural owners Number	Other rural owners Percent
Involved in an estate transfer?[a]	No	1,110	91.3	578	86.1
	Yes	106	8.7	93	13.9
Relationship of respondent to the decedent	Family member	85	84.2	84	94.4
	Friend or business associate	9	8.9	4	4.5
	Professional advisor/trustee	7	6.9	1	1.1
Form of ownership in which land was held	Individual	51	48.6	54	58.1
	Joint	28	26.7	26	28.0
	Partnership	11	10.5	1	1.1
	Corporation	8	7.6	4	4.3
	Other[b]	7	6.7	8	8.6
Value of gross taxable estate, Southern region[c]	Less than $600,000	21	60.0	17	73.9
	$600,000 to $999,999	4	11.4	4	17.4
	$1,000,000 to $1,999,999	5	14.3	0	0.0
	$2,000,000 to $2,999,999	1	2.9	0	0.0
	$3,000,000 or more	4	11.4	2	8.7
Value of gross taxable estate, Northern and Western regions[c]	Less than $600,000	26	40.6	40	67.8
	$600,000 to $999,999	16	25.0	8	13.6
	$1,000,000 to $1,999,999	9	14.1	7	11.7
	$2,000,000 to $2,999,999	6	9.4	1	1.7
	$3,000,000 or more	7	10.9	3	5.1
Total area transferred	1 to 99 acres	24	23.3	23	28.4
	100 to 499 acres	48	46.6	35	43.2
	500 acres or more	31	30.1	23	28.4
Forested area transferred[a]	0 acres	0	0.0	58	71.6
	1 to 99 acres	38	36.9	16	19.8
	100 to 499 acres	38	36.9	7	8.6
	500 acres or more	27	26.2	0	0.0
Area converted to cropland[a]	0 acres	69	67.0	22	27.2
	1 to 99 acres	25	24.3	26	32.1
	100 to 499 acres	7	6.8	23	28.4
	500 acres or more	2	1.9	10	12.3
Area converted to grazing[a]	0 acres	62	60.2	32	39.5
	1 to 99 acres	27	26.2	21	25.9
	100 to 499 acres	10	9.7	13	16.0
	500 acres or more	4	3.9	15	18.5
Estate planning helped by a professional?	Yes	67	64.4	64	71.1
	No	34	32.7	26	28.9
	Don’t know	3	2.9	0	0.0
Did professional help reduce taxes due?[a]	Yes	41	61.2	48	75.0
	No	21	31.3	8	12.5
	Don’t know	5	7.5	8	12.5

[a]The samples differ statistically at the $\alpha = 0.05$ level of significance.
[b]Test results are based on a small sample.
[c]Such as a Family Limited Partnership or a Limited Liability Company.

4,900 forest estates needed to sell a total of 2.4 million acres of timber each year to pay part or all of the Federal estate tax.

In 19 percent of all transfers, land was sold to pay estate tax, with 57 percent of the sales necessary because other assets were not sufficient to pay the tax. The forest size of ownerships that needed to sell land ranged from 100 to 2,000 acres, with a mean of 770 acres and a median of 490 acres. The amount of land sold ranged from 160 to 780 acres, with a mean of 387 acres and a median of 220 acres. Further, in 29 percent of the cases where land was sold to pay estate tax, the land was developed or converted to another use. Expanded nationally, these findings mean an estimated 3,300 forest estates needed to sell a total of 1.3 million acres of land each year to pay the Federal estate tax, of which on the order of 400,000 acres were developed or converted to other uses (Greene and others 2006).

Comparison with owners of other working lands—The questionnaire responses from owners of other working lands, largely farmers and ranchers, were more remarkable for their similarities to forest owners than their differences. The groups differed statistically in just 6 of the 20 characteristics surveyed, with most differences stemming from the different uses the two groups make of their land: whether it is mostly forest or mostly crop or grazing land, and whether special use valuation was applied to both land and timber or to the land only. Also, a lower percentage of forest owners had been involved in the transfer of an estate during the survey period, and forest owners were less likely than other landowners to believe the decedent's use of an estate planning professional had reduced the amount of estate tax due (Greene and others 2006).

Effectiveness of Financial Incentive Programs in Promoting Sustainable Practices

This section also reports findings from a national study. But the results for the survey of forestry officials, summarized from Jacobson and others (2009), are for the Southern States. And while the results for the forest owner focus groups, summarized from Daniels and others (2010) are for the entire United States, points where the South differs from other regions are noted.

Survey of State forestry officials—Table 11.9 summarizes the results for Federal financial incentive programs as ranked by the State forestry officials. None of the officials responded about the Landowner Incentive Program, which for that reason was excluded from the analysis. Section a of the table shows the officials' mean rankings for forest owner awareness of each program and its overall appeal among owners aware of it. All of the programs were ranked in the middle ranges for both awareness and appeal, with appeal generally rated higher than awareness. There were no statistically significant differences between the ratings for any of the programs (Table 11.9).

Section b of Table 11.9 summarizes the officials' mean rankings for the programs in terms of their effectiveness in encouraging sustainable forestry among participating owners. The Forest Legacy Program (FLP) was ranked highest overall, scoring well in all attributes of sustainability. Ranked next-highest were the Conservation Reserve Program (CRP), Forest Stewardship Program (FSP), and Forest Land Enhancement Program (FLEP). CRP scored particularly well for protecting soil productivity and water quality and preventing conversion of forest land. FSP scored well for protecting water quality, encouraging forest management, and protecting wildlife and fish, while FLEP scored quite well for encouraging forest management.

The Wetlands Reserve Program (WRP) was ranked next-highest overall, receiving its best scores for protecting water quality. The lowest rankings went to the Wildlife Habitat Incentives Program (WHIP), Environmental Quality Incentives Program (EQIP), and Southern Pine Beetle Prevention Program (SPBP), although WHIP scored quite well for protecting wildlife and fish, EQIP for protecting water quality and soil productivity, and SPBP for encouraging forest management (Table 11.9).

Section c of Table 11.9 summarizes the officials' mean rankings for the programs in terms of their effectiveness in helping owners meet their objectives of forest ownership. The officials generally scored the programs less effective in this area than in encouraging sustainable forestry. FLP again was ranked highest, scoring particularly well for helping owners meet objectives related to soil and water conservation, wildlife, and aesthetics. FSP and FLEP were ranked next-highest; FSP received high marks for objectives related to wildlife and timber production, while FLEP scored well for objectives related to timber production and soil and water conservation.

CRP and WHIP were ranked next-highest. CRP scored well for owner objectives related to soil and water conservation and wildlife, while WHIP received the highest possible score for objectives related to wildlife. None of the remaining programs rated above the moderately ineffective range, although EQIP received solid scores for objectives related to soil and water conservation, WRP for objectives related to wildlife, and SPBP for objectives related to timber production and soil and water conservation (Table 11.9).

The final section of Table 11.9 summarizes the officials' mean rankings for program practices remaining in place and enrolled acres remaining in forest over time. All eight Federal programs scored in the moderately to very

Table 11.9—State forestry officials' evaluations of Federal forestry incentive programs

Attribute	Likert rating of incentive program[a]							
	FSP	CRP	EQIP	FLEP	FLP	SPBP	WRP	WHIP
	Owner awareness and appeal							
Awareness	2.69^{A}	2.62^{A}	2.40^{A}	2.58^{A}	1.89^{A}	2.00^{A}	1.75^{A}	2.14^{A}
Appeal	3.31^{AB}	3.38^{AB}	2.50^{AB}	3.50^{A}	3.00^{AB}	2.75^{AB}	2.13^{B}	2.86^{AB}
	Effectiveness in encouraging sustainable forestry							
Prevents conversion	3.00^{ABC}	3.70^{A}	2.11^{C}	3.36^{AB}	3.89^{A}	2.83^{ABC}	3.00^{AB}	2.50^{BC}
Prevents parcelization	2.85^{ABC}	3.27^{ABC}	2.11^{C}	3.18^{ABC}	3.89^{A}	2.67^{BC}	3.38^{AB}	2.50^{BC}
Maintains forest type	3.00^{AB}	3.40^{AB}	2.40^{B}	3.27^{AB}	3.63^{A}	2.60^{AB}	3.25^{AB}	2.71^{AB}
Protects wildlife/fish	3.77^{A}	3.31^{A}	3.30^{A}	3.36^{A}	3.67^{A}	2.17^{B}	3.38^{A}	3.86^{A}
Protects water quality	3.92^{A}	3.77^{A}	3.70^{A}	3.36^{AB}	3.78^{A}	2.57^{B}	3.50^{A}	3.29^{AB}
Protects soil productivity	3.54^{AB}	3.92^{A}	3.50^{AB}	3.45^{AB}	3.78^{A}	2.43^{C}	3.25^{ABC}	2.86^{BC}
Encourages forest management	3.85^{A}	3.46^{ABC}	2.50^{CD}	3.91^{A}	3.56^{AB}	3.57^{AB}	2.25^{D}	2.71^{BCD}
Overall average	3.42^{AB}	3.44^{AB}	2.82^{CD}	3.42^{AB}	3.74^{A}	2.70^{D}	3.14^{BC}	2.92^{CD}
	Effectiveness in helping owners meet their objectives							
Timber production	3.54^{A}	3.00^{AB}	2.30^{BC}	3.82^{A}	3.13^{AB}	3.57^{A}	2.38^{AB}	1.86^{C}
Recreation	3.23^{A}	2.67^{A}	2.30^{A}	3.00^{A}	3.25^{A}	2.17^{A}	2.75^{A}	3.29^{A}
Wildlife	3.69^{A}	3.31^{A}	3.20^{AB}	3.55^{A}	3.50^{A}	2.43^{B}	3.38^{A}	4.00^{A}
Aesthetics	3.38^{AB}	2.69^{AB}	2.70^{AB}	2.91^{AB}	3.50^{A}	2.43^{B}	3.00^{AB}	3.14^{AB}
Soil/water conservation	3.38^{AB}	3.92^{A}	3.50^{AB}	3.64^{A}	3.75^{A}	2.86^{B}	3.25^{AB}	2.86^{B}
Invasive species control	2.62^{A}	2.50^{A}	3.10^{A}	2.91^{A}	3.00^{A}	2.67^{A}	2.00^{A}	2.71^{A}
Overall average	3.31^{AB}	3.11A^{BC}	2.85^{BC}	3.30^{AB}	3.36^{A}	2.70^{C}	2.80^{C}	2.98^{ABC}
	Over time							
Practices remain in place	3.38^{A}	3.69^{A}	3.50^{A}	3.50^{A}	3.89^{A}	3.71^{A}	3.63^{A}	3.17^{A}
Acres remain in forest	3.54^{A}	3.46^{A}	3.00^{A}	3.50^{A}	3.89^{A}	3.71^{A}	3.63^{A}	3.00^{A}

[a]Tukey's grouping across incentive programs for each respective program attribute. $\alpha = 0.05$. Means with the same superscript letter (A, B, or C) are not significantly different.
Forest Stewardship Program (FSP); Conservation Reserve Program (CRP); Environmental Quality Incentives Program (EQIP); Forest Land Enhancement Program (FLEP); Forest Legacy Program (FLP); Southern Pine Beetle Prevention Program (SPBP); Wetlands Reserve Program (WRP); Wildlife Habitat Incentives Program (WHIP).Likert Scale awareness ratings: 1 = very low, 2 = moderately low, 3 = moderately high, 4 = very high; Likert ratings for effectiveness: 1 = very ineffective, 2 = moderately ineffective, 3 = moderately effective, 4 = very effective.

effective range for these characteristics, with no statistically significant differences between the scores (Table 11.9).

The State forestry officials also ranked the success of State and private financial incentive programs. The questionnaire sections relating to private incentive programs were streamlined, however, to request only ratings for their effectiveness in encouraging sustainable forestry and helping owners meet their objectives of forest ownership; no data were collected for owner awareness and appeal, or for practices remaining in place and acres remaining in forest over time. For owner awareness, State property tax and incentive programs generally were rated higher than Federal programs; for owner appeal, they were rated about the same (table 11.10).

In terms of effectiveness in encouraging sustainable forestry, State incentive programs were ranked higher overall than property taxes, although both types of programs received high scores for preventing conversion of forest land. Among the private programs, incentives offered by nongovernmental organizations were ranked higher overall than those offered by industry firms and State forestry associations, scoring highest among all State and private programs for maintaining forest type and protecting wildlife and fish. Programs offered by firms and associations scored highest for encouraging forest management (table 11.10).

There were no statistically significant differences among the programs in the officials' mean rankings for effectiveness in helping family forest owners meet their objectives of ownership. State incentive programs again scored higher overall than property taxes, however, and programs offered by nongovernmental organizations again scored higher overall than those offered by industry firms and State forestry associations. Both types of State programs received their highest scores for helping owners meet objectives related to timber production and soil and water conservation. Programs offered by firms and associations scored best for objectives related to timber production, while programs offered by nongovernmental organizations received their highest marks for objectives related to soil and water conservation (table 11.10).

Property tax programs were ranked moderately to very effective for both practices remaining in place and enrolled acres remaining in forest over time. Other State incentives were ranked moderately effective for practices remaining in place, but moderately ineffective for acres remaining in forest. The differences, however, were not statistically significant (table 11.10; Jacobson and others 2009).

Focus group sessions with family forest owners—The focus group sessions were designed to foster discussion about family forest owners' experience with financial incentive programs, what objectives of forest ownership the programs helped them to meet, and what additional program approaches would help them meet other objectives. The actual responses were much wider in scope, however, comprising four broadly shared themes (Daniels and others 2010):

- Forest ownership is more strongly linked to self-identity and lifestyle than to profit. Despite marked differences in time of ownership, there was a broadly shared commitment to long-term stewardship and appropriate management. Land ownership seemed much more tied to self-identity and lifestyle than to financial return, and in many groups there were clear statements that financial return was not a major driver for management behavior. Of the eight focus groups, the one made up of forest owner organization members in the South was the most focused on timber management to generate financial return, but even in this group there was a strong intergenerational component in their motivations for land ownership.
- A strong ethic of conservation. A readily verbalized commitment to a strong conservation ethic appeared to be interwoven with the self-identity theme for forest ownership and management. Rather than saying they intended to sell off land or liquidate standing timber, participants emphasized a desire to pass the land to future generations, or to buy more land if they had the money.
- Landowners have heard about sustainable forestry, but generally are not clear as to its meaning. Many focus group participants said they knew about sustainable forestry, but when asked to articulate what the term meant to them, the responses became more hesitant or vague. In many cases, the participants offered statements resonant of sustained yield concepts—such as harvesting at a rate no greater than growth—or referred to the program of a particular group—for example, stating, "That is what Tree Farm is promoting."
- Landowners have a high interest in face-to-face technical assistance. Participants in every focus group said they would do a management practice they thought was important even if there was no incentive program, but needed someone to walk their land with them and guide them through the decision about what they should do. The need for on-the-ground help in understanding what was happening on their land was strongly expressed in every region.

Table 11.10—State forestry officials' evaluations of State tax and incentive programs, industry and State association programs, and nongovernmental organization (NGO) programs

Attribute	Likert rating provision or program[a]			
	Property tax provisions	State incentive programs	Industry programs	NGO programs
	Owner awareness and appeal			
Awareness	3.00[A]	2.70[A]	N/A	N/A
Appeal/effectiveness	3.25[A]	3.14[A]	N/A	N/A
	Effectiveness in encouraging sustainable management			
Prevents conversion	3.08[A]	3.71[A]	3.00[A]	2.66[A]
Prevents parcelization	2.91[A]	3.28[A]	2.87[A]	3.00[A]
Maintains forest type	3.00[A]	3.28[A]	3.14[A]	3.33[A]
Protects wildlife/fish	2.81[A]	3.14[A]	2.50[A]	3.33[A]
Protects water quality	3.00[A]	3.42[A]	3.12[A]	3.33[A]
Protects soil productivity	2.83[A]	3.43[A]	2.87[A]	3.33[A]
Encourages forest management	2.91[A]	3.71[A]	3.25[A]	3.00[A]
Overall average	2.94[B]	3.43[A]	2.96[B]	3.14[AB]
	Effectiveness in helping owners meet their objectives			
Timber production	3.08[A]	3.85[A]	3.86[A]	3.00[A]
Recreation	2.72[A]	3.00[A]	2.37[A]	3.33[A]
Wildlife	2.75[A]	3.28[A]	2.62[A]	3.33[A]
Aesthetics	2.82[A]	2.85[A]	2.50[A]	3.33[A]
Soil/water conservation	3.00[A]	3.57[A]	3.25[A]	3.66[A]
Invasive species control	2.30[A]	3.14[A]	2.43[A]	2.67[A]
Overall average	2.79[A]	3.28[A]	2.85[A]	3.22[A]
	Effectiveness over time			
Practices remain in place	3.66[A]	3.00[A]	N/A	N/A
Acres remain in forest	3.66[A]	2.25[A]	N/A	N/A

N/A = not applicable.
[a]Tukey's grouping across incentive programs for each respective program attribute. $\alpha = 0.05$.
Means with the same superscript letter (A or B) are not significantly different.
Likert Scale awareness ratings: 1 = very low, 2 = moderately low, 3 = moderately high, 4 = very high; Likert ratings for effectiveness: 1 = very ineffective, 2 = moderately ineffective, 3 = moderately effective, 4 = very effective.

DISCUSSION AND CONCLUSIONS

Because of the sources used for lists of family forest owners to receive survey questionnaires, the results of the some of the studies summarized in this chapter may be more representative of owners who are active and financially motivated than family forest owners in the South in general. For this reason, the findings should be considered conservative.

Family forest owner awareness and use of Federal income tax provisions—Owner awareness of the provisions available to taxpayers in general ranged widely, from nearly 80 percent for treatment of qualifying income as a long-term capital gain and annual deduction of management costs to between 50 and 60 percent for depreciation, the section 179 deduction, and loss deductions. In comparison, awareness of the provisions intended for owners of forests and other working lands—the reforestation incentives and special treatment of qualifying cost-share payments—was substantially lower, at roughly 50 percent or less.

Three demographic characteristics were associated with owner knowledge of each of the beneficial tax provisions: membership in a forest owner organization, having a written forest management plan, and a high level of household income. None of the demographic characteristics were associated across-the-board with owner use of beneficial tax provisions.

The study findings confirm the need for additional efforts to improve family forest owner awareness of beneficial tax provisions, particularly the provisions designed specifically for them. Historically, the tax handbooks, short courses, popularized articles, and extension workshops available to owners have focused on tax aspects of timber production. This approach has been beneficial and certainly needs to be continued. It seems likely, however, that approaches aimed at informing owners of the tax implications of other forest uses—nontimber forest products, recreation, and stewardship, for example—would appeal to the interests of additional owners (Greene and others 2004).

State property taxes—Most of the property tax administrators surveyed believed their State's program was effective at achieving its primary goal—reducing property tax—and approximately half believed it was effective at retaining forest land in areas highly susceptible to development. The findings from the survey indicate, however, that only a fraction of family forest land in the United States is enrolled in a preferential property tax program. Property taxes were of greater concern to the forest owners than any other type of tax, because they occur on an annual basis, are due whether or not the property produced income during the year, and are perceived as being high in relation to the value of the land. A common theme from the focus groups was that property taxes may be forcing some owners to sell timber or land when they would rather not. These decisions often are compounded by other factors, such as the loss of a job or the rigors of living on a fixed income. A number of owners had stories of relatives, friends, or friends of friends who had been forced to sell timber or land, and some feared they would be forced into the same position in the future. As well, several owners enrolled in a preferential property tax program stated that the program had enabled them to hold on to their land.

The study findings suggest that property tax policies should be simple, flexible enough to address the various threats to maintaining forest land that exist across a State, and appropriate to the challenges that the owners currently face. The preferential property tax programs in many States were put in place decades ago, when forest owners faced a different set of challenges. It needs to be determined whether these programs adequately address the current situation. If the primary objective of a property tax program is to keep forests as forests, it should focus primarily on discouraging conversion to other uses; promoting timber production or public access should be secondary.

The New Hampshire Forest Land tax program is one example of a flexible preferential property tax program that meets the needs of different types of owners. The basic program provides a property tax reduction for keeping land undeveloped. Forest owners who desire to manage their land according to a plan developed by a licensed forester are eligible for an additional reduction in tax. Owners who are willing to permit non-motorized recreation by the public on their property may be eligible for a further "recreational adjustment" in the assessment and taxation of their land (Butler and others 2010).

Combined impact of Federal and State taxes—Research has consistently shown that most family forest owners do not take taxes into consideration when making management decisions for their land. Nonetheless, Federal and State taxes affect the level of stewardship owners can practice and whether they are able to continue holding their land.

Federal and State taxes were found to reduce the pre-tax land expectation value of family-owned forest land in the South by amounts ranging from just over 25 percent to nearly 50 percent. Much of the reduction, but only a small part of the variation, is attributable to Federal income tax. All family forest owners in the United States face the same Federal capital gain tax rates on their net returns from timber harvests. The economic effect of the tax varies with the frequency and value of harvest returns and the amount of capitalized reforestation expenses, but within a defined area the variation falls within a fairly narrow range. In the Coastal Plain States, for example, Federal income tax decreased the pre-tax expectation value by 19 to 24 percent, and in the Appalachian-Cumberland highlands by 15 to 18 percent (table 11.7).

In contrast, the cumulative burden of State and local taxes varied widely across the South, from 4 percent of pre-tax land expectation value in Tennessee to 23 percent in Louisiana. Some of the variation can be explained by the number of different taxes a State imposes: Tennessee essentially levies only a property tax, while Louisiana levies harvest and income taxes as well as a property tax. The number of taxes levied did not, however, explain all of the variation. Like Tennessee, Texas levies only a property tax, while like Louisiana, Mississippi, levies property, income, and harvest taxes. Yet for Texas and Mississippi, the cumulative effect of State and local taxes was near the median for the region, and relative to pre-tax land expectation value, nearly identical (table 11.7).

Most variation in the cumulative effects stemmed from State-to-State variability in property tax rates. Property taxes occur annually and carry the greatest economic burden of any State and local tax. At the same time, property tax is the tax that family forest owners can do the most about; for example, they can ensure that their forest land meets the requirements to be assessed or taxed at its current use. Some States require a written management plan to qualify for this benefit, which encourages forest stewardship while providing tax relief. Owners also can seek other sources of income from their forest land—through, for example, a hunting lease, fee recreation, or nontimber forest products—to offset the annual tax levy.

The Federal income tax and State property taxes carry costs in addition to their economic impact. The Federal tax law changes continually. Although some changes are designed to benefit owners of forests and other working lands, they have the effect of increasing the complexity of the law and the cost of complying with it. As well, State-to-State variation in property taxes produces relative disadvantages to holding forest land and may have the unintended consequence of contributing to differential rates of development among States, particularly at the urban-rural interface or in areas undergoing gentrification (Cushing 2006).

Effect of the Federal estate tax—An estimated 77,200 forest estates, with 79.1 million acres of family-owned forest land, were transferred each year at the death of their owners. The median forest area transferred was 156 acres. Only a third of forest estates qualified for and one-quarter applied for special use valuation to reduce the Federal estate tax due. In three-fourths of the transfers where it was used, special use valuation was applied to both the land and timber. Although this may have been necessary to meet the requirements for the provision, it precluded the harvesting of timber for 10 years. The reduction in the gross value of forest estates from applying special use valuation averaged $325,000, well under the $750,000 maximum benefit in effect during the study period.

Owners of family forests and other rural lands were many times more likely than other taxpayers to incur the Federal estate tax. In about two-fifths of the transfers where Federal estate tax was due, timber or land was sold to pay part or all of the tax. Some three-fourths of the timber sales and nearly three-fifths of the land sales occurred because other estate assets were not sufficient to pay the tax. The need to sell timber or land to pay the estate tax was not limited to small holdings and the areas affected were not inconsequential. The mean forest size of ownerships that needed to sell timber was 3,035 acres and the mean area harvested was 498 acres; the mean forest size of ownerships that needed to sell land was 770 acres and the mean area sold was 387 acres.

The responses from forest owners and other owners of working lands were more remarkable for their similarities than their differences. The groups differed statistically in just 6 of the 20 characteristics surveyed, with most of the differences stemming from the different uses members of the two groups make of their land.

The results of this study provide insight into the magnitude of the effect of the Federal estate tax on family-owned forests and other rural lands. As well, they suggest avenues for development of an estate tax relief policy that would benefit both forest and other owners of working lands. Some elements of such a policy might include:

- A targeted increase in the effective exemption amount for estates that consist largely of working lands, such as farms, ranches, or forest land
- Revision of the requirements for special use valuation to permit timber harvests made in accordance with a management plan developed in consultation with a qualified professional forester
- Recognition of a business entity for family farms and forests, to help ensure that they qualify for business-oriented provisions in the tax code and to facilitate the transfer of working lands from one generation to another (Greene and others 2006).

Effectiveness of financial incentive programs in promoting sustainable practices—The results of the survey of State forestry officials indicate there are clear differences among the incentive programs available to family forest owners. The Forest Stewardship Program, Forest Land Enhancement Program, and Forest Legacy Program—all administered by the Forest Service—were among the top rated Federal programs by all measures, both overall and for individual attributes. All three programs stress multiple objectives, but their clientele is limited to forest owners. The other Federal incentive programs have forestry emphases, but their clientele includes farmers and ranchers as well as forest owners.

Regardless of their orientation or administrative agency, however, all of the Federal programs scored in or near the very effective range for practices remaining in place and acres remaining in forest over time (table 11.9). This finding speaks to the participating owners' long-term commitment to the supported practices as well as the long-term effectiveness of the programs themselves.

Programs sponsored by States, industry firms and State forestry associations, and nongovernmental organizations generally were more narrowly targeted than Federal programs, and scored higher for specific attributes. Such targeted programs have the potential to outperform general conservation programs for regional concerns, emerging issues (for example, invasive species control) or where program funding is constrained.

The findings from the survey of forestry officials must be interpreted with respect to acres enrolled in incentive programs, rather than by all acres held by family forest owners. The results of the forest owner focus groups clearly showed that public and private financial incentive programs play only a limited role in promoting sustainable practices on family-owned forest land. One reason is that funding of the programs limits the number of acres that may be enrolled. Another is that many forest owners remain unaware that the programs exist. Owner awareness of Federal financial incentive programs, for example, peaked in the moderately ineffective range (table 11.9; Jacobson and others 2009).

Southern forest owners share four strongly held sentiments with family forest owners nationwide:

- Their reasons for owning forest land are more strongly linked to self-identity than to profit;
- They have a strong ethic of conservation toward their land;
- The concept of sustainable forestry resonates with them, although they are not entirely clear as to its meaning; and
- They are more interested in face-to-face technical assistance than incentive programs or beneficial tax provisions.

Forest owner organization members in the South were more focused on managing timber for profit than owners in other regions, but still operated within these broad shared themes (Daniels and others 2010).

Since the research described in this chapter was completed, funding and legislative changes have occurred in the financial incentive programs available for family forest owners. The Forest Land Enhancement Program, among the top-rated programs, received no funding beyond its initial allocation. Forest Service distributions to States ended in 2006 and the program was not reauthorized in the 2008 Farm Bill (P.L. 110-246). As well, the Farm Bill modified provisions of the Environmental Quality Incentives Program and other programs administered by the Farm Service Agency and Natural Resources Conservation Service to include management and conservation practices on family-owned forest land as eligible for assistance. It also added protection of forests from threats such as invasive species, insects, and disease as a national priority for Federal assistance and established the Emergency Forest Restoration Program to address the new priority (Gorte 2008, Greene and others 2010).

The effect of these changes has largely been to shift incentive programs for family forest owners from the Forest Service to sister agencies within the Department of Agriculture whose traditional focus has been farmers and ranchers. The challenge for the Forest Service will be to find new ways to deliver direct assistance to landowners and to coordinate program delivery with other Federal and State agencies.

Kilgore and others (2007) proposed nine recommendations for financial incentive programs:

- Increase funding and availability of one-on-one technical assistance from both extension foresters and State service foresters;
- Approach the concept of forest sustainability through technical assistance that addresses owners' long-term stewardship and family legacy objectives rather than through certification;
- Make a written forest management plan a requirement to participate in all incentive programs;
- Design incentive programs to put forest owners in direct contact with a forester or other natural resource professional;
- Design some incentive programs with sufficient flexibility to address regional differences in forest characteristics, forest health concerns, or forest owner objectives;
- Link incentives directly to stewardship practices instead of general forest management practices;
- Fund cost-share applications according to their expected environmental benefit instead of first-come-first-served;
- Maintain adequate funding and stable program requirements for financial incentives over the long term; and
- Make the requirements for owners to participate in financial incentive programs more uniform, and coordinate program administration and delivery more closely.

KNOWLEDGE AND INFORMATION GAPS

Additional research is needed to update and validate the findings of each of the studies discussed above for current legislation, and to obtain larger and broader samples of family forest owners. Additional work also is needed to assess the policy implications that arise from the studies, including:

- Identify and evaluate program approaches for improving family forest owner awareness and use of beneficial income tax provisions, including assisting owners to develop written forest management plans, encouraging them to participate in forest owner organizations, and better informing them of the tax aspects of nontimber forest uses.
- Identify and evaluate approaches to develop an estate tax relief policy for owners of forests and other working lands, including a targeted increase in the exemption amount for estates that consist largely of working land, revising the requirements for special use valuation to permit timber harvests made in accordance with an approved management plan, and developing a business entity tailored for owners of family farms and forests.
- Monitor the development of property tax provisions intended to reduce urban sprawl and encourage provision of ecosystem services from rural land, and examine the level of their success.
- Determine whether property taxes on family forest land at the urban-rural interface remain stable over time or rise in response to development pressures.
- Determine whether property tax differentials in neighboring States continue or diminish over time.

Little is known about the effect of the changes to financial incentive programs made by the 2008 Farm Bill, which shifted major responsibility for program administration from the Forest Service to sister agencies in the Department of Agriculture. Research is needed to determine the effects of this shift on State forestry agency partners, family forest owners, and the number of family forest acres treated.

And finally, the period 2002–2012 has provided a veritable laboratory on the effects of continually changing tax provisions. Research is needed to determine the effect of such tax uncertainty on the management decisions of family forest owners.

ACKNOWLEDGMENTS

Our thanks to Robert J. Dee and Heather Irwin, Department of Forestry and Natural Resources, Clemson University; David H. Newman, Department of Forest and Natural Resource Management, State University of New York; Ted Beauvais, Cooperative Forestry, U.S. Forest Service; Steven H. Bullard, Temple College of Forestry and Agriculture, Stephen F. Austin State University; Stephen E. Daniels, Department of Sociology, Social Work, and Anthropology, Utah State University; Michael G. Jacobson, School of Forest Resources, Pennsylvania State University; and Michael L. Kilgore, Department of Forest Resources, University of Minnesota.

LITERATURE CITED

American Tree Farm System Web site. 2011. About us. http://www.treefarmsystem.org/about-american-tree-farm-system. [Date accessed: August 31, 2011].

Anderson, W.C. 1960. The small forest landowner and his woodland. Stn. Pap. 114. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 15 p.

Bailey, P.D.; Haney, H.L., Jr.; Callihan, D.S. [and others]. 1999. Income tax considerations for forest landowners in the South: a case study in tax planning. Journal of Forestry. 97(4): 10–15.

Bankrate.com. 2011. Click on our map to check taxes in your State. http://www.bankrate.com/finance/taxes/check-taxes-in-your-state.aspx. [Date accessed: August 31, 2011].

Baughman, M.; Reichenbach, M. 2009. Property tax relief for forest landowners. Presentation at fueling the future: the role of woody biomass for energy workshop, April 29, St. Cloud, MN. http://www.extension.umn.edu/agroforestry/components/Property-Tax-Relief-Forest-Landowners.pdf. [Date accessed: August 31, 2011].

Becker, J.; Jacobson, M. 2008. Preserving the family woods: tools to help guide transfer to the next generation of landowners. Publ. NA–IN–04–08. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry. 55 p.

Bettinger, P.; Haney, H.L., Jr.; Siegel. W.C. 1989. The impact of Federal and State income taxes on timber income in the South following the 1986 Tax Reform Act. Southern Journal of Applied Forestry. 13(4): 196–203.

Bettinger, P.; Haney, H.L., Jr.; Siegel. W.C. 1991. The impact of Federal and State income taxes on timber income in the West following the 1986 Tax Reform Act. Western Journal of Applied Forestry. 6(1): 15–20.

Birch, T.W. 1996. Private forest land owners of the United States, 1994. Resour. Bull. NE–134. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 183 p.

Bliss, J.C.; Martin, A.J. 1990. How tree farmers view management incentives. Journal of Forestry. 88(8): 23–29, 42.

Brockett, C.D.; Gerhard, L. 1999. NIPF tax incentives: do they make a difference? Journal of Forestry. 97(4): 16–21.

Butler, B.J. 2009. Forest ownership. In: Forest resources in the United States, 2007: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. WO–78. Washington, DC: U.S. Department of Agriculture Forest Service: 19–21.

Butler, B.J.; Hewes, J.H.; Catanzaro, P. [and others]. 2010. Effects of Federal, State, and local tax policies on family forest owners: technical report. FFRC Res. Pap. No. 2010-01. Amherst, MA: Family Forest Research Center. 76 p.

Butler, B.J.; Leatherberry, E.C. 2004. America's family forest owners. Journal of Forestry. 102(7): 4–9.

CCH. 2010. CCH tax briefing: 2010 Tax Relief/Job Creation Act. Special Report. Chicago, IL: CCH, A Wolters Kluwer Business. 10 p.

CCH. 2013. CCH tax briefing: American Taxpayer Relief Act of 2012. Special Report. Chicago, IL: CCH, A Wolters Kluwer Business. 12 p.

Chang, S.J. 1996. U.S. forest property taxation systems and their effects. In: Proceedings: Symposium on nonindustrial private forests: learning from the past, prospects for the future. St. Paul, MN: University of Minnesota Extension Service: 318–325.

Christensen, W.W.; Grafton, A.E. 1966. Characteristics, objectives, and motivations of woodland owners in West Virginia. Bull. 538. Morgantown, WV: West Virginia University, Agricultural Experiment Station. 28 p.

Cloud, M.C. 1966. Promoting forest management with owners of medium-sized parcels of land. Journal of Forestry. 64: 536–537.

Cushing, T.L. 2006. A comparison of the relative reduction in land expectation value due to taxation of private forest land in the United States. Athens, GA: University of Georgia. 148 p. Ph.D. dissertation.

Dana, S.T.; Fairfax, S. 1980. Forest and range policy. New York: McGraw-Hill Book Co. 458 p.

Daniels, S.E.; Kilgore, M.A.; Jacobson, M.G. [and others]. 2010. Examining the compatibility between forestry incentive programs in the U.S. and the practice of sustainable forest management. Forests. 1(1): 49–64. http://www.mdpi.com/1999-4907/1/1/49/. [Date accessed: August 31, 2011].

Daniels, S.E.; Walker, G.B. 2001. Working through environmental conflict: the collaborative learning approach. Westport, CT: Praeger Publishers. 328 p.

Dialog Group on Forested Lands and Taxation. 2001. Keeping forests as forests: recommendations for reducing forest fragmentation on private land in the United States through changes in Federal tax policy. Dillon, CO: Meridian Institute. 25 p.

Dillman, D.A. 1978. Mail and telephone surveys: the total design method. New York: Wiley-Interscience. 375 p.

Dillman, D.A. 2000. Mail and Internet surveys: the tailored design method. 2d ed. New York: John Wiley. 480 p.

Egan, A.; Gibson, D.; Whipkey, R. 2001. Evaluating the effectiveness of the forest stewardship program in West Virginia. Journal of Forestry. 99(3): 31–36.

Farrell, J.H. 1964. The small-woodland owner in the Missouri Ozarks—a close-up. Res. Pap. CS–10. Columbus, OH: U.S. Department of Agriculture Forest Service, Central States Forest Experiment Station. 15 p.

Fecso, R.S.; Kaiser, H.F.; Royer, J.P. [and others]. 1982. Management practices and reforestation decisions for harvested southern pinelands. Staff Rep. AGES821230. Washington, DC: U.S. Department of Agriculture, Statistical Reporting Service. 74 p.

Folweiler, A.D.; Vaux, H.J. 1944. Private forest land ownership and management in the loblolly-shortleaf type of Louisiana. Journal of Forestry. 42(11): 783–790.

ForesTech International. 2003. SiMS 2003 individual stand simulator. Watkinsville, GA: ForesTech International LLC.

Gayer, P.D.; Haney, H.L., Jr.; Hickman, C.A. 1987. Financial impact of current-use assessment of forest land in Virginia. Res. Pap. SO-240. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 10 p.

Gorte, R.W. 2008. CRS report for Congress: forestry in the 2008 Farm Bill. Order Code RL33917. Washington, DC: Congressional Research Service. 20 p.

Granskog, J.E.; Haines, T.; Greene, J.L. [and others]. 2002. Policies, regulations, and laws. In: Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 189–223. Chapter 8.

Greene, J.L. 1998. The economic effect of Federal income tax incentives in southern timber types. In: Meeting in the middle: Proceedings of the 1997 Society of American Foresters national convention. Bethesda, MD: Society of American Foresters: 231–241.

Greene, J.L.; Blatner, K.A. 1986. Identifying woodland owner characteristics associated with timber management. Forest Science. 32: 135–146.

Greene, J.L.; Bullard, S.H.; Cushing, T.L. [and others]. 2006. Effect of the Federal estate tax on nonindustrial private forest holdings. Journal of Forestry. 104(1): 15–20.

Greene, J.L.; Daniels, S.E.; Kilgore, M.A. [and others]. 2010. Effectiveness of financial incentive programs in promoting sustainable forestry in the West. Western Journal of Applied Forestry. 25(4): 186–193.

Greene, J.L.; Siegel, W.C.; Hoover, W.L. [and others]. 2013. Forest landowners' guide to the Federal income tax. Agric. Handb. 731. Washington, DC: U.S. Department of Agriculture Forest Service. 151p.

Greene, J.L.; Straka, T.J.; Dee, R.J. 2004. Nonindustrial private forest owner use of Federal income tax provisions. Forest Products Journal. 54(12): 59–66.

Gregory, G.R. 1972. Forest resource economics. New York: The Ronald Press Co. 548 p.

Haney, H.L., Jr. 2011. Flexible tax strategies: part 1 of 2. Forest Landowner Magazine. 70(2): 36–41.

Helms, J.A., ed. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 224 p.

Hibbard, C.M.; Kilgore, M.A.; Ellefson, P.V. 2003. Property taxation of private forests in the United States: a national review. Journal of Forestry. 101(3): 44–49.

Hickman, C.A. 1982. Property tax impacts of current-use assessment of forest and other rural land in Tennessee. Res. Pap. SO-180. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 17 p.

Hickman, C.A.; Crowther, K.D. 1991. Economic impacts of current-use assessment of rural land in the East Texas pineywoods region. Res. Pap. SO-261. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 20 p.

Hoover, W.L.; Koontz, M. 2010. Timber tax management for family forest owners. Meridian, ID: Timber Tax LLC. 340 p.

Howard, T.E. 1985. Estate planning for nonindustrial forest owners. Land Economics. 61(4): 363–371.

Internal Revenue Service. 2010. 2011 adjusted items: valuation of qualified real property in decedent's gross estate. Internal Revenue Bulletin. 2010-46: 666.

Internal Revenue Service. 2012. Part III. Administrative, procedural, and miscellaneous. Internal Revenue Bulletin. 2012-45: 538-542.

Jacobson, M.G.; Greene, J.L.; Straka, T.J. [and others]. 2009. Influence and effectiveness of financial incentive programs in promoting sustainable forestry in the South. Southern Journal of Applied Forestry. 33(1): 35–47.

Jacobson, M.; McDill, M. 2003. A historical review of forest property taxes in Pennsylvania: implications for special forest land tax programs. Northern Journal of Applied Forestry. 20(2): 53–60.

James, L.M.; Hoffman, W.P.; Payne, M.A. 1951. Private forest landownership and management in central Mississippi. Tech. Bull. 33. State College, MS: Mississippi State College, Agricultural Experiment Station. 38 p.

Kays, J.; Schultz, V.M. 2002. Tax and estate planning for Maryland forest landowners. Fact Sheet 630. College Park, MD: University of Maryland, Maryland Cooperative Extension. 12 p.

Kernan, H. 2004. Commentary—New York's Forest Tax Law 480A. The New York Forest Owner. 42(6): 14–18.

Kilgore, M.A.; Greene, J.L.; Jacobson, M.G. [and others]. 2007. The influence of financial incentive programs in promoting sustainable forestry on the nation's family forests. Journal of Forestry. 105(4): 184–191.

Klemperer, W.D. 1988. Revising forest property taxes: recent trends and policy questions. In: Proceedings, forest taxation—adapting in an era of change. Madison, WI: Forest Products Research Society: 9–14.

Klemperer, W.D. 1989. An income tax wedge between buyers' and sellers' values of forests. Land Economics. 65(2): 146–157.

Kluender, R.A.; Walkingstick, T.L.; Pickett, J.C. 1999. The use of forestry incentives by noninindustrial forest landowner groups: Is it time for a reassessment of where we spend our tax dollars? Natural Resources Journal. 39: 799–818.

Koontz, M.A. 1999. Financial incentives to promote environmental management by nonindustrial private forest land owners. West Lafayette, IN: Purdue University. 102 p. M.S. thesis.

Land Trust Alliance Web site. 2011. Conservation easements. http://www.landtrustalliance.org/conserve/landowners/conservation-easements. [Date accessed: August, 31, 2011].

National Timber Tax Web site. 2011a. State tax laws. http://www.timbertax.org/statetaxes/statetaxes.asp. [Date accessed: August, 31, 2011].

National Timber Tax Web site. 2011b. Tax related publications. http://www.timbertax.org/publications/. [Date accessed: August, 31, 2011].

Perry, J.D.; Guttenberg, S. 1959. Southwest Arkansas' small woodland owners. Occas. Pap. 170. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 14 p.

Peters, D.M.; Haney, H.L., Jr.; Greene, J.L. 1998. The effects of Federal and State death and gift taxes on nonindustrial private forest lands in the Midwestern States. Forest Products Journal. 48(9): 35–44.

Private Landowner Network Web site. 2011. Conservation programs and technical resources. http://www.privatelandownernetwork.org/grantprograms/. [Date accessed: August, 31, 2011].

Rodenberg, J.; Jacobson, M.; McDill, M. 2004. An evaluation of forest property tax programs in the United States. In: Bugs, budgets, mergers, and fires: Proceedings of the 2003 southern forest economics workshop. [Compact Disk]. Mississippi State, MS: Mississippi State University, Department of Forestry, Forest and Wildlife Research Center. 106 p. http://sofew.cfr.msstate.edu/papers/Rodenberg03.pdf [Date accessed: August 31, 2011].

Royer, J.P. 1987. Determinants of reforestation behavior among southern landowners. Forest Science. 33(3): 654–667.

Siegel, W.C. 2010. The current status of the Federal estate and gift taxes. National Woodlands. 33(1): 20–22.

Siegel, W.C.; Haney, H.L., Jr.; Greene, J.L. 2009. Estate planning for forest landowners: what will become of your timberland? Gen. Tech. Rep. SRS–112. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 180 p.

Siegel, W.C.; Haney, H.L., Jr.; Peters, D.M. [and others]. 1996. The impact of Federal and State income taxes on timber income in the Northeast and Midwest following the 1986 Tax Reform Act. Northern Journal of Applied Forestry. 13(1): 8–15.

Smith, N.R.; Bailey, P.; Haney, H., Jr. [and others]. 2007. The impact of Federal and State income tax liabilities on timber investments in the Midwest and Northeast. Northern Journal of Applied Forestry. 24(4): 245–251.

Smith, N.R.; Bailey, P.; Haney, H., Jr. [and others]. 2008. The impact of Federal and State income tax liabilities on timber investments in the West. Western Journal of Applied Forestry. 22(2): 121–126.

Smith, W.B.; Miles, P.D.; Perry, C.H. [and others]. 2009. Forest resources in the United States, 2007: a technical document supporting the Forest Service 2010 RPA assessment. Gen. Tech. Rep. WO–78. Washington, D.C.: U.S. Department of Agriculture Forest Service. 337 p.

SRS Forest Economics and Policy Web site. 2011. Financial incentive programs for nonindustrial private forest owners. http://www.srs.fs.usda.gov/econ/data/forestincentives/. [Date accessed: August, 31, 2011].

Stoddard, C.H. 1961. The small private forest in the United States. Washington, D.C.: Resources for the Future, Inc. 171 p.

Straka, T.J.; Greene, J.L. 2007. Reforestation tax incentives under the American Jobs Creation Act of 2004. Southern Journal of Applied Forestry. 31(1): 23–27.

The Longleaf Alliance Web site. 2011. Homepage. http://www.longleafalliance.org/. [Date accessed: August, 31, 2011].

Timber Mart-South. 2003. Timber Mart-South: 1st–4th quarter 2003 stumpage prices for Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Texas, and Virginia. Athens, GA: University of Georgia, Warnell School of Forest Resources. 10 p.

Tufts, R.A.; Dubois, M.R.; Zabawa, R.E. [and others]. 2003a. Estate planning for landowners: distribution of assets. [CD–ROM 1]. Auburn, AL: Auburn University, Office of Information Technology, Media Production Group.

Tufts, R.A.; Dubois, M.R.; Zabawa, R.E. [and others]. 2003b. Estate planning for landowners: using a business entity. [CD–ROM 2]. Auburn, AL: Auburn University, Office of Information Technology, Media Production Group.

U.S. Department of Agriculture (USDA) Forest Service. 2002. Sourcebook on criteria and indicators of forest sustainability in the Northeastern Area. Tech. Pub. NA-TP-03-02. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry. 64 p.

U.S. Department of Agriculture (USDA) Forest Service. 2004. National report on sustainable forestry—2003. Publication FS-766. Washington, D.C.: U.S. Department of Agriculture Forest Service. 139 p.

U.S. Department of Agriculture (USDA) Forest Service Valuing Ecosystem Services Web site. 2011. Frequently asked questions. http://www.fs.fed.us/ecosystemservices/About_ES/faq.shtml. [Date accessed: August, 31].

Walden, J.B.; Haney, H.L., Jr.; Siegel, W.C. 1987. The impact of recent changes in State and Federal death tax laws on private nonindustrial forest estates in the South. Southern Journal of Applied Forestry. 11(1): 17–23.

Walden, J.B.; Haney, H.L., Jr.; Siegel, W.C. 1988. Federal-state death tax implications for private nonindustrial forest landowners in the Northeast. Northern Journal of Applied Forestry. 5(2): 135–141.

Wang, L.; Greene, J.L. 2011. Tax tips for forest landowners for the 2011 tax year. Manage. Bull. R8–MB 139. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 2 p.

Yin, R.; Newman, D.H.; Siry, J. 2002. Testing for market integration among southern pine regions. Journal of Forest Economics. 8(2): 151–166.

CHAPTER 12.
Employment and Income Trends and Projections for Forest-Based Sectors in the U.S. South

Karen L. Abt[1]

KEY FINDINGS

- The southern logging sector is expected to experience small increases in both industry output (3 percent) and jobs (2 percent) from 2008 to 2018. Increased demand from bioenergy is expected to counteract increasing trends toward mechanization and reduced demand from some traditional wood-using industries.
- Southern wood products manufacturing is expected to increase in industry output (2.2 percent) in conjunction with the housing recovery after the 2007–09 recession. Technical change is expected to continue—with capital substituting for labor—leading to continued declines in jobs through 2018 (8 percent).
- The southern paper manufacturing sector is expected to continue contracting, with industry output declining by 17 percent through 2018. Output declines and continued technical change are expected to reduce jobs by 26 percent from 2008 to 2018.
- Forest-based recreation is expected to increase following the 2007–09 recession, but at lower rates than overall travel and tourism. Increases in output may be limited because forest-based recreation per capita is not expected to increase at the same rate as other travel and tourism. In addition, technical change is expected to continue to reduce labor demand for the same level of output.
- Bioenergy demands resulting from State and Federal policies are expected to lead to increases in logging sector jobs and output. If competition occurs between bioenergy demands and traditional wood products demands, additional losses in jobs and output in the wood products and paper manufacturing sectors would be expected. Output and employment gains from bioenergy development and production would be offset by losses in conventional energy, including mining, drilling, transport, and fuel and electricity generation and distribution. The overall effects on output and employment in the South are expected to be small.

[1]Karen L. Abt is a Research Economist at the Forest Economics and Policy Research Work Unit, Southern Research Station, U.S. Department of Agriculture Forest Service, Research Triangle Park, NC 27709.

INTRODUCTION

Southern forests are used for recreation, provide wood inputs to manufacturing, create scenery, and enhance the quality of life. In addition to providing jobs and income to the local and regional economy, forests are now considered a potential source of woody biomass for bioenergy. This chapter addresses the short-term future output and jobs in forest-using sectors of the southern economy. Specific sectors addressed include forestry and logging, wood products manufacturing, paper manufacturing, forest-based recreation, and the new bioenergy sectors.

Economists represent the regional economy through production functions. A production function is a stylized model that expresses industry or business outputs (typically measured in dollars) as a function of the inputs needed to generate the outputs. For example, a generic production function would represent output as a function of capital, labor, energy, materials (such as wood), and other inputs. Over time, we expect this production function to change as technology reduces the amount of inputs needed to produce the same level of output by substituting capital for labor, energy, and other inputs.

Assuming that companies are profit maximizing and risk-neutral, the optimal output level and the optimal combination of inputs needed to achieve it will be driven by the prices of the inputs and outputs. We typically expect the inputs to be complements (an increase in one input requires an increase in the other) or substitutes (an increase in one input leads to a decrease in the other). Changes in input use levels can be the result of changes in the output level or changes in input price or quality. Thus, an industry or business can decrease its demand for labor (jobs) because of decreased demand for its outputs, or because capital or another input is substituting for labor in the production function.

A conundrum of economic analysis is that a positive outcome in one area is likely offset by a negative outcome elsewhere. For example, increasing wages is usually perceived as a positive because it leads to a higher standard of living for workers, but it also leads to increased labor costs, which will result in substituting capital for labor in the production function. The result is a loss of jobs, which is typically seen as a negative outcome. Similarly, gains in one sector (such as logging) are likely offset by losses in a different sector (such as coal mining); and gains in one geographic area (such as the South) may be offset by losses in other regions (such as the Northern Appalachians). These outcomes illustrate that the definition of sectors, inputs, and areas of interest are likely to influence the outcome of any economic analysis of a region's economy, which should be kept in mind while reading the following assessment.

Throughout this chapter, we use some specific economic and modeling terms. They are defined below:

Recession: an economic term implying, generally, a decline in economic activity that is between a peak and trough of economic activity. The National Bureau of Economic Research is the accepted arbiter of when recessions begin and end (see http://www.nber.org/cycles/recessions.html). The recession referred to in this chapter began in December 2007 and continued until June of 2009.

Technical change: Technical change is an economic term representing any change in the relationship between inputs to a production process and outputs from a production process. This is often an improvement in capital use, leading to a reduction in labor use, but can also result from administrative or policy changes.

Jobs (also employment): These are not full-time equivalents, and so represent any continuous employer-employee relationship for wages and salary, whether full- or part-time.

Output (also total industry output): Output is an economic term representing the total dollar value of a firm or sector or economy. This value "double counts" the contribution of a sector when adding up the totals for an economy—the value of a log would be counted in the output of the logging sector, and, for example, in the output of the sawmill sector. When adding up the sector values across an economy, the total value added should be used in place of output; however in this chapter we use output because the models and forecasts were developed for output and not for total value added.

Gross regional product (also gross domestic product): an economic term representing the total value of the production of goods and services for a region (or State or country).

Total value added: an economic term that nets out the cost of inputs (such as logs) that are counted as another firm's outputs and is nearly equivalent to gross domestic (or regional) product (indirect taxes are excluded). Other components of total value added include proprietor's income and property-type income.

Income: represents, in this chapter, wage and salary income from a job. Wage and salary income is a large component of total value added, and thus is a large component of gross regional product.

Forestry and logging: a sector that includes both the growing and management of forests [forestry is part of North American Industry Classification System (NAICS) sector 115] and the harvesting and transportation of timber (NAICS 113).

Forest-based recreation: a sector that represents all expenditures made to participate in forest-based recreation, including hiking, hunting, winter sports, water sports, fishing, nature study and other recreation activities taking place in forests. This sector is not defined separately in NAICS, but could include portions of other sectors including transportation (NAICS 48), accommodations (NAICS 721), eating and drinking places (NAICS 722), recreation and entertainment (NAICS 713) as well as parts of other sectors.

Bioenergy: a sector that represents current (or potential) uses of wood to produce energy (pellets, liquid fuels, and electricity). This sector is not defined separately in NAICS, but could include portions of miscellaneous wood products (NAICS 321999), electricity generation (NAICS 237130) and ethanol sectors (NAICS 325193).

Wood products manufacturing: a sector that includes primary sawmills as well as manufacturers of veneer and/or plywood, engineered wood members, and reconstituted wood products (NAICS 321). These companies manufacture and/or use solid wood products such as lumber, millwork, pallets, mobile homes, and trusses.

Paper manufacturing: a sector (NAICS 322) that includes firms that make pulp, paper and/or converted paper products.

Input-output models: models used to represent static, detailed production relationships between inputs and outputs, and jobs and income.

Computable general equilibrium models: models used to represent changes in an economy using estimated or assumed equations and parameters.

METHODS

To address the future of jobs, income, and contributions of forest-using sectors to the regional or local economy, we first evaluated historical trends and current conditions in the forestry and logging, wood products, and paper manufacturing sectors, as well as forest-based recreation and future bioenergy sectors. We then developed projections, to the extent possible given the data limitations, for forest-using sectors.

The forest-based recreation and bioenergy sectors have inadequate data and/or analyses at the national level and for the South that limits our ability to project these sectors. Forest-based recreation is not specifically tracked in the national economic accounts, and even the data available nationally have not been subset for the South, limiting our ability to provide Southwide trends. The bioenergy sector (distinct from by-products of wood products and paper manufacturing) is fairly new and does not have separate data for historical analysis.

Forecasts for the logging, wood products manufacturing, and paper manufacturing sectors were developed for a single decade, using trends in the southern component of each sector to downscale national forecasts. These national and southern trends were developed from the IMPLAN (MicroImplan Group, Inc. 2010) database (percent of each sectors' outputs that were from the South) and from the 2007 Resources Planning Act database (percent of each sectors' inputs that were from the South). Forecasts of economic activity at the sector level were not available beyond 2018.

The national forecasts were developed by the Bureau of Labor Statistics, Department of Labor using methods outlined in chapter 13 of the BLS Handbook of Methods (U.S. Department of Labor BLS, 2011). These forecasts are developed every two years, for a 10-year forecast period. There are six separate modeling components, each of which builds on the previous outputs. These six components are:

1. Forecast of Labor Supply: developed from forecasts of labor participation rates and population.
2. Forecast of Aggregate Economic Growth: BLS contracts with Macroeconomic Advisers, LLC to develop these forecasts, using the forecast of labor supply as an input.
3. Forecast of Commodity Final Demand: this modeling component disaggregates the economic growth into growth in the components of final demand (personal consumption expenditures, gross private domestic investment, foreign trade, and government demand) for each commodity.
4. Forecast of Sectoral Industry Outputs: using an input-output model with inputs from above and production relationships from the Bureau of Economic Analysis, the commodity final demands are converted into industry total outputs.
5. Forecasts of Industry Employment: jobs are estimated as a function of total industry output, wages, prices and time, as a system of equations. Wages derived from the Current Employment Statistics and the Current Population Survey, prices are adjusted using forecast inflation, and time accounts for changes in labor productivity.
6. Forecasts of Occupational Employment and Job Openings: a matrix of 300 industries by 750 occupations is used to calculate how forecasts of industry employment result in particular jobs.

The national forecasts for the tourism-related sectors are also presented, as are the expected changes in jobs and income that could result from these sectors. Forecasting the bioenergy sector is complicated because the technologies are under development and the markets are not well established. In addition, there is considerable uncertainty regarding the policies and technologies that will drive the industries and resulting outputs and jobs.

DATA SOURCES

Data used in this analysis are primarily from the U.S. Department of Commerce, Bureau of Economic Analysis (BEA) (2010), Woods (2009), and the Travel and Tourism Satellite Account (Griffith and Zemanek 2009). In addition, data from IMPLAN (MicroImplan Group, Inc. 2010) and from the 2007 Resources Planning Act database were used to downscale the national labor forecasts to the South.

RESULTS

Past and Current Role of Forest-Based Sectors in the Southern Economy

Wood-related manufacturing, including logging and forestry comprised less than 1 percent of southern jobs and employment income in 2008 (figs. 12.1 and 12.2) (U.S. Department of Commerce 2010). This was down from 1.2 percent in 1990 (figs. 12.3 and 12.4), and resulted from both the growth of the entire southern economy as well as a decline in wood-related employment (figs. 12.5 and 12.6). Wood-related income (in constant 2008 dollars) increased from 1990 to 2000, but fell back to 1990 levels after 2000, with most of the variation coming from the wood products and paper manufacturing sectors (fig. 12.6). Wood-related manufacturing comprised 10 percent of all southern manufacturing employment (fig. 12.7) and 8 percent of all southern manufacturing income (fig. 12.8). This compares to food manufacturing with 13 percent of employment and 10 percent of income, and textiles manufacturing with 6 percent of employment and 4 percent of income (fig. 12.7 and fig. 12.8).

Of the three wood-related manufacturing sectors' employment, wood products manufacturing is the largest component (47 percent of wood-related employment) and forestry and logging is the smallest (14 percent) (fig. 12.9). The paper manufacturing sector, however, provides a much larger proportion of wood-related income (51 percent)

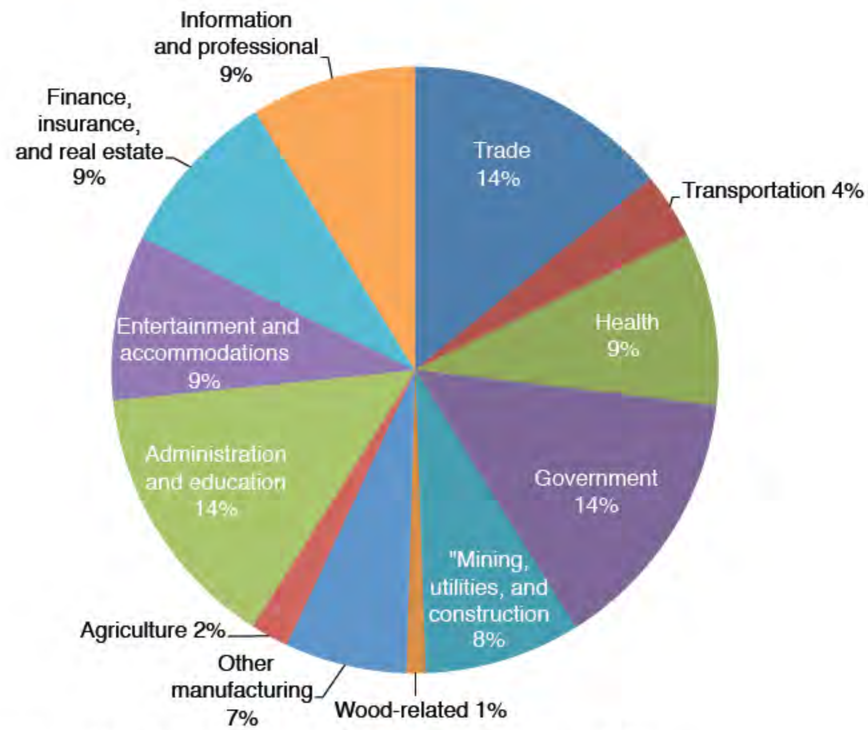


Figure 12.1—Employment by major economic sector in the South, 2008.

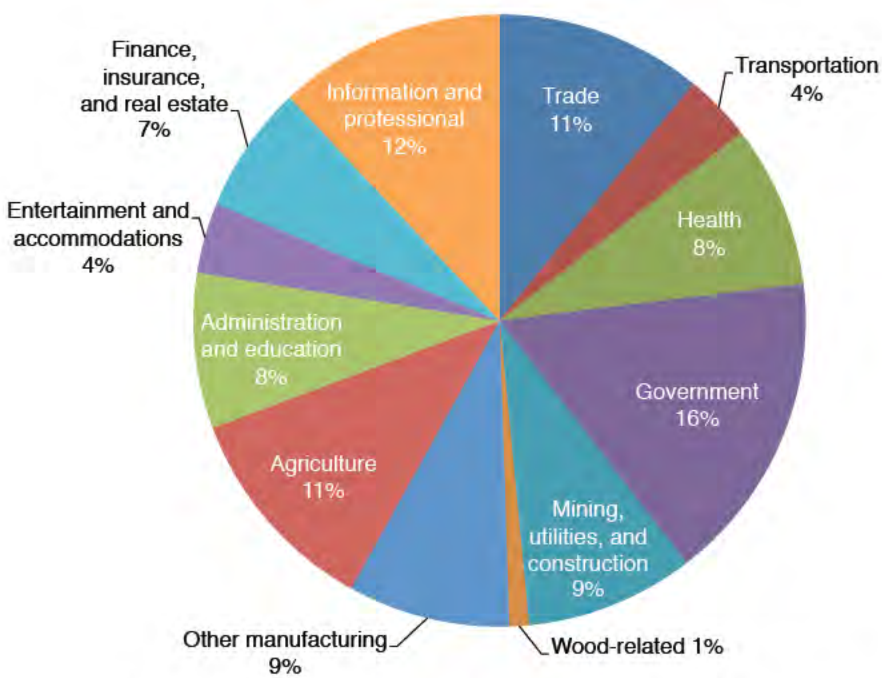


Figure 12.2—Income from employment by major economic sector in the South, 2008.

Figure 12.3—Employment in wood-related sectors as a percent of the southern economy, 1990 to 2008.

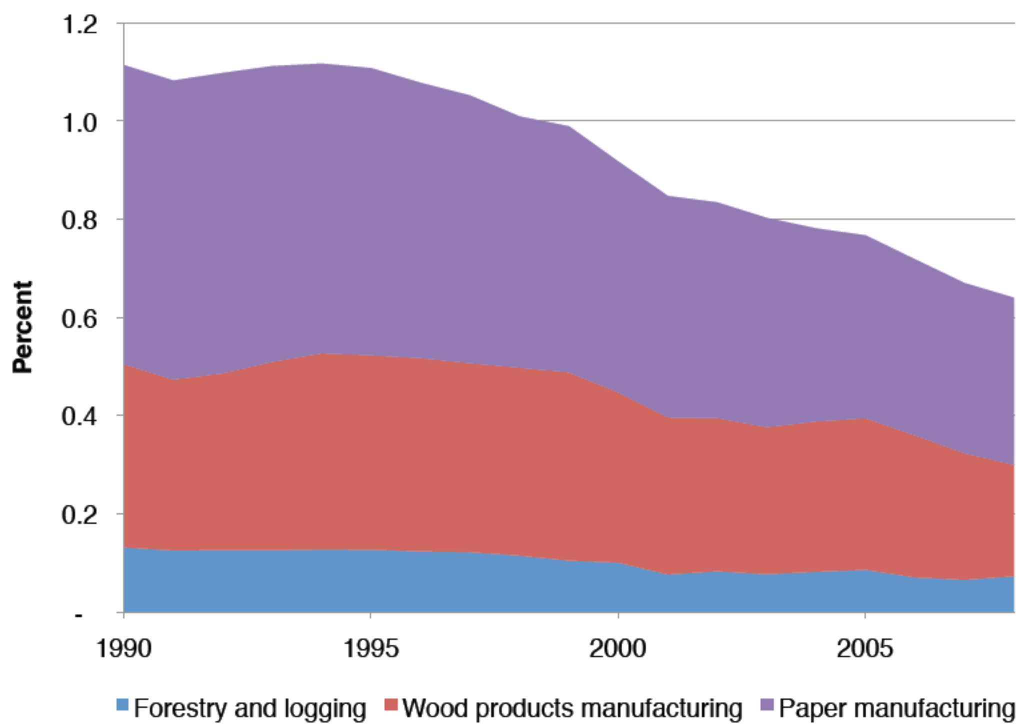


Figure 12.4—Income from employment in wood-related sectors as a percent of the southern economy, 1990 to 2008.

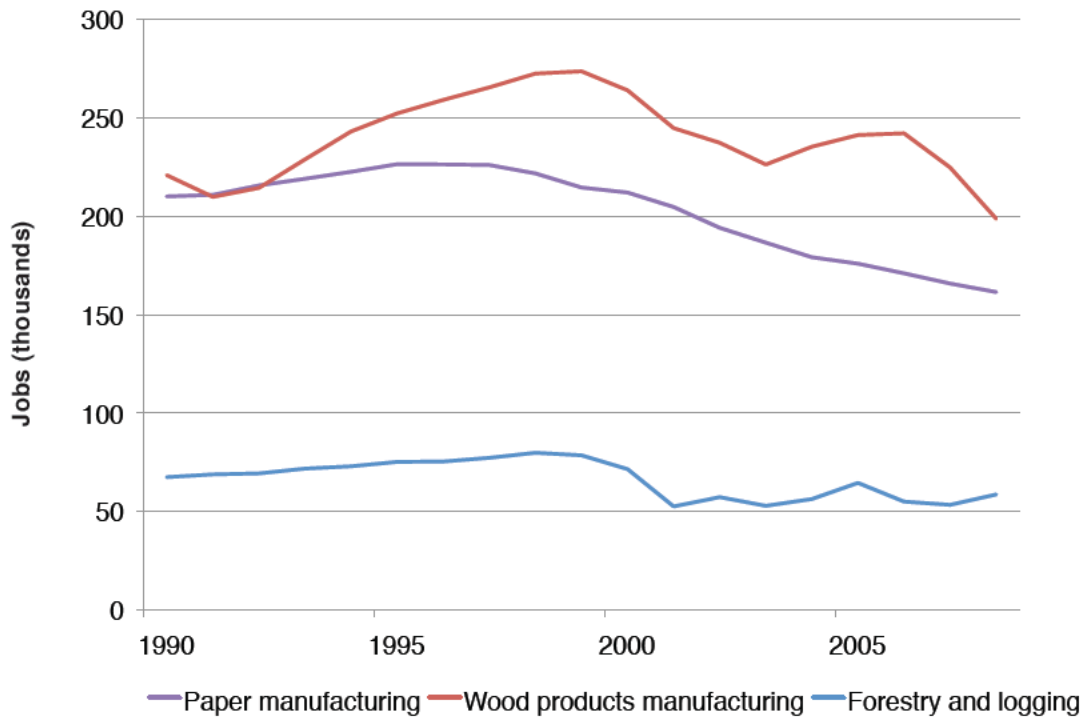


Figure 12.5—Employment in southern wood-related sectors, 1990 to 2008.

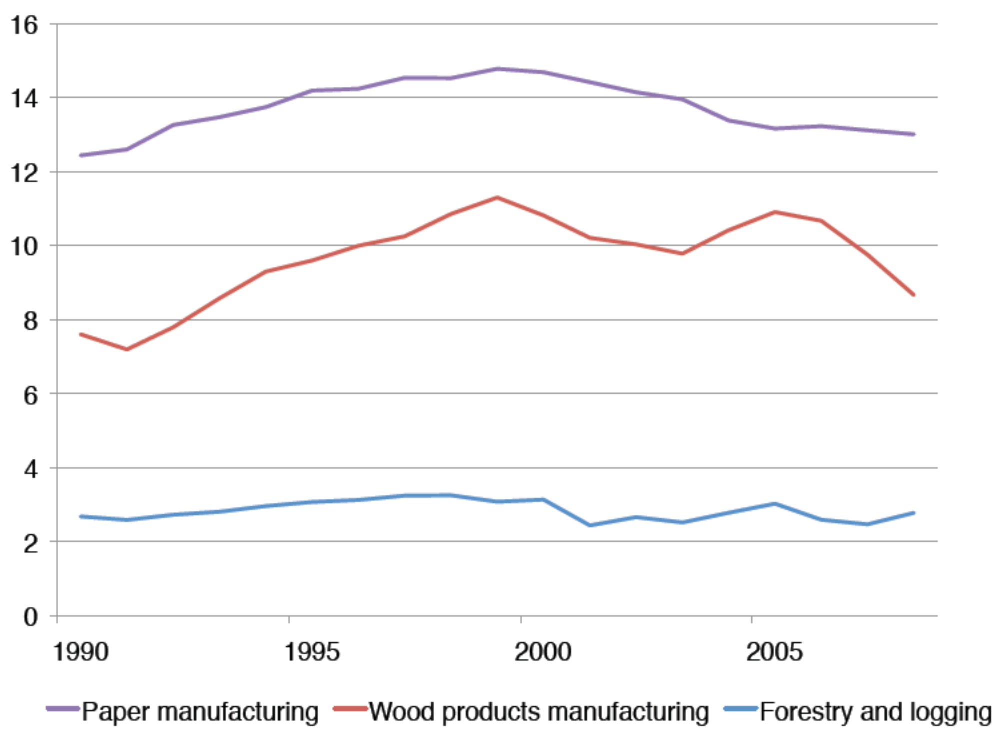


Figure 12.6—Income from employment in southern wood-related sectors, 1990 to 2008, in billions of 2008$.

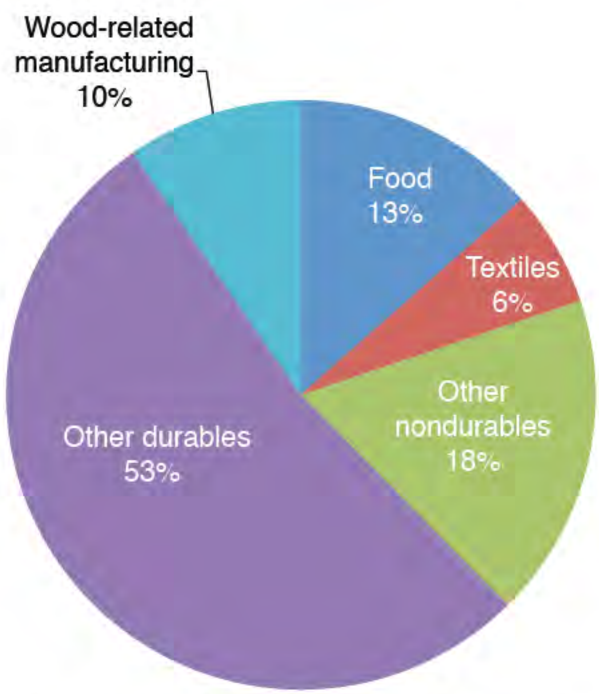


Figure 12.7—Employment by manufacturing sector in the South, 2008.

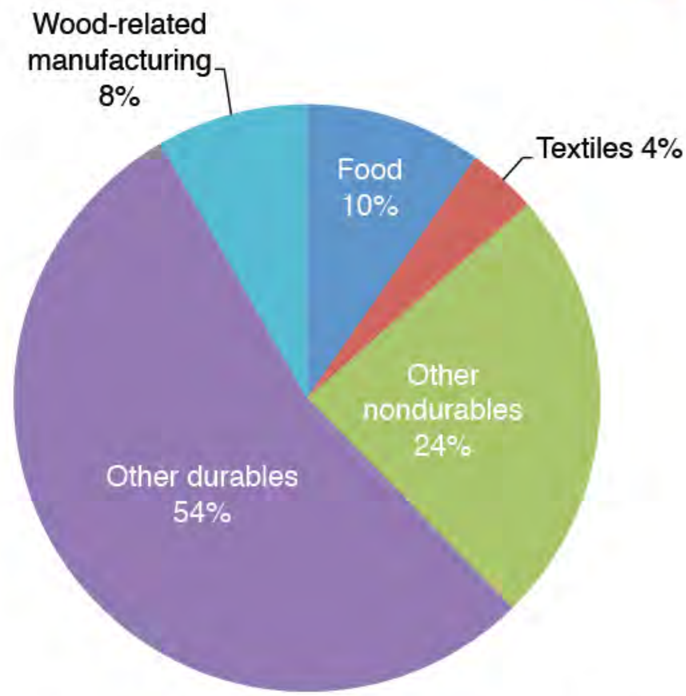


Figure 12.8—Income from employment by manufacturing sector in the South, 2008.

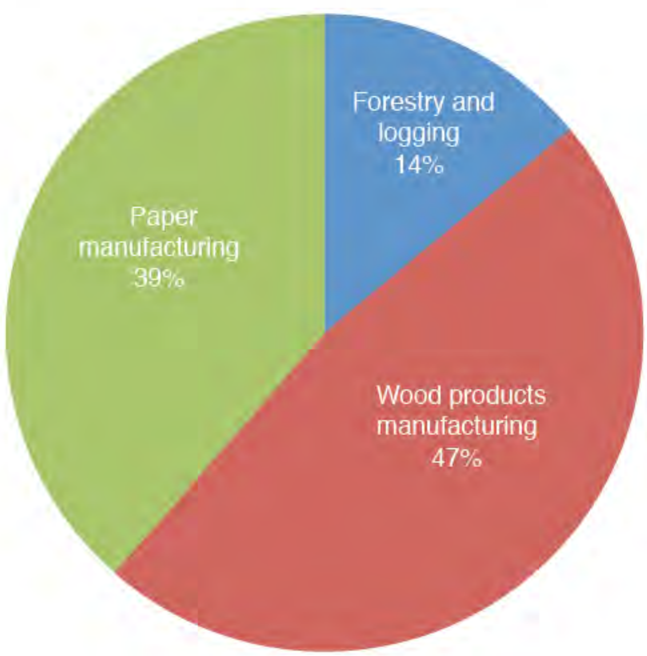


Figure 12.9—Employment by wood-related sector in the South, 2008.

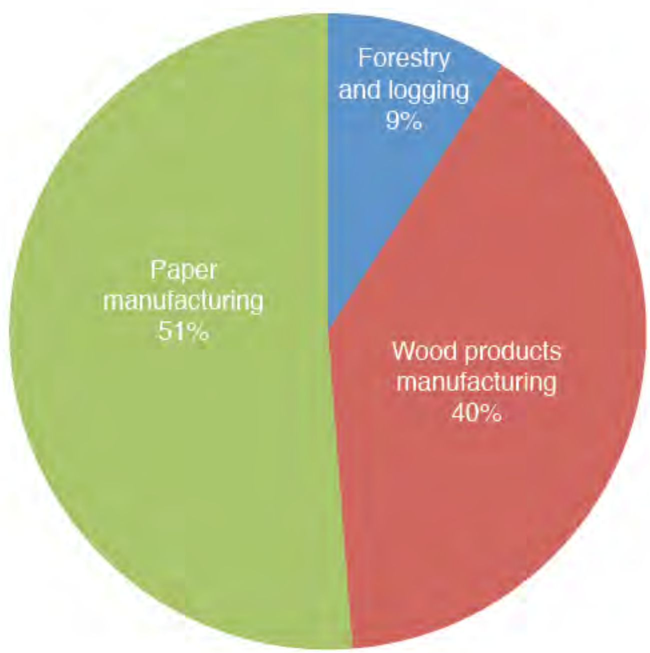


Figure 12.10—Income from employment income by wood-related sector in the South, 2008.

reflecting the higher wages and more full-time employment in this sector (fig. 12.10).

The direct and total contribution of the wood-related manufacturing sectors was also assessed using the IMPLAN (MicroImplan Group, Inc. 2010) input-output model. The thirteen Southern States were aggregated, and then the forestry and logging, wood products manufacturing, and paper manufacturing sectors were aggregated. Table 12.1 shows the direct contributions of these sectors to southern employment, employee compensation, wage and salary income, total value added, and total industry output in 2009. Table 12.2 shows the total contribution of wood-related manufacturing, which is the sum of the direct contribution plus the multiplier effects, for each sector. For details about the calculation of these results, see Abt and others (2002). Using the IMPLAN data, which is derived from different sources than the BEA data, we found that the direct contribution of the wood-related manufacturing sectors was between 0.6 (employment) to 1.4 percent (total industry output) of the southern economy. The total contribution of these sectors ranged from 1.9 percent (employment) to 2.8 percent (total industry output), with the total contribution to employee compensation and total value added in between.

The U.S. travel and tourism sector has increased since 1990 (fig. 12.11) (Griffith and Zermanek 2009, Kern and Kocis 2007). However, because a comparable analysis has not been done for the South alone, and because forest-based recreation comprises only a portion of the total travel and tourism sector, we cannot determine precisely what portion of jobs and income in the tourism-related sectors can be attributed to southern forest-based recreation.

Logging

Concerns over a shortage of loggers have been voiced in the South for more than 50 years (Pikl 1960, Wollf and Nolley 1977). More recently, surveys of loggers indicate increases in average age, a reluctance to encourage children to enter the field, and increasing financial concerns, all of which could signal a future shortage of loggers (Baker and Greene 2008; Egan and Taggart 2004a, 2004b; Egan and Taggert 2007; Luppold and others 1998). At the same time, increasing mechanization could lead to reduced need for loggers as more of the work is accomplished by machinery.

Past surveys have indicated that insurance was a primary concern for sustainability of logging companies, but respondents to more recent surveys reported that fuel prices and timber prices are more critical today (Baker and Greene 2008, Moldenhauer and Bolding 2009). Issues that were not reported as significant barriers to sustainability include taxes and regulations (Baker and Greene 2008) and tract size and development (Egan and others 2007, Moldenhauer and Bolding 2009).

The future is likely to bring increasing mechanization and the substitution of equipment for jobs in the logging sector. This mechanization, as well as regulations and laws, has also led to increased safety and less strenuous work, which may serve to make logging a more attractive career choice. However, many current loggers indicate that their preference for logging work is derived in part from the hard, physical nature of the work (Egan and Taggart 2004a, 2004b); making the work safer and easier might lead to fewer (or different) new entrants into the field.

Although current loggers report that wages are low, they do not view wage increases as a priority. However, economic theory would imply that an increase in wages would result in an increase in numbers of loggers. Even so, the risky nature of both the work and the business may prevent a sufficient number of workers from choosing logging as a profession. If shortages do occur, other market solutions are expected; for example, arrangements could be made between wood-using companies and loggers that could include long-term contracts, immigrant labor contracts, loans for equipment, or other solutions.

The national projection shows a slight increase in the number of logging jobs and in output for the logging industry in 2018 (Woods 2009). Scaling this to the South shows increases of 2 percent in jobs and 3 percent in output for 2008 to 2018, reversing the trend from 1998 to 2008 (fig. 12.12). This increase is attributed, in part, to a slight increase in the expected use of wood for energy. Income per logging job in the South has increased and now surpasses the national average (fig. 12.13). This increase results from a combination of both increasing hourly wages and increasing hours per job (more full time employment). Beyond the projection (2018), we expect the number of logging jobs to correlate strongly with changes in harvest levels, while also continuing to respond to technical change by declining as mechanization continues to increase.

Wood Products Manufacturing

The sector is strongly linked to the housing market, and the decline in output and jobs from 1998 to 2008 (fig. 12.14) reflects the decline in housing starts during the 2007 recession (Woods 2009). As the housing market recovers, output is expected to rise by 2.2 percent through 2018, but technical change and a change in the product mix is expected to cause employment to continue declining by 8 percent (fig. 12.14). These values were downscaled from the national labor forecasts (Woods 2009) by proportioning the national trends to the South's share of total output and employment for this sector.

Table 12.1—Direct contributions of three wood-related sectors to employment, compensation, value added, and total industry output of the South in 2009, in millions of 2009 U.S. dollars and by percent of totals for the South

NAICS sector	Sector name	Employment		Employee compensation		Total value added		Total industry output	
			percent	*millions of 2009$*	*percent*	*millions of 2009$*	*percent*	*millions of 2009$*	*percent*
131	Forestry and logging	57,676	0.10	1,454	0.06	3,776	0.09	9,613	0.12
321	Wood products manufacturing	145,936	0.26	6,468	0.27	10,168	0.25	28,065	0.34
322	Paper manufacturing	143,984	0.25	11,440	0.48	23,390	0.57	79,991	0.98
	All wood-related manufacturing	347,596	0.61	19,363	0.81	37,333	0.92	117,668	1.44

Table 12.2—Total contribution of three wood-related sectors to employment, compensation, value added, and total industry output of the South in 2009, in millions of 2009 U.S. dollars and by percent of totals for the South

NAICS sector	Sector name	Employment		Employee compensation		Total value added		Total industry output	
			percent	*millions of 2009$*	*percent*	*millions of 2009$*	*percent*	*millions of 2009$*	*percent*
131	Forestry and logging	137,461	0.24	4,104	0.17	9,000	0.22	19,350	0.24
321	Wood products manufacturing	348,001	0.61	15,180	0.63	26,803	0.66	58,474	0.72
322	Paper manufacturing	591,934	1.04	31,995	1.34	63,240	1.55	152,075	1.86
	All wood-related manufacturing	1,077,396	1.89	51,279	2.14	99,044	2.43	229,900	2.82

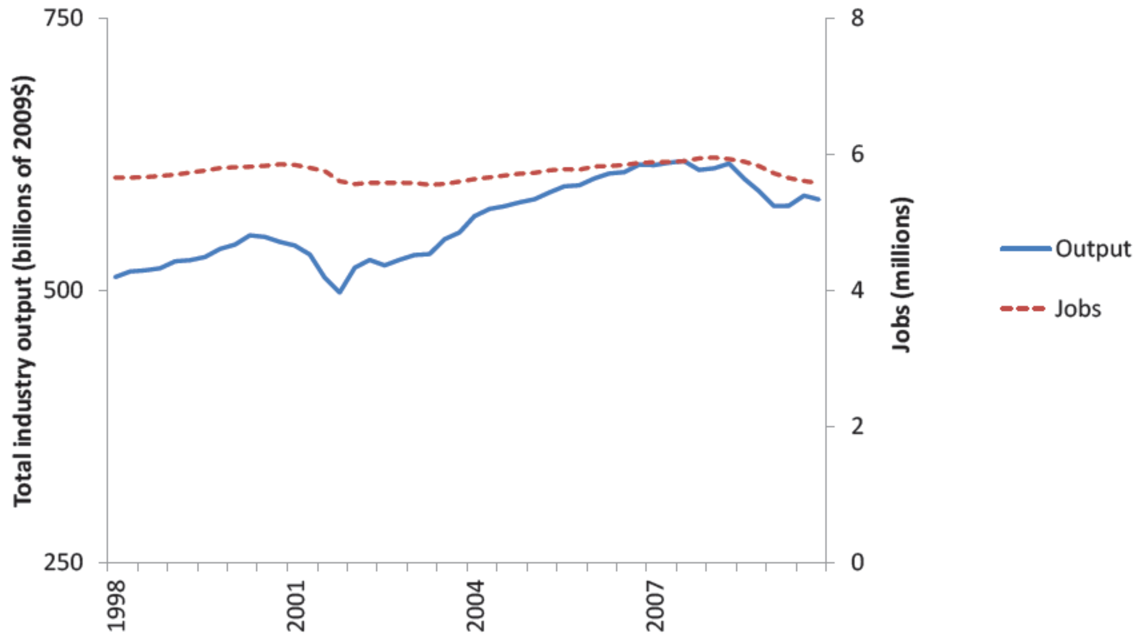


Figure 12.11—Travel and tourism total industry output and job trends, 1998 to 2009.

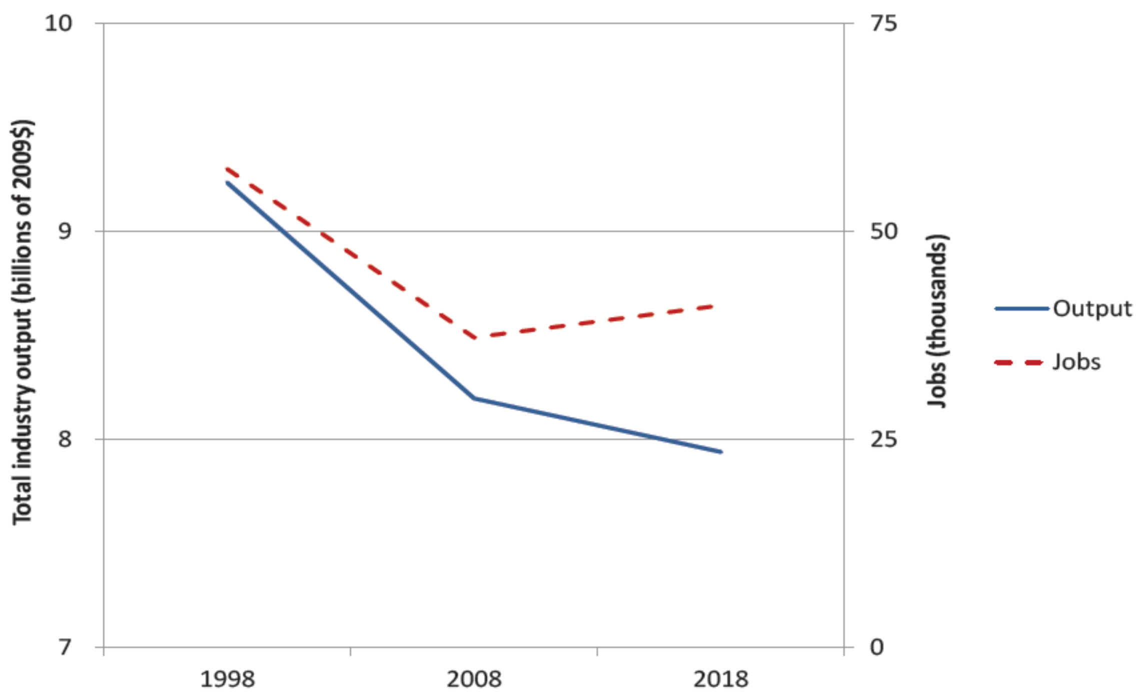


Figure 12.12—Historical (1998 and 2008) and projected (2018) jobs and total industry output for the southern logging sector.

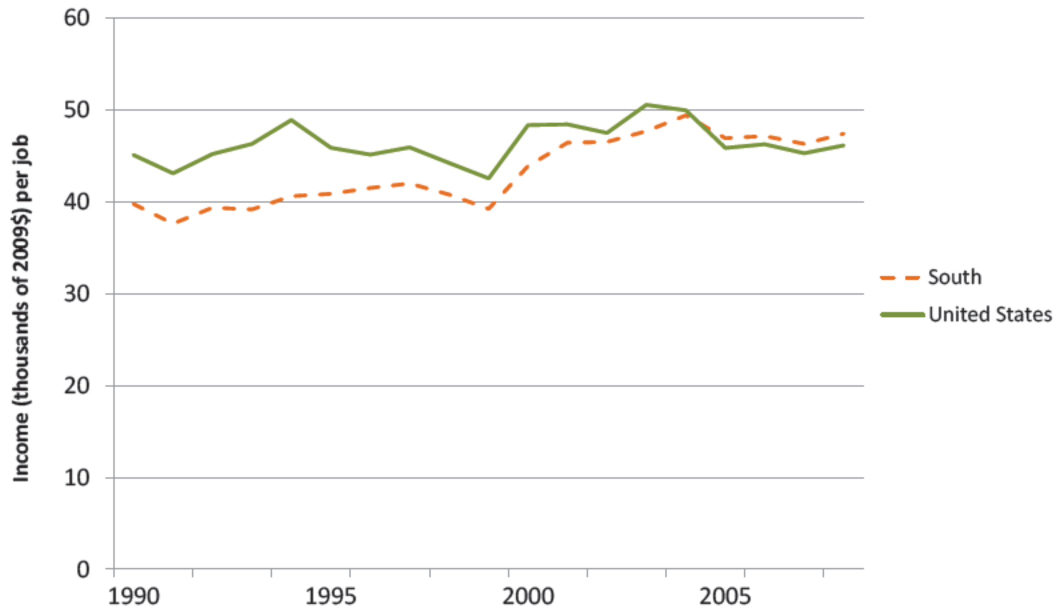


Figure 12.13—Income per logging job in 2009 dollars for the United States and the South, 1990 to 2008.

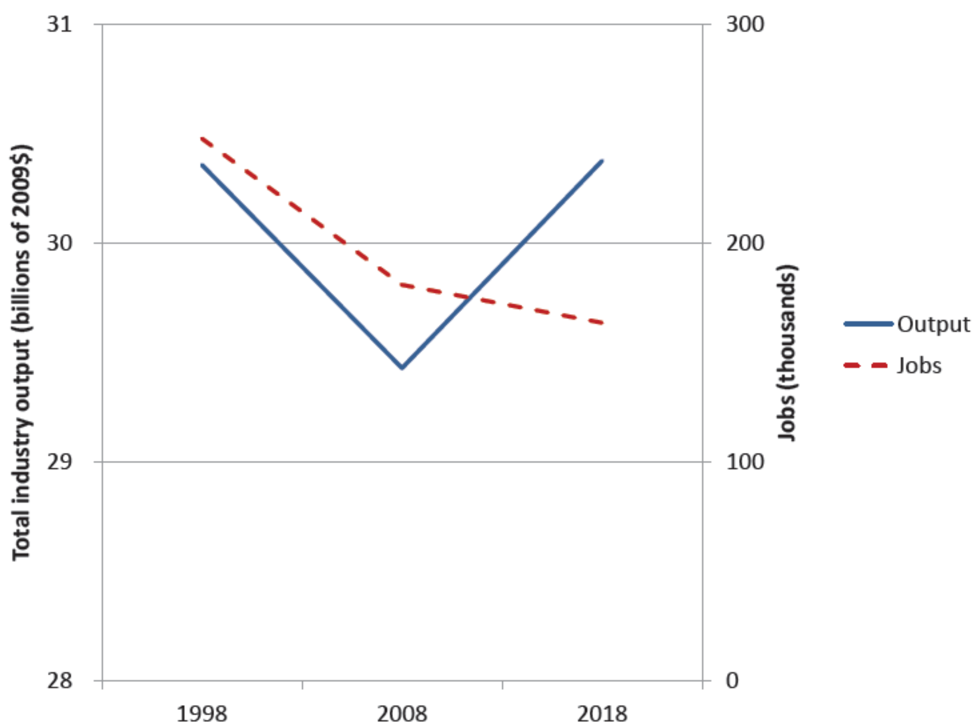


Figure 12.14—Historical (1998 and 2008) and projected (2018) jobs and total industry output for the southern wood products manufacturing sector.

The future of housing starts is critical to the level of production expected in this sector. A second influence is the level of lumber production in other U.S. regions: if the South experiences more (or fewer) mill closures than other regions as a result of the 2007–09 recession, the recovery could shift less (or more) lumber production to the South. A third influence will be the level of lumber and other wood-product imports, particularly from Canada. Large swathes of beetle-killed timber could be harvested and exported to the United States at prices below southern pine prices, thus representing competition for southern lumber. Complexities of the U.S./Canadian timber trade will influence the levels of imports and the ultimate price effects on national and southern lumber markets. These effects are beyond the scope of this study.

Thus, overall, wood products manufacturing is expected to recover to pre-recession levels in output, but employment is expected to continue to decline through 2018.

Paper Manufacturing

The paper manufacturing sector (NAICS 322) is potentially the most volatile of the traditional forest-based sectors. Changes in land ownership over the last decade, followed by the sale and/or merging of many of paper manufacturing mills and companies have changed the structure of the industry in ways not contemplated a few years ago. A further change occurred as the paper companies reduced production of fine papers, closing mills and substantially reducing hardwood pulpwood demand across the South. Overall pulping capacity declined from 1997 to 2008 (Johnson and others 2010), and additional declines are thought to have occurred since 2008 as a result of the 2007-2009 recession, although data are not yet available to confirm these declines.

Major changes could continue if the demand for wood use in bioenergy grows and if public policies support the diversion of pulpwood into renewable energy feedstocks. Increasing competition for pulpwood could result in the displacement of some current pulpwood use (Abt and others 2010). Positive impacts could result if companies are rewarded for current co-generation of power (such as tax rebates for using a pulping byproduct called black liquor to run pulpwood mills) or if opportunities arise for co-locating bioenergy producers at existing pulping facilities.

Labor forecasts for the United States show a decline of 24 percent in paper manufacturing jobs from 2008 to 2018

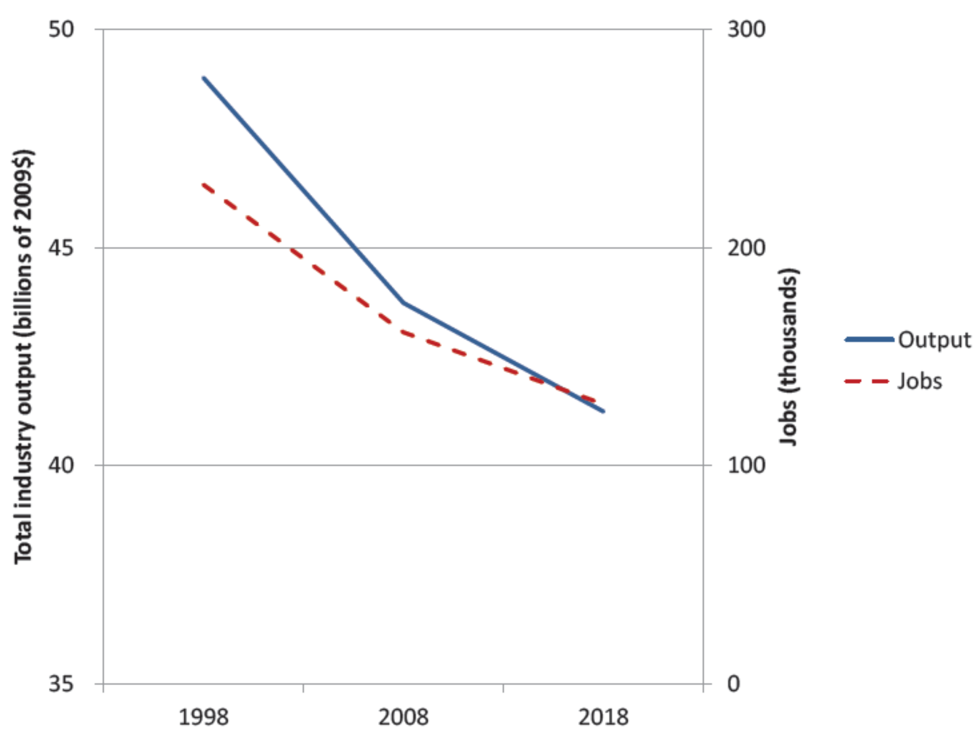


Figure 12.15—Historical (1998 and 2008) and projected (2018) jobs and total industry output for the southern paper manufacturing sector.

(Woods 2009). Any recovery from the recession is masked by overall declines in this sector. Downscaling these forecasts to the South resulted in projected declines of 26 percent in jobs and 14 percent in output (fig. 12.15). This larger decline in jobs in both the United States and the South in the paper sector represents expectations of continued technical change involving the substitution of capital for labor.

Forest-Based Recreation

Forests in the South are used for a variety of recreational opportunities, ranging from whitewater kayaking to nature study. Forest-based recreation is not recorded as a single economic sector, but is instead part of several sectors, including transportation, entertainment, accommodations, sporting goods manufacturing, and eating and drinking places. This is also true for overall travel and tourism, where expenditures are recorded in other sectors, but then consolidated and tracked nationally as a separate account (Griffith and Zemanek 2009, Kern and Kocis 2007). Forest-based recreation is expected to be only a part of this much larger travel and tourism sector.

In a separate chapter in this study, Bowker and others (2013) developed projections for forest-based recreation participation by southern residents. They concluded that per capita forest-based recreation would stay fairly constant for most activities, while declining slightly for hunting, fishing, and motorized off-road activities. This contrasts with the projections for national forests, where the per capita rate of recreation visits declines for all activities. Their chapter also shows that national forest per capita recreation visits are expected to decline more for overnight and general visits than for day use developed visits. Further, they conclude that recreation pressures are likely to increase proportionately more near urban areas. A separate study shows that expenditures per visit per party are three to four times higher for overnight visits than for day visits, and are 40 to 80 percent higher for non-local visits (Stynes and White 2006). These results, taken together, provide some, although weak, support for somewhat lower per capita expenditures on forest-based recreation in the South, resulting in forest-based recreation becoming a smaller part of total travel and tourism expenditures in the future. Expenditures, and thus output, are expected to grow, however, although below the rate of population growth, which will reduce the percentage of the economy deriving from forest-based recreation.

Alternatively, we could assume that the projected demand for forest-based recreation aligns with the demand for all travel and tourism and that the South follows the national trends. In this case, forest-based recreation total industry output in the South would increase slightly through 2018. Even this small increase in output, however, will likely not keep jobs in tourism, and thus in forest-based recreation, from rising at a rate slower than the rate of rise in output. Even the service-based sectors in travel and tourism have experienced, and are expected to continue to experience, technical change that reduces the jobs even if output were to stay the same. Franchising, low-service accommodations, self- and low-service restaurants, and central offices for management and marketing are all expected to reduce labor demand in the travel and tourism sectors (Griffith and Zemanek 2009, Woods 2009).

Bioenergy

Small amounts of wood are currently used to produce liquid transportation fuels or electricity in the South, although there is a potential for significant increases in one or both of these uses of southern wood in the near future, depending on policies and markets. In this chapter, we discuss the potential for changes in jobs and output that might result from an increase in the use of wood for energy and previous literature in this area.

Introduction of policies to reduce the amount of carbon in the atmosphere (including Federal and State renewable fuel standards and renewable electricity standards) or the imposition of a carbon tax or carbon cap-and-trade could shift production of energy to renewable sources, including wood. Thus, economic theory would imply that output and jobs in the conventional liquid fuels and conventional electricity sectors would decrease, with an offsetting increase in output and jobs in the bioenergy sectors, all other things held constant. This means that increases in the demand for non-renewable energy could lead to increases in output and jobs in the conventional liquid fuels and electricity sectors, provided that technology is held constant. If markets fail to account for the costs of carbon disposal to the atmosphere and if all other aspects of the economy are held constant, we expect that any imposition of new standards and regulations would cause an overall decrease in output and jobs in the economy (Huang 2010).

All of the studies conducted to date indicate that economic activity (including output and jobs) will increase in the logging sector. These increases are likely at the expense of jobs and output in the coal-mining sector, which is often excluded from the smaller regional analyses (English and others 2009, Faaij and others 1998, Gan and Smith 2007, Hodges and others 2010, Perez-Verdin and others 2008). Depending on the variations in wage rates and in full-time/part-time employment rates, net jobs may be increased or decreased slightly as a result of bioenergy-feedstock procurement policies. In the bioenergy sector, jobs and output are expected to increase, with a corresponding decrease in jobs and output in the conventional energy sector (Huang 2010, Hodges and others 2010, Winston 2009).

Previous studies of the conversion to bioenergy typically use either a computable general equilibrium model or an input-output model to evaluate the impacts on jobs and output. Input-output models are simple and rich in data, providing a snapshot of the economy and clearly illuminating the linkages among sectors in the system. Computable general equilibrium models, often using the data developed for the input-output models, are more complex and can provide either a snapshot or a dynamic view of the economy. Although they have the advantage of allowing input substitution to adjust over time, their complexity often makes explaining results and outcomes difficult.

In the development of input-output and computable general equilibrium models, the designation of the regions of importance has a significant effect on outcomes: the smaller the region the greater the likelihood of excluding areas where losses would occur, while including areas where gains would occur. Input-output models may also overstate impacts because dynamic adjustment is not part of the modeling framework. English and others (2009), Faaij and others (1998), Gan and Smith (2007), and Perez-Verdin and others (2008) all conducted studies in States, regions, or countries without coal, and thus do not address the negative effects on coal mining. Many of these studies also fail to account for the negative effects of bioenergy production on the conventional electricity sector. Only English and others (2009) address the negative effects that a utility rate increase would have on households. Forecasts of increased economic activity from the conversion to bioenergy result from some or all of the following: (1) large multiplier effects from increases in bioenergy feedstock production, as well as increases in power and fuel production; (2) smaller multiplier effects from costs to households; (3) analysis of small regions that may not fully capture effects on sectors such as coal mining; and (4) excluding the coal feedstock, conventional power and fuel sectors. The incomplete nature of these analyses limits their usefulness in evaluating economy-wide effects of a conversion to bioenergy or indeed, any renewable energy, from conventional energy.

Computable general equilibrium models typically include the effects on households (increasing utility and fuel costs), conventional energy providers, wood-products companies (increasing wood costs), and bioenergy providers (Hodges and others 2010, Huang 2010, Winston 2009). These studies predict losses to conventional energy providers and households, gains to bioenergy providers, and varying effects on the wood-products sector. One reason for the discrepancy in the wood-products predictions may be Huang's (2010) assumption of a large increase in biofuels, which may exceed the model's ability to correctly represent the sectors. Huang provides no explanation for the counterintuitive results that sawmill output and jobs increase when cellulosic ethanol production increases, or that jobs decrease and output increases for woody electricity with implementation of the bioelectricity policies. Hodges and others (2010) show small increases in economic activity while Huang shows small decreases. As these studies use the same model and data, one possible explanation for discrepancies is the geographic scale of their analyses as Huang analyzes the southeast while Hodges and others analyze only Florida.

The most complete studies, Hodges and others (2010) and Huang (2010), indicate small future changes overall (reductions in conventional sectors and increases in the bioenergy sector) with the changes occurring in the power sectors. For the South, economic theory would imply an increase in logging jobs and output, which may be offset at larger regional and national levels by declines in coal production and transport but would nonetheless provide increases in local jobs and income. Depending on the specific policies implemented, competition for wood between traditional wood-using companies and bioenergy companies may increase wood costs and thus decrease jobs and output in the traditional sectors, although these changes will likely be masked by larger structural changes in the wood products and paper manufacturing sectors. Finally, a shift to bioenergy on a large scale would require the construction of facilities with accompanying growth, albeit temporary, in jobs and income. It is unclear how much of this construction will substitute for decreases in construction and/or maintenance of conventional energy facilities.

DISCUSSION AND CONCLUSIONS

The future of forest-related jobs and income in the South is uncertain. Forecasting is complicated by large recent changes in these sectors, combined with the effects of the 2007–09 recession and the potential for bioenergy. The logging sector is expected to respond to changes in the demand for timber products at paper mills, sawmills, and bioenergy plants. Unknowns include how the evolution to a more highly mechanized and less family-firm oriented sector will affect timber production. Shortages of workers have been noted in Maine, although contract loggers from Canada have readily filled the void. Concern is frequently voiced, but shortages have not been documented.

The wood products manufacturing sector, which includes sawmills, is expected to recover to pre-recession levels of output, although jobs per unit of output is likely to continue to decline due to technical change, which will influence overall sector employment. Beyond the next decade, we do not know precisely how wood will continue to be used in housing, or how technical change will affect the production process.

The paper manufacturing sector is expected to continue to contract slightly, even after recovering from the recession. A reduction in fine paper production in the South and declining overall demand for virgin paper are likely to reduce output. And continued technical change is likely to further reduce employment in this sector over the next decade.

Future changes in jobs, income, and output deriving from forest-based recreation in the South will depend on changes in the demand for recreation and the level of technical change in the service sector. Recreation demand is a positive function of population and income, so increases in these factors would be expected to lead to increases in jobs and income in the sectors that provide recreation services. However, it is likely that forest-based recreation will increase at rate slower than the rate of increase in population.

Considerable uncertainty surrounds the potential for wood use in bioenergy, including the success of commercial conversion technologies for cellulosic ethanol, policy requirements for renewable energy, carbon emissions control schemes, and even the future employment and output profiles of specific activities such as co-firing and ethanol production. Under standard economic theory, implementation of policies to correct a nonmarket externality, such as unpriced carbon emissions, would be expected to lead to short-run monetary losses in an economy. By sector, an increase in wood use for bioenergy could lead to (1) increases in logging accompanied by decreases in coal mining, (2) increases in bioenergy production accompanied by decreases in conventional energy production, (3) decreases in household income because of increases in electricity and fuel costs, (4) increases in construction activity, and (5) a potential loss in traditional wood products sectors if increased demand for timber results in higher timber costs.

KNOWLEDGE AND INFORMATION GAPS

Considerable information is lacking in the literature and in the data that complicate the development of industry and employment forecasts for the forest-based sectors. The bioenergy sector is new and currently untracked in national data as a distinct sector and thus is lacking historical data. As in any developing industry, technologies and industry structures are likely to change significantly over the next decade. And this assumes the bioenergy sector does develop—there is a chance this sector will not become a major wood user. Interactions between existing sectors and this new sector are also unknown.

Assessing the future of employment and output in the forest-based recreation sector is likewise hampered by the lack of data, although this is neither a new nor developing sector. The only data available on forest-based recreation are collected by individual land management agencies. For example, the National Visitor Use Monitoring Survey conducted by the U.S. Forest Service (Stynes and White 2006), collects information on recreational activities on national forests only and a comparable study is not available for private- and State-owned forest-based recreation.

LITERATURE CITED

Abt, R.C.; Abt, K.L.; Cubbage, F.W.; Henderson, J.D. 2010. The impact of bioenergy demands on southern forests: a case study of North Carolina. Biomass and Bioenergy. 34: 1679–1686.

Abt, K.L.; Winter, S.A.; Huggett, R.J., Jr. 2002. Local economic impacts of forests. In: Wear, D.N.; Greis, J.G., eds. Southern Forest Resource Assessment. Gen. Tech Rep. SRS-53. Asheville, NC: United States Department of Agriculture, Forest Service, Southern Research Station: 239-267.

Baker, S.A.; Greene, W.D. 2008. Changes in Georgia's logging workforce, 1987-2007. Southern Journal of Applied Forestry. 32(2): 60–68.

Bowker, J.M.; Askew, A. 2012. U.S. outdoor recreation participation projections 2010 to 2060. In: Cordell, H.K., ed. Outdoor recreation trends and futures. Gen. Tech. Rep SRS-150. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 105-124.

Bowker, J.M.; Askew, A.; Cordell, H.K.; Bergstrom, J.C. 2013. Outdoor recreation. In: Wear, D.N.; Greis, J.G.; eds. The Southern Forest Futures Project: technical report. Gen. Tech. Rep. SRS-178. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 542 pp.

Egan, A.; Taggert, D. 2004a. Who will log in Maine's north woods? A cross-cultural study of occupational choice and prestige. Northern Journal of Applied Forestry. 21(4): 200–208.

Egan, A.; Taggert, D. 2004b. Who will log? Occupational choice and prestige in New England's north woods. Journal of Forestry. 102(1): 20–25.

Egan, A.; Taggart, D.; Annis, I. 2007. Effects of population pressures on wood procurement and logging opportunities in northern New England. Northern Journal of Applied Forestry. 24(2): 85–90.

English, B.; Jensen, K.; Menard, J.; De La Torre Ugarte, D. 2009. New markets and opportunities for agriculture in Colorado, Florida, Kansas, and North Carolina: an economic analysis of a Federal renewable portfolio standard. http://www.bipartisanpolicy.org/library/research/U-T-RES-Study. [Date accessed: June 25, 2011].

Faaij, A.; Meuleman, B.; Turkenburg, W. [and others]. 1998. Externalities of biomass based electricity production compared with power generation from coal in the Netherlands. Biomass and Bioenergy. 14(2): 125–147.

Gan, J.; Smith, C.T. 2007. Co-benefits of utilizing logging residues for bioenergy production: The case for east Texas, USA. Biomass and Bioenergy. 31: 623–630.

Griffith, E.S.; Zemanek, S.L. 2009. U.S. travel and tourism satellite accounts for 2005-2008. Survey of Current Business. June: 25–32.

Hodges, A.W.; Stevens, T.J.; Rahmani, M. 2010. Economic impacts of expanded woody biomass utilization on the bioenergy and forest products industries in Florida. http://www.floridaforestservice.com/forest_management/woody_biomass.html. [Date accessed: June 25, 2011].

Huang, M-Y. 2010. Regional impacts of bioenergy policies in the Southeastern United States: a computable general equilibrium analysis. Gainesville, FL: University of Florida. 134 p. Ph.D. dissertation.

Johnson, T.G.; Steppleton, C.D.; Bentley, J.W. 2010. Southern pulpwood production, 2008. Resour. Bull. SRS–165. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 42 p.

Kern, P.V.; Kocis, E.A. 2007. U.S. travel and tourism satellite accounts for 1998-2006. Survey of Current Business. June: 14–28.

Luppold, W.G.; Hassler, C.C.; Grushecky, S. 1998. An examination of West Virginia's logging industry. Forest Products Journal. 48(2): 60–64.

MicroImplan Group, Inc. 2010. IMPLAN-3, 2008 database. Stillwater, MN. www.implan.com. [Date accessed: June 25, 2011].

Moldenhauer, M.C.; Bolding, M.C. 2009. Parcelization of South Carolina's private forest land: Loggers' reactions to a growing threat. Forest Products Journal. 59(6): 37–43.

Perez-Verdin, G.; Grebner, D.L.; Munn, I.A. [and others]. 2008. Economic impacts of woody biomass utilization for bioenergy in Mississippi. Forest Products Journal. 58(11): 75–83.

Pikl, I.J. 1960. The southern woods-labor "shortage" of 1955. Southern Economic Journal. 27(1): 43–50.

Stynes, D.J.; White, E. 2006. Spending profiles for national forest recreation visitors by activity. http://www.fs.fed.us/recreation/programs/nvum/spending_profiles_2006.pdf. [Date accessed: April 1, 2011].

U.S. Department of Commerce, Bureau of Economic Analysis. 2010. Regional economic accounts. http://www.bea.gov/iTable/iTable.cfm?ReqID=70&step=1. [Date accessed: June 25, 2011].

U.S. Department of Labor, Bureau of Labor Statistics (BLS). 2010. Home page. www.bls.gov. [Date accessed: June 25, 2011].

U.S. Department of Labor, Bureau of Labor Statistics. 2011. BLS handbook of methods, Chapter 13: employment projections. http://www.bls.gov/opub/hom/pdf/homch13.pdf. [Date accessed: October 9, 2011].

Winston, R.A.P. 2009. Enhancing agriculture and energy sector analysis in CGE modeling: an overview of modifications to the USAGE model. Gen. Pap. G–180. Victoria, Australia: Monash University, Centre of Policy Studies; and Washington, DC: U.S. International Trade Commission. 37 p.

Woods, R.A. 2009. Industrial output and employment projections to 2018. Bureau of Labor Statistics Monthly Labor Review. November: 52–81.

Wollf, C.H.; Nolley, J.W. 1977. Changes in the logging labor force. Res. Pap. NE–359. Upper Darby, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 7 p.

CHAPTER 13.
Forests and Water

Graeme Lockaby, Chelsea Nagy, James M. Vose,
Chelcy R. Ford, Ge Sun, Steve McNulty,
Pete Caldwell, Erika Cohen,
and Jennifer Moore Myers[1]

KEY FINDINGS

- Forest conversion to agriculture or urban use consistently causes increased discharge, peak flow, and velocity of streams. Subregional differences in hydrologic responses to urbanization are substantial.
- Sediment, water chemistry indices, pathogens, and other substances often become more concentrated after forest conversion. If the conversion is to an urban use, the resulting additional increases in discharge and concentrations will produce even higher loads.
- Although physiographic characteristics such as slope and soil texture play key roles in hydrologic and sediment responses to land use conversion, land use (rather than physiography) is the primary driver of water chemistry responses.
- Conversion of forest land to urban uses may decrease the supply of water available for human consumption and increase potential threats to human health.
- Increases in urbanization by 2060 in the Appalachians, Piedmont, and Coastal Plain will increase imperviousness and further reduce hydrologic stability and water quality indices in the headwaters of several major river basins and in small watersheds along the Atlantic Ocean and Gulf of Mexico.
- On average, water supply model projections indicate that water stress due to the combined effects of population and land use change will increase in the South by 10 percent by 2050.
- Water stress will likely increase significantly by 2050 under all four climate change scenarios, largely because higher temperatures will result in more water loss by evapotranspiration and because of decreased precipitation in some areas.
- Approximately 5,000 miles of southern coastline are highly vulnerable to sea level rise.

INTRODUCTION

Compared to all other land uses, southern forests provide the cleanest and most stable water supplies for drinking water, recreation, power generation, aquatic habitat, and groundwater recharge (Brown and others 2008, Jackson and others 2004, Sun and others 2004). Forests are unique among land covers because they are long-lived and relatively stable. However, they are subject to substantial structural and functional alterations by management practices and/or natural disturbances, the intensity of which determines whether alterations are short or long-term. Water resources in the South are at risk of degradation from a growing population, continued conversion of forests to other land uses, and climate change. Urban and agricultural lands can impair water resources by introducing nutrients, sediment, bacteria, and other pollutants to streams. Additionally, altered hydrology—including higher peak flows, and lower baseflows and hydroperiods (Amatya and others 2006)—is common with forest conversion to other land uses. Together, these changes can modify the habitat and consequently the composition of aquatic (and riparian) communities.

Historical land use practices have dramatically changed the landscape of the South. Soil erosion and sedimentation were prevalent throughout the region during the period of agricultural expansion in the 18th and 19th centuries. Evidence can still be seen today in the sediment deposits of floodplains. This massive topsoil erosion and depleted soil productivity was followed by a period of agricultural abandonment and reforestation throughout much of the South. Today major land uses include forestry, agriculture,

[1]Graeme Lockaby is a co-lead author and Associate Dean and Professor, Auburn University School of Forestry and Wildlife Sciences, Auburn, AL 36849. Chelsea Nagy is a Graduate Research Assistant, Brown University, Department of Ecology and Evolutionary Biology, Providence, RI 02912. James M. Vose is a co-lead author and Project Leader, U.S. Department of Agriculture Forest Service, Southern Research Station, Center for Integrated Forest Science, College of Natural Resources, North Carolina State University, Raleigh, NC 27695. Chelcy R. Ford is an Ecologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory, Otto, NC 28763. Ge Sun is a Research Hydrologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Eastern Forest Environmental Threats Assessment Center, Raleigh, NC 27606. Steve McNulty is a Supervisory Ecologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Eastern Forest Environmental Threats Assessment Center, Raleigh, NC 27606. Pete Caldwell is a Research Hydrologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Eastern Forest Environmental Threats Assessment Center, Raleigh, NC 27606. Erika Cohen is a Resource Information Specialist, U.S. Department of Agriculture Forest Service, Southern Research Station, Eastern Forest Environmental Threats Assessment Center, Raleigh, NC 27606. Jennifer Moore Meyers is a Resource Information Specialist, U.S. Department of Agriculture Forest Service, Southern Research Station, Eastern Forest Environmental Threats Assessment Center, Raleigh, NC 27606.

and increasing urbanization, each of which has its own signature on water resources. Table 13.1 shows the total impervious area as a percent of the total land area for eight southern States—all indications are that the amount of impervious area is likely to increase significantly in the coming decades. Much of the increase in impervious surfaces will be derived from losses of forest land through conversion to urban land uses (chapter 4). One implication for these losses is likely to be an intensification of management activities on remaining forest lands to provide sufficient wood products from a shrinking land base (chapter 9). In addition, expanding wood-based biofuels markets may also increase management intensity and may shorten rotations, increase the use of irrigation and fertilization, and change species composition to favor fast growing species (chapter 10). This intensification and alteration of management practices could have important implications for water resources.

Table 13.1—Total impervious area for eight Southern States reported by Exum and others (2005)

	Percent land area classified as impervious				
State	**>20**	**10-20**	**5-10**	**2-5**	**<2**
Alabama	0.8	1.9	6.0	29.6	61.8
Florida	7.0	7.2	12.1	23.7	50.1
Georgia	2.4	4.0	7.9	30.1	55.7
Kentucky	0.8	2.2	7.0	40.2	49.8
Mississippi	0.1	1.2	2.9	20.5	75.2
North Carolina	1.9	5.2	11.0	38.9	43.1
South Carolina	1.7	4.0	10.1	37.7	46.7
Tennessee	1.9	3.1	6.9	37.7	50.4

Although population growth, land use change, and intensification and expansion of managed forests are the most obvious sources of impacts on southern water resources, other factors, including climate change, increasing climatic variability, and climate change induced sea level rise could have large impacts as well. For example, some climate models project more frequent El Niño-like conditions (Thomson and others 2003) resulting in more extreme rainfall events. Climate change and increased climate variability will both directly and indirectly affect water resources. Higher temperatures could decrease streamflow by increasing evapotranspiration, although this outcome may be buffered by increased annual precipitation (Oki and Kanae 2006, Sun and others 2005). Subsequently, lower streamflow decreases water supply, degrades aquatic communities, and diminishes water quality. Extreme rainfall events increase flood severities and frequencies that negatively impact human safety and welfare and the functioning of aquatic communities. Changes in hydroperiod (Ernst and Brooks 2003, Ford and Brooks 2002) that result from disturbance- and climate-induced rises in sea level (Ross and others 1994) will have significant direct effects on ecosystem processes in forested wetlands (Amatya and others 2006) and potentially devastating impacts on human welfare in urban and rural areas. For example, the Intergovernmental Panel on Climate Change fourth assessment report (AR4) estimated global mean sea-level rise between 0.28 m and 0.43 m by end of the 21st century (Parry and others 2007). Those estimates excluded dynamic ice changes such as massive movement in the Greenland ice cap. Before 1990, thermal expansion was the largest contributor to sea-level rise but since then, its importance has been eclipsed by a combination of melting glaciers, ice caps, and ice sheets (McCullen and Jabbour 2009). Since the AR4 report there have been other estimates of sea-level rise using non-dynamic modeling techniques and models that include dynamic ice changes. These models predict that sea-level may rise from 0.4 to 2.0 m by the end of the 21st century (McMullen and Jabbour 2009, Rahmsorf 2007, Solomon and others 2009).

Climate change and variability and sea level rise do not act alone to affect water resources. They interact with land use change and exacerbate the impacts on water quality and quantity. An understanding of the relationships between forest cover and water resources, and how these relationships interact with climate change and growing water demand, is critical to crafting actions that minimize the detrimental effects of land conversion now and in the future (Vose and others 2011).

The goals of this chapter are to (1) outline the surface-water consequences of forest conversion to urban and agricultural land uses and highlight differences among physiographic subregions, (2) evaluate and discuss the water-resource implications of intensifying and altering forest management practices, (3) discuss the implications of climate change, growing demand for water, and land use change on water resources, and (4) to discuss the potential impact of sea-level rise on the Southern United States.

METHODS

Literature Review and Syntheses

An extensive literature synthesis was conducted to address our research questions. We began by evaluating general relationships between forest cover and water resource, with a primary focus on water quality and quantity. Then we explored specific practices in greater detail including forest harvesting, intensification of forest management, agriculture, and urban land use. Finally, we examined studies of particular physiographic subregions to isolate and compare the geographic nature of responses to these land uses and management activities.

Regional Modeling

Water resources are influenced by many complex factors such as climate variability, land use/land cover change, groundwater availability, surface water storage, population growth, and economics (fig. 13.1). To account for these factors, we applied a water accounting model, WaSSI or Water Supply Stress Index (Sun and others 2008), to examine future changes in water stress induced by humans, biological factors, and climate.

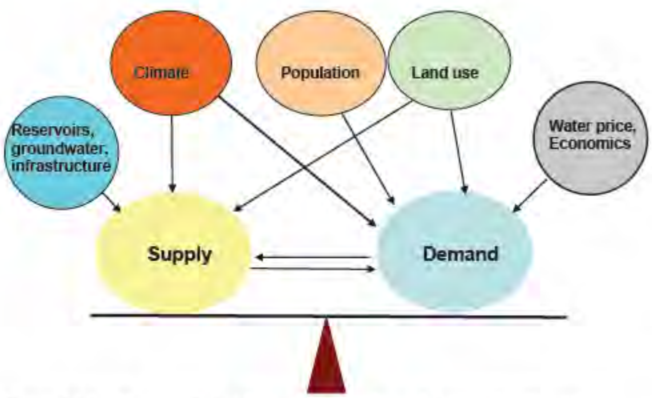


Figure 13.1—Key controls of on water supply and demand and their interactions. (Sun and others 2008)

The scale of the WaSSI model can encompass an entire system from watershed to basin or any portion thereof, depending on the research question and availability of data to examine human water use and demand. The model simulates full monthly water balance, including evapotranspiration, soil moisture content, and water yield. Within each basin, spatially explicit land cover and soil data are used to account for evapotranspiration, infiltration, soil storage, snow accumulation and melt, surface runoff, and baseflow processes; and discharge is routed through the stream network from upstream to downstream watersheds. Evapotranspiration is estimated by applying an empirical equation to multi-site eddy covariance-based evapotranspiration measurements, using MODIS derived Leaf Area Index (a measure of the amount of leaf cover), potential evapotranspiration, and precipitation as independent variables (Sun and others 2010). Estimations of infiltration, soil storage, and runoff processes are derived by integrating algorithms from the Sacramento Soil Moisture Accounting Model and STATSGO-based soil parameters (Koren and others 2003).

Water Supply Stress Index is defined as water demand divided by water supply (WaSSI=Water Demand/Water Supply). Monthly water supply was defined as the total potential water available for withdrawal from a basin including total surface water supply, groundwater supply (Kenny and others 2009), and return flow from each of seven water sector users including commercial, domestic, industrial, irrigation, livestock, mining, and thermoelectric (Solley and others 1998). Return flow rates vary among watersheds and water use sectors. For example, in the South return flow rate for the domestic use sector averages 68 percent but ranges from 1.6 to 90 percent across HUCs. Similarly, the thermoelectric sector averages 76 percent but ranges from 0.1 to 100 percent. Water demand represents the sum of all water use by each of the seven sectors and public supply or water withdrawal by public and private suppliers for use by domestic and industrial sectors. Historic annual water use values reported by USGS (Kenny and others 2009) were redistributed to each month across the South for the irrigation and domestic sectors by applying a series of monthly water use functions.

WaSSI uses the Natural Resources Conservation Watershed Boundary Dataset 8-digit Hydrologic Unit Code (HUC) watershed as the working scale (NRCS 2009). There are approximately 2,100 8-digit HUC watersheds in the lower 48 States, 674 of which are in the South.

The databases required for WaSSI include historic water use and return flow rates by water use sectors, groundwater withdrawal, historic and projected climate, population, and land use and other remote sensing products such as leaf area index. Because these databases had different temporal and spatial scales, conversion to the 8-digit HUC watershed level was necessary before scenarios could be developed to individually and collectively quantify the impacts of climate, land use, and population changes on water supply and demand (table 13.2).

DATA SOURCES

Regional Modeling Databases

Historic water withdrawals and use—The 2005 National Anthropogenic Water Use Survey datasets published by the U.S. Geologic Survey were used to determine historic water demand (Kenny and others 2009). Return flows from each water use sector came from the 1995 U.S. Geologic Survey water use survey dataset (Solley and others 1998), the most recent water use dataset to include return flow information. The U.S. Geologic Survey grouped national water users into one of seven categories: domestic (1.1 percent), industrial (5 percent), irrigation (37 percent), livestock (0.6 percent), mining (41 percent), thermoelectric (0.7 percent), and aquaculture (3 percent). For the purposes

Table 13.2—Scenarios for water supply stress index simulations (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand), based on inputs from historic and projected estimations of population, land use, and climate

Scenerio name	Annual WaSSI averaging period	Population scenario	Land use input[a]	Climate input
Historic climate, land use, and population	1995 to 2005	2000	1997	NCAR[b] 1960 to 2007
Historic climate and land use; future population	1995 to 2005	2050	1997	NCAR 1960 to 2007
Historic climate and population; future land use	1995 to 2005	2000	2050	NCAR 1960 to 2007
Historic climate; future population and land use	1995 to 2005	2050	2050	NCAR 1960 to 2007
Csiromk35a1b climate; historic population and land use	2045 to 2055	2000	1997	csiromk35a1b
Miroc32a1b climate; historic population and land use	2045 to 2055	2000	1997	miroc32a1b
Csiromk2b2 climate; historic population and land use	2045 to 2055	2000	1997	csiromk2b2
Hadcm3b2 climate; historic population and land use	2045 to 2055	2000	1997	hadcm3b2
Csiromk35a1b climate; future population and land use	2045 to 2055	2050	2050	csiromk35a1b
Miroc32a1b climate; future population and land use	2045 to 2055	2050	2050	miroc32a1b
Csiromk2b2 climate; future population and land use	2045 to 2055	2050	2050	csiromk2b2
Hadcm3b2 climate; future population and land use	2045 to 2055	2050	2050	hadcm3b2

[a] See chapter 4.
[b] National Center for Atmospheric Research in Boulder, CO.

of this analysis of southern water use, an eighth category, public supply, was added to represent the water withdrawal by public and private utilities for general distribution to domestic and industrial sectors (12 percent of total freshwater). In contrast to national usage, thermoelectric water withdrawal dominates (54 percent) in the South, followed by irrigation centered in the Mississippi valley and western Texas. However, return flow rates from power plants are typically high (> 90 percent), because water is returned to the ecosystem shortly after being withdrawn, thus making irrigation the largest consumptive user (47 percent) followed by public supply (34 percent) and thermoelectric (10 percent). Over half of the water withdrawn is from groundwater in the Mississippi valley, western Texas, and the coastal plain.

Climate data—The full climate data cover the 48 conterminous States at a county scale and range from 1950 to 2099. For this analysis, hydrologic simulations were conducted through 2050 for the Southern States defined by the Futures Project ecoregions. Data included monthly air temperature and precipitation as predicted by three General Circulation Models (Hadley Centre for Climate Prediction and Research UKMO-HadCM3, Australian Commonwealth Scientific and Research Organization Atmospheric Research CSIRO-Mk2.0 and CSIRO-Mk3.5, and the Center for Climate System Research (The University of Tokyo) National Institute for Environmental Studies and Frontier Research Center for Global Change MIROC3.2) and under two Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES A1B and B2). The county climate data were scaled to the 8-digit HUC watersheds, and the WaSSI modeling effort used the following climate change and emissions scenarios: CSIROMK35A1B, MIROC32A1B, CSIROMK2B2, and

HadCM3B2. It should be noted that climate models are often calibrated to best address climate within a specific geographic region (e.g., MIROC32A1B was specifically developed for Japan). The application of any general circulation model (GCM) will not be universally reliable (i.e., accurately able to predict future climate). In this study the MIROC32A1B predicts climatic conditions for the Southern United States that are extreme for most parts of the globe. Other models could be considered more moderate in their predictions of future climate. The results of all for model predictions are presented in this chapter but further discussion of the GCM can be found in chapter 3.

Population and land use change data—The U.S. Census Bureau (2001) records indicate that population increased about 30 percent from 1980 to 2000. Population projections at the census block level were aggregated to the 8-digit HUC watershed scale for each year from 1967 to 2050 (NPA Data Services Inc. 1999). For the WaSSI model simulation, we selected the land use data (chapter 4) belonging to Cornerstone A (Intergovernmental Panel on Climate Change storyline A1B, level crop prices, high timber prices). For model simulations, the land use classes described in chapter 4 were grouped into eight categories as: crop, deciduous forest, evergreen forest, mixed forest, grassland, shrub land, savanna, and water/urban/barren. In addition, the land use data were rescaled from the county to the 8-digit HUC watershed for model input. The representative year was 2000 for historic baseline model simulations, and 2050 was selected for future model simulations.

Sea Level Rise

We used the analysis of Titus and Richman (2001) to identify land area 1.5 m, 1.5 to 3.5 m, and >3.5 m above sea level and generated 66 maps (based on 1-degree digital elevation models) to outline coastal areas on the Gulf of Mexico and the southern Atlantic States from Virginia to Florida. The vulnerability of coastal regions (coastal vulnerability index, or CVI) was calculated using the analyses of Hammar-Klose and Thieler (2001), who incorporated geomorphology, coastal slope, rate of relative sea-level rise (mm yr^{-1}), shoreline erosion and accretion rates (m yr^{-1}), mean tidal range (m), and mean wave height (m) into calculations of CVI for the Atlantic, Pacific, and Gulf of Mexico coasts. A ranking was applied to each variable for ~5 km segments (or 3 minutes) of coastline and then combined to form an index of risk using the following equation:

$$CVI = \sqrt{\left(\frac{a*b*c*d*e*f}{6}\right)}$$

Where *a* is geomorphology, *b* is coastal slope, *c* is relative sea-level rise, *d* is shoreline erosion/accretion rate, *e* is mean tide range, and *f* is mean wave height, and the final *CVI* was broken into to four risk categories: low (<8.7), moderate (8.7 to 15.6), high (15.6 to 20.0), and very high (>20.0).

Data sources used to calculate CVI included state geologic maps and 1:250,000-scale topographic maps to determine geomorphology; a combination of U.S. Navy ETOPO5 and National Geophysical Data Center digital topographic and bathymetric elevation databases to determine coastal slope; National Ocean Service data to determine relative sea-level rise and mean tidal range; a combination of the May and others (1982) Coastal Erosion Information System dataset and more recent State and local regional studies to estimate shoreline erosion and accretion rates; and the U.S. Army Corps of Engineers Wave Information Study to estimate mean wave height (Hammar-Klose and Thieler 2001). After all data were compiled and rescaled to a 5 km grid, each variable was ranked from 1 (very low vulnerability to sea level rise) to 5 (very high vulnerability to sea level rise).

RESULTS

Physical Environment of the Southern Region

The southern climate is predominantly humid subtropical; however, the western most areas, such as Texas and Oklahoma, are semi-arid. The average annual temperature range is 15 to 21 °C and the precipitation range is 1010 to 1520 mm yr^{-1} (Bailey 1980). Ultisols, the predominant soil order of the South, are strongly leached and nutrient poor with a subsurface accumulation of clay (Bailey 1980, USDA Natural Resource Conservation Service 2009). The relief is mostly level along much of the Atlantic and Gulf of Mexico, however, the upper Coastal Plain of Alabama and Mississippi is moderately to gently rolling (Martin and Boyce 1993). Coastal Plain soils are sandy. The Piedmont has gently rolling to steep terrain with clayey surface and subsurface soils. Consequently, the potential for erosion is high throughout the Piedmont and even higher toward the Blue Ridge subregion of the Southern Appalachians (Trimble 2008). The Southern Appalachians have steep topography and elevation ranges from 225 to 900 m. The three major river basins of the South are the Mobile, Tennessee, and Cumberland (World Wildlife Fund 2010). Southern streams support a diversity of freshwater species and are thus a high conservation priority (World Wildlife Fund 2010). Physiographic subregions, and the landscape components of watersheds within them, are connected through the flow of energy and materials, the movement of species, and the movement of insects, disease, and other disturbance agents. Unlike many of the exchanges, the movement of water across most of the South is fairly predictable because water follows hydrologic flowpaths that are primarily driven by elevation gradients. Exceptions occur in the lower Coastal Plain and other systems where hydrology is dominated by groundwater hydrology. Understanding how changing landscapes will alter the quantity, quality, and value of surface water and groundwater requires analyses at expanding spatial scales to examine how rapid urbanization affects forest practices such as cutting, road building, and drainage.

Functions of Forested Wetlands and Riparian Forests

Forested wetlands can be described by hydrogeomorphic considerations such as landscape position, water source, and hydrodynamics are dominant process regulators (Ainslie 2002). The three most common classes of southern forested wetlands are riverine, depressional, and flat with mineral or organic soil (table 13.3). In general, forests and hydrological cycles are connected through the processes of evapotranspiration (Amatya and others 2008). Hydrological functions of southern forested wetlands may include flood mitigation or short-term surface water storage; and to a lesser extent than forested wetlands in other regions of the United States, they abate storms and recharge groundwater (National Research Council 1995, Walbridge 1993). Biogeochemical functions of wetlands, including cycling of elements and retention and removal of dissolved substances, serve to improve surface, subsurface, and ground water quality (Blevins 2004, National Research Council 1995). Regardless of type, all forested wetlands contribute to food web maintenance by providing habitat for plants and animals (Faulkner 2004, Walbridge 1993). Some forested wetlands may provide unique functions based on their distinctive characteristics and structure. For example, Carolina Bays may contain rare and endangered plants and also provide desirable breeding sites and habitat for birds and wildlife (Ainslie 2002). And mineral soil flats can have very high herbaceous species richness in part because of their unique fire regime (Ainslie 2002).

Riparian forests also provide hydrological, biogeochemical, and habitat functions. Many studies have shown that riparian forests help to stabilize stream banks and trap pollutants such as sediment, nutrients, bacteria, fertilizers, and pesticides from runoff (Anderson and Masters 1992, Binkley and Brown 1993, de la Crétaz and Barten 2007, Klapproth and Johnson 2000, Naiman and others 2005, USDA National Agroforestry Center 2008, Vellidis 1999). In particular, Naiman and others 2005 found that "The hydraulic connectivity of riparian zones with streams and uplands, coupled with enhanced internal biogeochemical processing and plant uptake, make riparian zones effective buffers against high levels of dissolved nutrients from uplands and streams, while geomorphology and plant structure make them effective at trapping sediments." However, an intact riparian corridor does not ensure stream protection as this relationship is dependent on other factors including residence time of pollutants in the buffer, depth and variation of water table, upland land use practices, climate, and watershed characteristics such as topography, hydrology, soils, and vegetation (de la Crétaz and Barten 2007, Groffman and others 2003, Tomer and others 2005, Walsh and others 2005).

Habitat functions provided by riparian forests include lower water temperatures for aquatic animals due to shading from trees, along with shelter for birds and wildlife (Anderson and Masters 1992, Binkley and Brown 1993, Naiman and others 2005, Vellidis 1999). Riparia are sources of large woody debris, which creates habitat heterogeneity, acts as a substrate for colonization, and provides nutrients to the aquatic (and

Table 13.3—Southern wetland types and characteristics

Wetland type	Characteristics	Sources
Riverine (bottomland hardwood wetlands)	Occurring in floodplains or riparian corridors	Ainslie 2002, Brinson 1993, Palmer 1994, Childers and Gosselink 1990, National Research Council 1995, Naiman and others 2005, Walbridge 1993, Meyer 1992, Dennis 1988
	Many connections between wetland and stream channel (overbank flow and subsurface connections)	
	Including cypress stands, sloughs, and hardwood swamps associated with brown-, black-, and red-water streams in Atlantic and Gulf Coastal Plains	
Depressional	Named for their depressional topography which promotes surface water accumulation	Ainslie 2002, Brinson 1993, Duryea and Hermansen 1997, Dennis 1988
	Cypress trees predominant	
	Including cypress domes (Gulf Coastal Plain) and Carolina bays (Atlantic Coastal Plain)	
Wet flats	Can have either organic soils (pocosins) on plateaus or mineral soils in the Atlantic Coastal Plain between rivers or floodplain terraces	Ainslie 2002, Brinson 1993, Gresham 1989
	Pocosins characterized by dense evergreen shrub vegetation	
	Mineral flats characterized by a closed canopy of hardwoods or an open savannah with some pines	

riparian) community (Naiman and others 2005). Inputs of organic matter from riparian forests supply an allochthonous energy source to stream ecosystems, thereby linking the riparian and aquatic foodwebs. Additionally, if Best Management Practices are implemented appropriately, riparian forests can also provide wood products, pasture for livestock, and recreational opportunities (Anderson and Masters 1992).

Hydrologic Effects of Forest Conversion to Other Land Uses

Harvesting forests reduces evapotranspiration and infiltration; creating impervious surfaces increases overland flow (Paul and Meyer 2001). Similarly, forest conversion to agricultural land may compact soils, reduce evapotranspiration and infiltration, and increase overland flow. Regardless of post-harvesting use, characteristic changes in hydrology following forest removal include greater streamflow and peak flows (Bosch and Hewlett 1982, Crim 2007, de la Crétaz and Barten 2007, Hibbert 1967, McMahon and others 2003, Schoonover and others 2006). Representative hydrographs for typical forested, agricultural, and urban watersheds are shown in figures 13.2 to 13.4. A study of the 13 Southern States showed that streamflow increased by 69 to 210 mm yr^{-1} following forest harvesting (Grace 2005). Stednick (1996) found that a 20 percent change in forest cover produces a quantifiable change in water yield in the Appalachians, but that the threshold is about 25 percent higher for the Piedmont and Coastal Plain. Since the 1970s in Houston, impervious surfaces were responsible for 32 percent of the 159 percent increase in peak flows, and 77 percent of the 146 percent increase in annual runoff (Olivera and DeFee 2007). Similarly since the 1960s in the White Rock Creek watershed of northeastern Texas, peak flows increased by 20 to 118 percent with varying precipitation intensities in response to dramatic increases in impervious cover (Vicars-Groening and Williams 2007). Stream hydrographs of urban watersheds reflect a flashy hydrology with greater pulses and faster attainment of peak flows during storm events (Beighley and others 2003, Boggs and Sun 2011, Calhoun and others 2003, Crim 2007, Schoonover and others 2006). However, as arid regions naturally have flashy hydrology due to inherent precipitation regimes, urban effects may be obscured on the hydrographs of streams in those parts of the South (Grimm and others 2004). Flow-duration curves also depict changes in hydrology by displaying the percentage of time streamflow equals or exceeds a particular value. The pre-urbanization flow duration curve exhibits more gradual variations while the post-urbanization curve is much steeper (fig. 13.5).

In urban and agricultural watersheds, decreased infiltration produces less groundwater recharge, possibly reducing baseflows (Calhoun and others 2003, Rose and Peters 2001, Wang and others 2001). As an example, in tributaries of

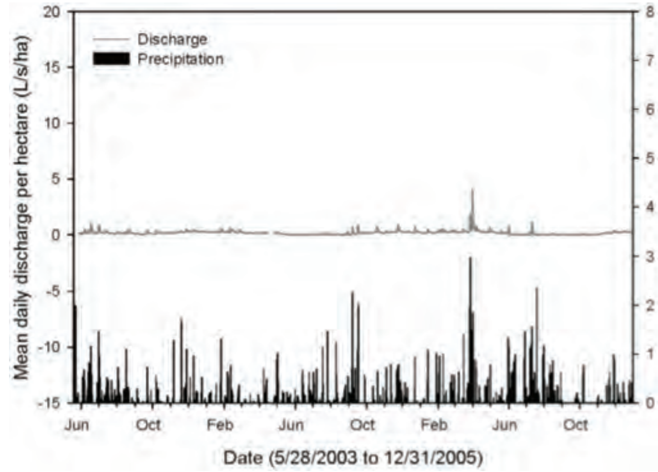


Figure 13.2—Representative hydrograph of a forested watershed (Crim 2007). Discharge units are liters per second per ha.

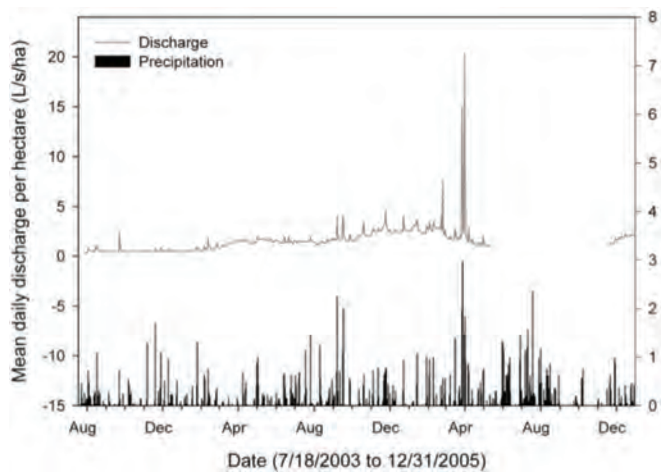


Figure 13.3—Representative hydrograph of a pastoral watershed (Crim 2007). Discharge units are liters per second per ha.

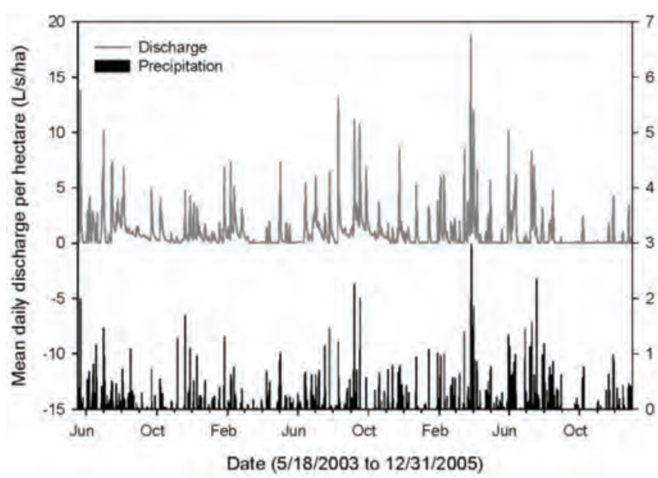


Figure 13.4—Representative hydrograph of an urban watershed (Crim 2007). Discharge units are liters per second per ha.

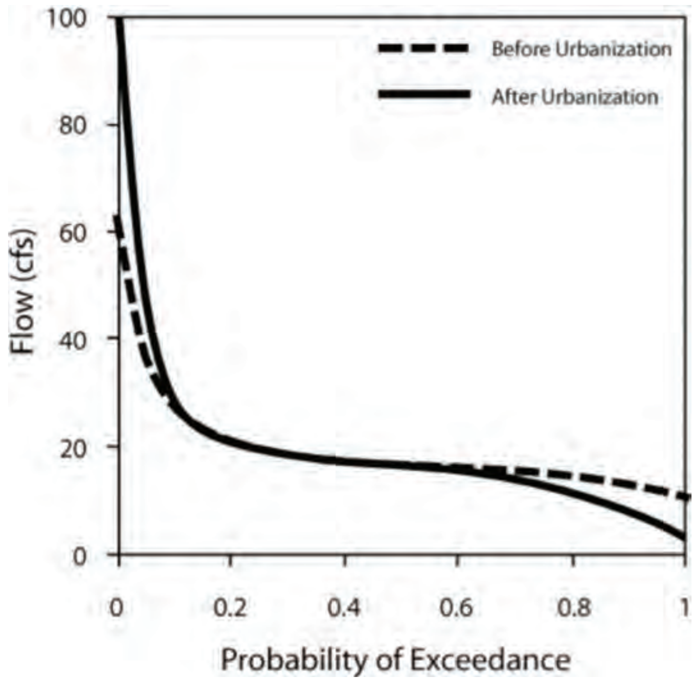


Figure 13.5—Stream flow-duration curves in cubic feet per second before and after urbanization. (Source: L. Kalin, unpublished data; Auburn University, School of Forestry and Wildlife Sciences, Auburn, AL, 36849; latif@auburn.edu)

the upper Chattahoochee River, Calhoun and others (2003) estimated that every 1 percent increase in impervious surface reduces baseflow by 2 percent. However, this is not always the case as illustrated by the lack of baseflow response to increases in impervious surface in the Florida Panhandle (Nagy and others 2012); and by higher median baseflow in pastoral watersheds compared to forested watersheds in the Georgia Piedmont (Schoonover and others 2006). The less responsive baseflow in the Coastal Plain may be explained by differences between the extent of surface water and baseflow recharge zones in very flat terrains where baseflow zones may extend beyond surface catchment boundaries. In the case of the pastoral vs. forested watersheds in the Piedmont, apparently reduced ET and adequate surface infiltration rates in the pastures accounted for the higher baseflows there.

Although historically the South has not experienced a great deficiency of water supply compared to other regions in the United States, with continued forest loss and expanding urbanization, water supply may become a more pressing issue in this region. When modeling land use effects only, Sun and others (2008) predicted reduced water deficits due to increased water yield following conversion of forest to urban land uses. However, they found that water resources would likely be under greater pressure in the future when the effects of climate change and population growth are also taken into account. Additionally, it should be noted that despite increased streamflow following forest removal, available surface water might decline due to unstable flow regimes. After increasing withdrawal rates from Alabama streams near Birmingham, surface water available for human use ranged from about 20 to 45 percent of discharge for urban watersheds and 20 to 60 percent for forested watersheds; and at higher withdrawal rates water availability was significantly higher in forested than urban watersheds.[2] Therefore, although total water yield is often reduced in forested watersheds compared to urban watersheds, forested watersheds may have a greater percentage of water available for use, suggesting that increasing urbanization contributes to greater stress. Lastly, degradation of water quality from point- and non-point source pollution can also reduce the amount of available water (Sun and others 2008).

Effects of Forest Conversion on Sediment

Forests stabilize soils (Jackson and others 2004); therefore soil is more readily eroded following removal of vegetation, and is transported as sediment into floodplains and other areas of lower topography (Jackson and others 2005a, Trimble 2008) and/or directly into stream channels. The effects of historical agricultural use, in particular row-crop agriculture, on soil erosion and subsequent sediment deposition throughout the South were profound (Casarim 2009, Jackson and others 2005a, Trimble 2008). For example, in the Georgia Piedmont, sediment deposition from historical agriculture was as much as 1.6 m in the Murder Creek floodplain (Jackson and others 2005a) and averaged 1.8 m in Bonham Creek and Sally Branch watersheds (Casarim 2009). It can be difficult to differentiate sediment contributions from current land use versus historical agricultural use within a watershed because the legacy effects of historical land use can be observed decades later. Jackson and others (2005a) estimated that 25 to 30 percent of the sediment load of Murder Creek consisted of re-suspended legacy sediment. This means that land use conversions in the Piedmont have the potential to re-suspend legacy sediment that accumulated in the stream beds decades ago in addition to generating sediment export from terrestrial sources.

The combined effects of altered hydrology, removal of vegetation, and an increase in impervious surface often cause urban watersheds to exhibit stream sediment concentrations much higher than forested watersheds (Clinton and Vose 2006, Lenat and Crawford 1994, Schoonover and others 2005). In the Southern Appalachians, total suspended solids concentrations were 4 to 5 times greater in an urban

[2]L. Kalin, unpublished data; Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Dr., Auburn, Alabama, 36849; kalinla@auburn.edu.

compared to a reference stream (Clinton and Vose 2006). In the Georgia Piedmont, total dissolved solids concentrations were twice as high in urban streams compared to forested streams (Crim 2007, Schoonover and others 2005), but total suspended solids did not increase significantly under urban cover. In the Coastal Plain, Wahl and others (1997) found a twofold increase in total suspended solids in urban compared to forested streams (up to 200 mg/L during stormflow in the urban stream). Erosion associated with urban land uses can be particularly high at construction sites and areas of new development (Novotny 2003, Paul and Meyer 2001). For example 100- to 10,000-fold increases over nondeveloped conditions were reported by Paul and Meyer (2001), especially in areas with greater topographic variation such as the Southern Appalachians.

Effects of Forest Conversion on Water Chemistry

Undisturbed forested watersheds are generally associated with low stream-water concentrations of most ions. Since most forests are deficient in one or more elements, forested systems are generally effective in retaining inputs of nutrients. Consequently, net export of macronutrients, or nutrients required in large quantities such as N, P, and K, from undisturbed forested catchments is often negative, indicating an accretion of forest biomass (Likens and Bormann 1995, Swank and Douglass 1977). As an example, the 3600 ha Table Rock Reservoir watershed in the Southern Appalachians of South Carolina has been highly restricted in terms of any human activity since 1930, and water quality there remains unchanged since that time.[3]

Increased nutrient concentrations and loads have been observed in urban and agricultural streams compared to forested streams. Excess nutrients may arise from fertilizers, wastewater effluent, and industrial waste in urban areas; and from animal waste and fertilizers in agricultural areas. Concentrations of NO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, and Mg^{2+} were all higher in an urban stream than a reference stream in the Southern Appalachians during baseflow and stormflow both (Clinton and Vose 2006). Nitrates had the most pronounced increase with mean concentrations of about 0.01 mg/L in the reference stream and 0.7 mg/L in the urban stream (Clinton and Vose 2006). However, ammonium concentrations were higher in the forested stream during stormflow. Bolstad and Swank (1997), working in the same physiographic subregion, found no increases in nitrate, ammonium, or phosphate concentrations during baseflow as urbanization indices increased. However, during stormflow, slight increases were noted for nitrate (from 0.05 to 0.07 mg/L with a significant regression relationship) and ammonium.

In the Georgia Piedmont, Schoonover and Lockaby (2006) found results similar to those of Clinton and Vose (2006) for dissolved organic carbon, NO_3^-, Cl^-, and K^+, as well as SO_4^{2-} when comparing streams with <5 percent and >24 percent impervious surface. The concentrations in streams of watersheds with >24 percent impervious surface were generally two-to-four times higher than those of less developed catchments. For instance, median baseflow nitrate concentrations were 0.61 mg/L for streams with <5 percent impervious surface and 1.64 mg/L for streams with >24 percent impervious surface; stormwater concentrations were 0.36 and 1.93 mg/L respectively for the same comparison (Schoonover and Lockaby 2006). Although ammonium concentrations have been reported to be higher in forested than in urban streams (Clinton and Vose 2006, Tufford and others 2003), two Piedmont studies produced different results (Crim 2007, Schoonover and Lockaby 2006). Similarly, dissolved organic carbon concentrations are often higher in forested watersheds than in urban streams (Wahl and others 1997) although there are exceptions (Schoonover and Lockaby 2006).

Unlike most studies of land-use/land-cover impacts on water quality, which have substituted space for time, Weston and others (2009) evaluated water quality changes within the Altamaha River Basin of the Georgia Piedmont for more than 30 years. The increases in population during that period exceeded 100 percent in some of the basin's watersheds. During that period, agricultural land use declined as populations rose, producing decreases in stream ammonium and organic carbon concentrations but increases in total nitrogen and nitrogen oxide concentrations and loads. Phosphorus concentrations did not increase with urbanization, which the authors suggest may reflect the elimination of phosphates in detergents after 1972. They also suggest that for the Piedmont, elevated total nitrogen and nitrogen oxides may serve as water quality signatures of urbanization and elevated ammonium, and that organic carbon may be associated with agriculture. Ammonium and organic carbon are also often linked with forest cover but the effects of changes in forest cover were beyond the scope of this chapter.

There are fewer studies of land-use/land-cover associated with the Coastal Plain than with the Piedmont. Wahl and others (1997) compared water quality within two coastal watersheds: one with increasing urbanization (18 percent impervious surface) and the other with predominately forest cover (no impervious surface). Nitrate was consistently higher in the urban stream: 130 ug/L in winter (90 ug/L in summer) versus 42 ug/L in winter (29 ug/L in summer). Ammonium was higher in the forested stream regardless of season (159 ug/L versus 70 ug/L) as were dissolved organic carbon concentrations (27 ug/L versus 13 ug/L). In a study within the Florida Panhandle (Nagy and others 2012),

[3] Okun, D.A. 1992. Properties of the Table Rock and Poinsett Reservoirs: their future. Unpublished report. 24 p. On file with: the Greenville Watersheds Study Committee, P.O. Box 728, Greenville, SC 29602.

median concentrations of nitrate, ammonium, calcium, potassium, and sulfate were higher in watersheds with more urbanization (impervious surface up to 16 percent) than in their forested counterparts. However, nitrate concentrations in the Coastal Plain were well below those generally observed in some studies of urban watersheds of the Piedmont (0.35 mg/L versus 1.78 mg/L). Median concentrations of total phosphorus were high and increased from 0.31 mg/L in watersheds with <5 percent impervious surface to 0.43 mg/L in watersheds with >10 percent impervious surface. Similarly, total suspended solids increased from 1.50 to 2.40 mg/L for impervious-surface levels above 10 percent. In contrast, dissolved organic carbon declined from 36 mg/L in watersheds with low impervious surface to 30 mg/L in watersheds with >10 percent impervious surface. Tufford and others (2003) found that total phosphorus was significantly higher in urban streams than forested streams in the Coastal Plain (concentrations of roughly 0.06 mg/L versus 0.03 mg/L).

In general, increases in stream concentrations of several elements within urbanized watersheds are very common although the magnitude of increase and sometimes the particular ions involved vary considerably within and among physiographic subregions. While nitrate and potassium ions commonly increase (probably due to their mobility in water), responses of total potassium or phosphate are much more variable and may not occur at all. Responses of the other major elements fall in between those of nitrate and phosphate. Since discharge usually increases with urbanization, loads increase as well regardless of physiographic subregion. Consequently, there do not seem to be clear distinctions among subregions in terms of stream chemistry responses, which may indicate that the influence of land use overrides that of physiography in the South.

Higher loads of base cations (K^+, Ca^{2+}, and Mg^{2+}), Cl^-, and total nitrogen were found in agricultural streams than in forested streams in the Coastal Plain (Lowrance and others 1985). Increased nitrate concentrations and loads in agricultural streams compared to forested streams are common in the Appalachians (Hagen and others 2006), Piedmont (Crim 2007), and Coastal Plain (Lehrter 2006, Lowrance and others 1985). For example, nitrate loads were 1.5 to 4.4 times higher in watersheds with greater agricultural land than watersheds with less agricultural land (Lowrance and others 1985) and nitrate concentrations were 2.1 to 4.4 times higher in agricultural versus forested watersheds (Hagen and others 2006).

Effects of Forest Conversion on Human Health

Urban and agricultural land uses contribute to increased bacterial concentrations in stream waters. Connected stormwater and sewer overflow systems or failures in sewer systems (such as broken pipes, mechanical failures, and blockages from tree roots) can directly or indirectly release raw sewage into surface waters. Additionally, pet and wildlife feces can be transported in runoff over lawns and impervious surfaces in urban areas. Fecal coliform bacteria counts were higher in urban than forested or reference streams in the Coastal Plain (DiDonato and others 2009, Holland and others 2004, Mallin and others 2000), Piedmont (Crim 2007, Schoonover and others 2005), and Southern Appalachians (Clinton and Vose 2006). For example, Mallin and others (2000) report that fecal coliform is highly correlated with impervious surface (r=0.975, p=0.005), percent development (r=0.945, p=0.015), and population (r=0.922, p=0.026). Similarly, concentrations of *E. coli* can be much greater in urban watersheds than forested watersheds (Crim 2007, Mallin and others 2000). Urban watersheds in the Georgia Piedmont had the highest median *E. coli* concentrations (as measured in MPN or most probable number), ranging from 135 to 1255 MPN/100 mL, compared to median ranges of 94 to 169 MPN/100 mL for pine covered watersheds and 59 to 170 MPN/100 mL for oak-pine covered watersheds (Crim 2007). Becker (2006) reported that residential areas (2.2 percent of the watershed) did not appear to be a source of bacteria to Travertine Creek subbasin in Oklahoma, but attributed increased bacterial concentrations in the nearby Rock Creek basin to livestock grazing and sewage effluent in periods of high precipitation. Andrews and others (2009) reported fecal coliform counts as high as 10,000 colonies/100 mL with the highest counts in stormflow for the portions (42.17 percent) of the Illinois River basin in Oklahoma and Arkansas that are in agricultural use (pastures for cattle and confined feeding operations for poultry and swine); they also observed rapid urban development on the upper portion of this basin that may further impair water resources.

In addition to the danger of elevated concentrations of bacteria in surface waters, other health risks from urban and agricultural land uses include metals, pesticides, and personal care products (Klapproth and Johnson 2000, Paul and Meyer 2001). Trace metal sediment concentrations can be 2 to 10 times higher in streams near urban and industrial areas than in forested watersheds or suburban watersheds (Holland and others 2004); they tend to accumulate, rather than degrade, over time in sediments and plant and animal tissue (Klapproth and Johnson 2000). Metal concentrations may be inversely related to sediment particle size (Paul and Meyer 2001) and thus we might expect high concentrations of metals to be more problematic in the Southern Appalachians or Piedmont with more silty and clayey soils than in the Coastal Plain. Pesticides enter streams through runoff from agricultural and urban areas (Klapproth and Johnson 2000, Paul and Meyer 2001) again underscoring the importance of riparian buffers and other forested areas in slowing runoff and enhancing infiltration before contaminants can reach the stream. Personal care products including deodorants, perfumes, and pharmaceuticals may not be removed by traditional water treatment methods and are not as widely regulated as other substances (Kolpin and others 2002).

Effects of Forest Conversion on Aquatic Communities

Altered hydrology and channel-morphology and higher stream temperatures caused by forest conversion can dramatically affect aquatic communities. With increasing urban and/or agricultural uses, species richness and abundance often decline as reported for algae (Sponseller and others 2001), macroinvertebrates (Helms 2008, Lenat and Crawford 1994, Maloney and Feminella 2006, Paul and Meyer 2001, Roy and others 2003), fish (Onorato and others 1998, Walsh and others 2005), and amphibians (Houlahan and Findlay 2003, Orser and Shure 1972, Price and others 2006, Wang and others 2001). These effects may be offset somewhat for algae by additional stream nutrients (Biggs 1996, Chessman and others 1999) and for macroinvertebrates by perennial flows (Chadwick and others 2006). Mussels have virtually disappeared from some southern streams as a result of increased conversion of land to urban uses (Gangloff and Feminella 2007, Gillies and others 2003). These detrimental effects on aquatic organisms are particularly evident in the Southern Appalachians (Scott and others 2002, Walters and others 2003) where both diversity and endemism are very high (Wallace and others 1992). Cuffney and others (2010) found a high correlation of macroinvertebrate assemblages with urban metrics in eastern metropolitan areas (including Raleigh, NC; Atlanta; and Birmingham, AL), but not in central metropolitan areas such as Dallas-Fort Worth. Additionally, species composition may shift as sensitive species are replaced by more tolerant species or species better suited for the new conditions (Lenat and Crawford 1994, Onorato and others 1998, Price and others 2006, Roy and others 2005, Sutherland and others 2002, Walters and others 2003, Weaver and Garman 1994). For example, in urban streams of the western Georgia Piedmont, reptile species richness increased at the same time that the richness of salamanders and other amphibian species decreased (Barrett and Guyer 2008).

Fish communities may also be strongly affected by changes in hydrology and water quality that are derived from land use changes. Higher velocities and discharge as well as increased sediment loads may degrade stream habitat to a significant degree (Nagy and others 2011). In particular, higher deposition of sediment in stream channels may reduce diversity of habitat with negative implications for some fish species. Reduced abundance of benthic feeders and lower spawning success in general may accompany such changes (Nagy and others 2011). In addition, near Columbus, GA, Helms and others (2005) noted indicators of reduced fish health such as occurrence of lesions and tumors in fish from urban streams and a negative correlation between biotic integrity of fish and the proportion of impervious surface within watersheds.

Implications of Land Use Change Projections on Water Quality

The decreases in forest cover and increases in urbanization that are projected by 2060 carry important implications for water resources in the region. Losses of forest cover across much of the Piedmont of North Carolina, South Carolina, Georgia, and, to a lesser extent, Alabama (chapter 5) imply that further degradation of water quality and destabilization of surface water hydrology are likely in localized catchments within that subregion. In addition, it is likely that the alterations in the hydrologic cycles within the headwaters of major river basins (fig. 13.6) will affect conditions downstream. River basins and watersheds will undergo reductions in evapotranspiration due to lower leaf area indices as well as increases in impervious surfaces. Consequently, responses to deforestation—reduced infiltration, increased runoff, reduced baseflow, and increased discharge and velocity—that already exist on the Piedmont to some extent (but are more often associated with steeper terrains) will likely be exacerbated.

These hydrologic responses, combined with the increased quantities of potential pollutants in urbanizing watersheds, will increase streamwater concentrations and/or loads of sediment, nutrients, pathogens, and various chemicals. The result could be significant degradation of water quality within river basins and stream systems, and concurrent negative effects on diversity of aquatic organisms. Although responses will be manifested throughout river basins, cumulative effects will magnify the trends along their lower reaches. If streams remain connected to the floodplain forests that lie below the physiographic fall line, some fraction of pollutant loads may be filtered as sediment is deposited by spreading floodwaters. However, although upper coastal forests are projected to be cleared to a lesser extent than Piedmont forests, they remain at some risk of conversion with subsequent reduction of pollutant filtration potential on floodplains. In addition, the increased velocity of streams and rivers draining highly urbanized upper reaches will tend to increase channel incisement, thereby reducing the filtering benefits of overbank flooding and sediment deposition. Although reservoirs created by dams may trap significant amounts of sediment and other substances, they have a finite capacity for sediment filling, which is already being approached in some areas. Consequently, loads of sediment, nutrients, and pathogens will likely increase in lower reaches of river basins, with exports of these materials expected to elevate levels in coastal estuaries as well.

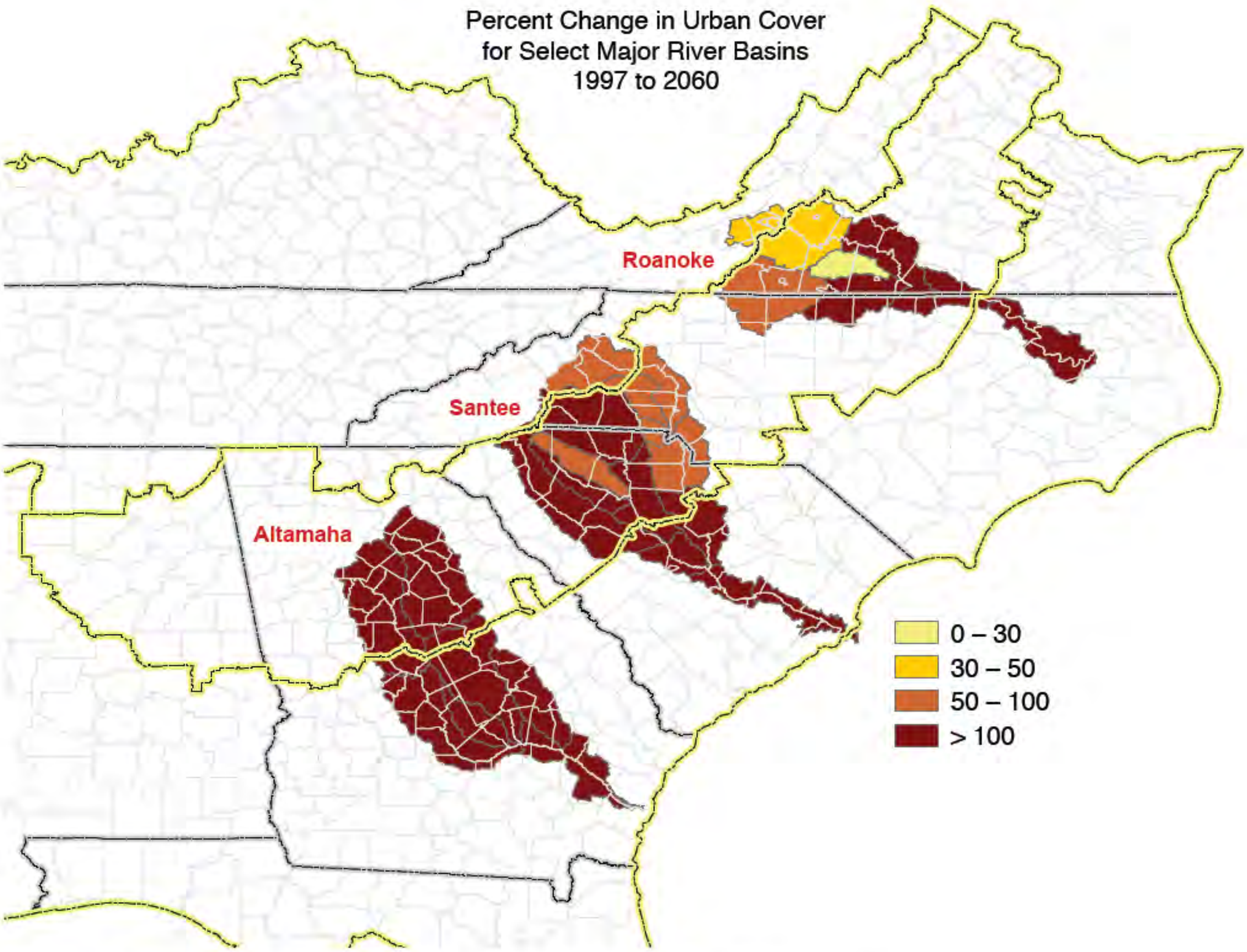


Figure 13.6—Projected increases in urban cover within three major river basins of the South from 1997 to 2060.

Another trend is the large loss of forest cover that is expected within Gulf of Mexico and Atlantic coastal counties from southern Texas, through parts of Louisiana, Mississippi, Alabama, Florida, Georgia, South and North Carolina, to southern Virginia (chapter 5). Although many of these counties are already experiencing varying degrees of urbanization, additional development is projected, bringing major changes to freshwater resources as well as new hydrologic, biogeochemical, and other inputs to coastal estuaries. Outputs from large rivers are mainly driven by large-scale interactions between land-use/land-cover and climate throughout basins that may extend far northward and touch multiple States. Meanwhile, numerous lower order coastal streams will be directly impacted by reductions in forest cover and increased impervious surfaces at local scales—placing them at risk to increased levels of nitrate, pathogens, and other substances (Nagy and others 2012). Given the proximity of groundwater tables to the surface in some coastal areas, the risk may extend to those waters as well. Elevated exports of nonpoint source pollutants from large rivers and lower order coastal streams can significantly increase eutrophication of coastal waters and risks to humans from contaminated seafood and direct contact while swimming.

Apart from scattered locations (e.g., near Dallas, Houston, Little Rock, AR, and Oklahoma City, OK), little change in the proportion of forest land is expected across much of southwestern Alabama, and most of Mississippi, Louisiana, Arkansas, and eastern Texas and Oklahoma (chapter 5). This stabilization of forest area may preclude further declines in water quality in the Lower Mississippi Alluvial Valley, an area that has traditionally been associated with heavy exports of sediment and nutrients into the Mississippi River Basin; however improvements in water quality appear unlikely without the major increases in forest land (15 to 27 million acres) that would be required to substantially reduce nonpoint source pollutant exports (Mitsch and others 2001). Increased forest coverage will also be characteristic on many inland Coastal Plain areas of Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Louisiana (chapter 5), a trend that could protect floodplain forests and maintain water quality of those systems.

Another location that is anticipated to undergo major increases in urbanization is the southern half of Florida, where forested wetlands (both riparian and depressional) are prevalent and associated water quality functions are at risk. At a time when additional nonpoint source pollutant exports are originating from newly urbanized landscapes, a portion of the natural systems with potential to filter pollutant loads will disappear with the demise of forested wetlands.

Effects of Expanded Intensive Forest Management on Water

The establishment of pine plantations has resulted in vast acreages of intensively managed pine forests in the South. Plantation based forestry–using pine and fast growing hardwood species–is likely to increase in the future (chapter 9), and demand from a shrinking land base and emerging wood fiber markets for bioenergy is likely to increase management intensity on new and established plantations. Considerable information is available on the impacts of forest management on streamflow throughout the United States (Brown and others 2005, Jones and Post 2004). For example, removing the forest canopy increases streamflow for the first few years, but the magnitude, timing, and duration of the response varies considerably among ecosystems. In some, streamflow returns to preharvest levels within 10 to 20 years; whereas in others, streamflow remains higher for several decades after cutting, or can even drop lower than pre-harvest levels (Jackson and others 2004). This wide variation in responses is attributable to the complex interactions between climate, which can vary considerably from dry to wet regimes, and vegetation, which can vary in structure and phenology (coniferous versus deciduous forest).

Information on the relationships between specific ecosystems or forest types and streamflow can be inferred from studies quantifying annual evapotranspiration. At annual time scales, streamflow is approximated by the difference between precipitation (PPT) and evapotranspiration (ET), streamflow = PPT - ET. Therefore, for a given amount of precipitation, management actions that alter evapotranspiration will also alter streamflow. It is well established that coniferous forests, with their greater capacity for interception and transpiration, have higher evapotranspiration (and hence lower streamflow) than deciduous hardwood forests (Ford and others 2011, Swank and Douglass 1974). Averaged across several climate regimes and forest types, the difference between coniferous and hardwood forests is about 55 percent at 1200 mm yr^{-1} precipitation and increasing precipitation widens this difference in the two forest types. Evapotranspiration also varies considerably between managed and unmanaged southern forests (table 13.4). This variation is important for evaluating the implications

Table 13.4—Mean annual transpiration (mm yr^{-1}) for southern forest types

Vegetation type	Transpiration	Source
Longleaf pine savanna	244	Ford and others 2008
Old field	250	Stoy and others 2006
Oak-pine-hickory forest	278	Oren and Pataki 2001
Upland oak forest	313	Wullschleger and others 2001
Mixed pine hardwood	355	Phillips and Oren 2001
Mixed pine hardwood	442	Stoy and others 2006
Planted loblolly pine	490	Stoy and others 2006
Mixed pine hardwood	523	Schafer and others 2002
Slash pine flatwoods	563	Powell and others 2005
Eucalyptus hybrid plantation	882	Estimated for Baker County, southwestern Georgia in 2006 for an average climate and rainfall year[a]
Planted loblolly pine (early rotation)	328	Domec and others 2012; Sun and others 2010
Planted loblolly pine (mid-rotation)	777	Domec and others 2012; Sun and others 2010

[a]Derived from a model that used data collected in 2006 by the Joseph W. Jones Ecological Research Center, 3988 Jones Center Drive, Newton, GA 39870. Model assumed no soil water limitation; all trees at age 5; 1,111 trees ha^{-1}; and a leaf area index of 6 m^2 m^{-2} (Mielke and others 1999).

of increasing pine plantation forests in the South because the magnitude of the effects on streamflow depends on the species, forest type, or land use being replaced. For example, pine plantations may consume nearly twice the water consumed by longleaf pine savannas (table 13.4).

Implications of increasing management intensity on water resources will depend on the specific management activity. Increasing acreages of fast growing species for bioenergy production or carbon sequestration may have negative consequences for water yield (Farley and others 2005, Jackson and others 2005b). To illustrate, a mature eucalyptus plantation (age 5, 1,111 trees ha^{-1}, leaf area index of 6 m^2 m^{-2}) growing in southwestern Georgia could potentially consume 882 mm yr^{-1} of water, exceeding other forest types by a factor of 2.5 (table 13.4). Nitrogen fertilization improves productivity primarily though increased leaf area (Vose and Allen 1988), and evapotranspiration is highly correlated with leaf area index (Sun and others in press). Shortening rotation times usually increases streamflow by decreasing the amount of time that the stand is at canopy closure, when leaf area index is highest and streamflow is lowest. For any given leaf area, younger or shorter trees also have higher stomatal conductance than older or taller trees (Moore and others 2004, Novick and others 2009, Schafer and others 2000). Although transpiration per unit leaf area is less than for younger forests, older forests have larger leaf area and can intercept more water, and therefore have greater evapotranspiration. This means that managing for older forests is likely to decrease streamflow.

Impacts on water quality will depend on the type of management activity and the effectiveness of established Best Management Practices, which were originally developed for less intensive management. For example, in review of the impacts of forests fertilization, Fox and others (2007) concluded that correctly applied fertilizer rarely degrades water quality. In contrast, increasing the frequency of harvest for shorter rotations may have impacts on sediment yield, especially if the harvests result in greater soil disturbance (Ursic 1986) or require more roads and more frequent road usage (Swift 1988).

Implications of Climate Change, Land Use Change, and Population on Water Resources

Climate change impacts on water resources—Because of the combination of biological and physical controls on hydrologic processes, climate change will both directly and indirectly impact southern water resources (Brian and others 2004, Sun and others 2008). The direct impacts will depend on how the amount and timing of precipitation are altered and how this influences baseflow, stormflow, groundwater recharge, and flooding. Long-term U.S. Geological Survey streamflow data suggest that average annual streamflow has increased and that this increase has been linked to greater precipitation in eastern States over the past 100 years (IPCC 2007, Karl and Knight 1998, Lins and Slack 1999); however, fewer than 66 percent of all General Circulation Models can agree on the direction of predicted precipitation change, whether wetter or drier (IPCC 2007). Annual precipitation within a year or from one year to the next is a natural phenomenon related to large-scale global climate teleconnections, such as El Niño Southern Oscillation, Pacific Decadal Oscillation, and North Atlantic Oscillation cycles. Many regions of the United States have experienced an increased frequency of precipitation extremes over the last 50 years (Easterling and others 2000, Huntington, 2006, IPCC 2007). As the climate warms in most General Circulation Models, the frequency of extreme precipitation events increases across the globe (O'Gorman and Schneider 2009); however, the timing and spatial distribution of extreme events are among the most uncertain aspects of future climate scenarios (Allen and Ingram 2002, Karl and Knight 1998). Despite this uncertainty, recent experience with droughts and low flows in many areas of the United States indicate that even small changes in drought severity and frequency will have a major impact on society, among them a reduction in drinking water supplies (Easterling and others 2000, Luce and Holden 2009).

The indirect impacts of climate change are related to changes in temperature and atmospheric carbon dioxide. In the short term, higher temperatures have the potential to increase evaporation and plant water use via transpiration (as temperatures increase, the energy available for evapotranspiration increases), and therefore decrease excess precipitation available for streamflow or groundwater recharge. Warmer temperatures will also influence the duration and timing of snowmelt, a critical factor in ecosystems where snowmelt dominates hydrologic processes. The impacts of temperature may be offset (or exacerbated) by changes in other factors that influence evapotranspiration such as vapor pressure (warm air holds more water), wind patterns (which impact boundary layer resistance), increases in carbon dioxide (which decrease stomatal conductance), and changes in net radiation (influenced by changes in cloud cover and aerosols). In the longer term, a warmer climate in combination with changes in precipitation will likely shift distributions of tree species, which differ considerably in the amount of annual and seasonal water they use via transpiration and interception (Ford and others 2011, Sun and others 2011). For example, in some geographic areas, a shift from hardwood to pine forests may result in year-round transpiration and interception and greater water use. Controlled studies have demonstrated that increased atmospheric carbon dioxide reduces transpiration in many tree species, which may translate into increased streamflow

(Ainsworth and Rogers 2007); however, it is not certain that these patterns will persist over the long-term.

Modeled impacts of future climate change on water resources—The impacts of climate change on water resources are complex and variable over space and time (Dale and others 2001). In addition, changes in land cover and human demands for water resources are likely to be complicating factors. For these reasons, models are often useful for integrating complex interactions across multiple scales. Past forest hydrological studies using small experimental watersheds clearly show that climate variability and land cover can substantially impact water quantity and quality. However, at the large basin or regional scale, the magnitude and areal sizes of disturbances will determine how water resources will be affected by climate change, forest clearing in preparation for urbanization, or disease/bioenergy-induced changes in species distribution. Over the entire southern region, WaSSI model simulations reveal that on average (year 2002-2007) forests represented 27 percent of the land cover but were the source of 34 percent of the total water yield (fig. 13.7).

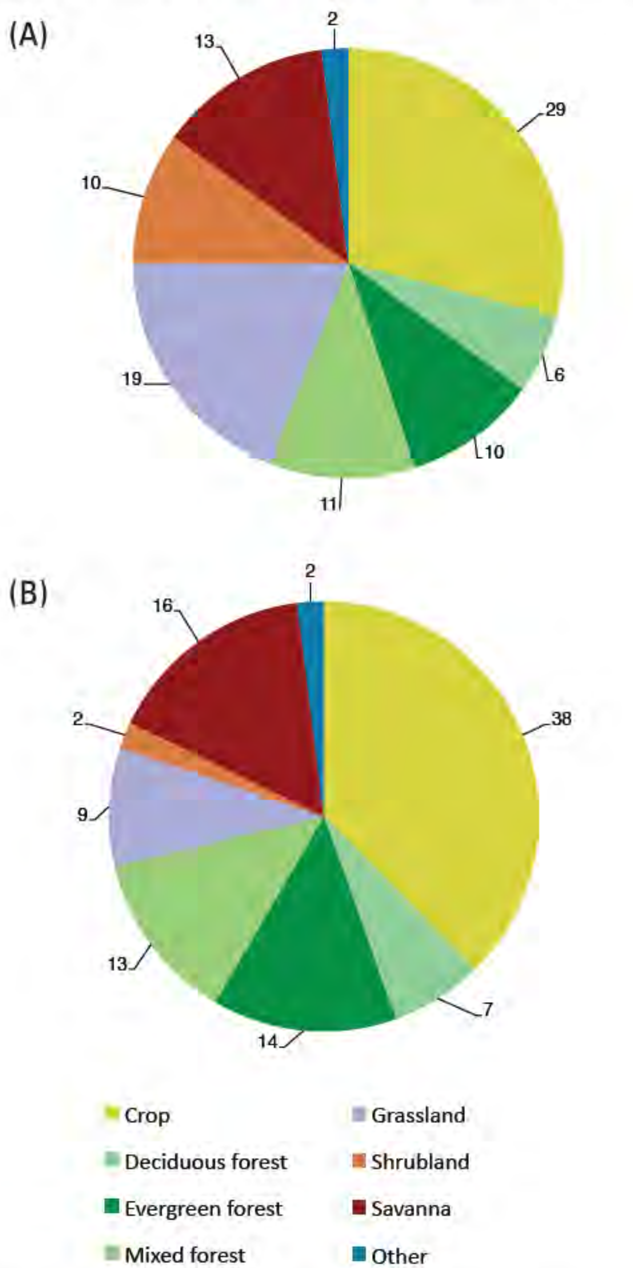


Figure 13.7—(A) 2001 MODIS percent land cover and (B) simulated mean water yield by land cover in the South from 2002 to 2007, showing that forests cover 27 percent of the land area but produce 34 percent of total water yield in the region.

Future global climate change is expected to have regional impacts, but the severity depends on the magnitude of changes in both precipitation and atmospheric warming. Key findings from multiple scenario modeling (table 13.2) by the WaSSI model are summarized below to show the projected impacts of climate change and other contributors to water stress, or imbalance between supply and demand, around the year 2050.

1. Average water stress in the South is low (WaSSI = 0.16) but high in southern and western Texas (WaSSI > 0.90) because of naturally low precipitation and high evapotranspiration (fig. 13.8). A few isolated basins also show moderate water stress (WaSSI 0.4 – 0.9), primarily near population centers and other areas of high water demand.
2. The highest water stress occurs during the growing season when ecosystem water use and human water withdrawal are the highest (fig. 13.9). In particular, irrigation, domestic, and thermoelectic uses are greatest during the summer months. All future climate change scenarios will likely increase monthly WaSSI relative to historic levels across the region and may shift the timing of peak WaSSI from late summer to early fall.
3. Population will increase by 104 percent by 2050 in the South as a whole (NPA Data Services 1999). Population growth alone will increase water stress 10 to 50 percent in much of the Piedmont and Coastal Plain, with increases of 50 to 100 percent in the Florida Panhandle (fig. 13.10). On average, population growth will increase water stress by about 12 percent.
4. Land use change alone may increase or decrease water stress, depending on the historic and future use for a given land area. For example, in areas converted from forest to urban use, water stress will likely decrease due to reductions in evapotranspiration. However, areas converted from forest to crop use will likely experience increases in water stress due to higher irrigation water demand. By 2050, land use change alone is not likely to significantly change water stress in the South as a whole (fig. 13.11).
5. Population growth and land use change will produce an array of effects on water stress across the South and may aggravate water shortages at the regional scale (fig. 13.12).

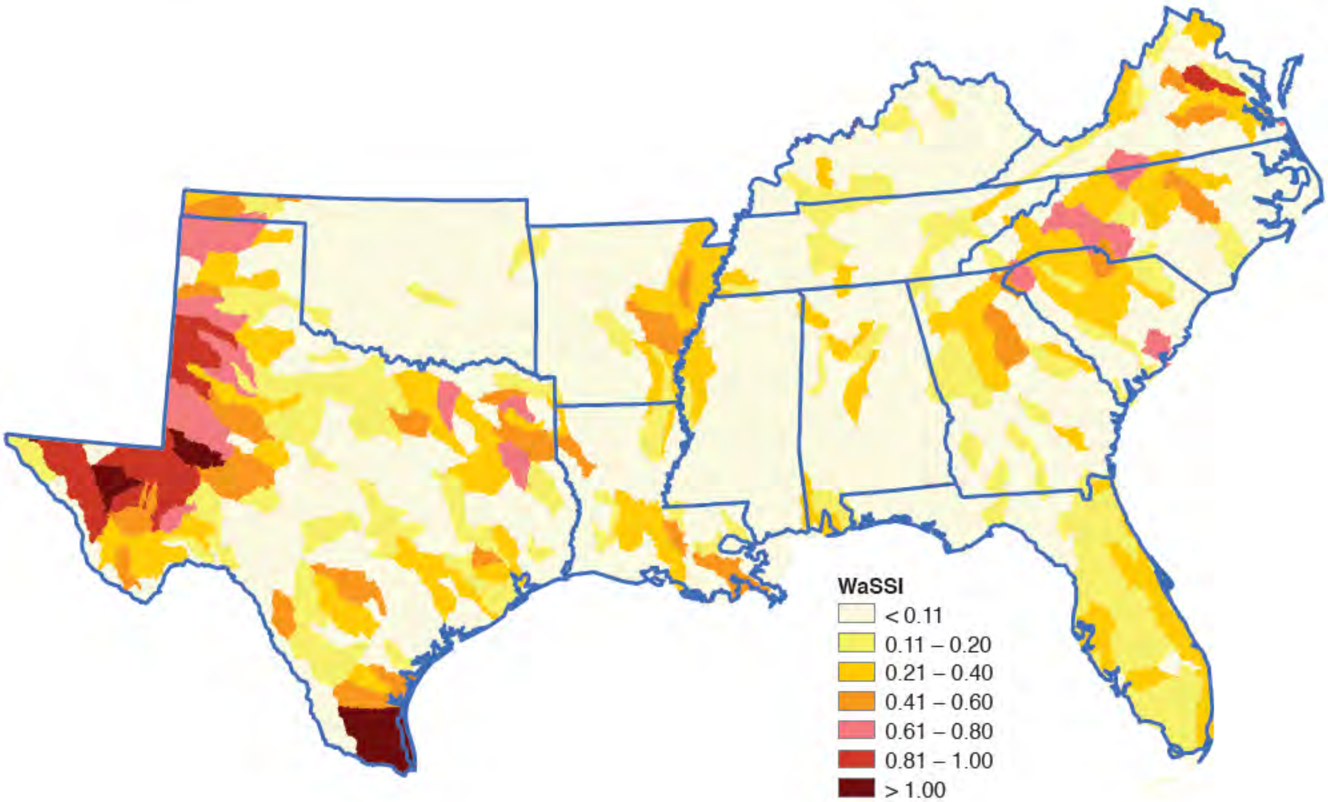


Figure 13.8—Water supply stress index (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) under baseline, 1995 to 2005, conditions.

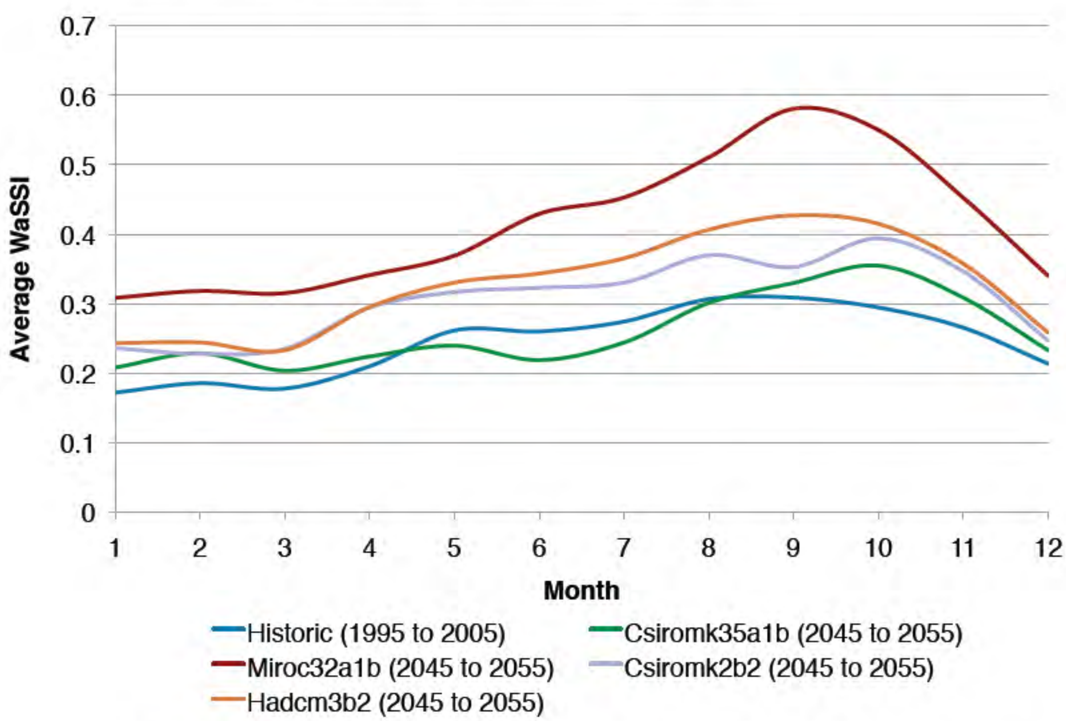


Figure 13.9—Average monthly water supply stress (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) among all Natural Resource Conservation Service Watershed Boundary Dataset Hydrologic Unit Code watersheds (HUCs) in the South under historic and four future climate scenarios.

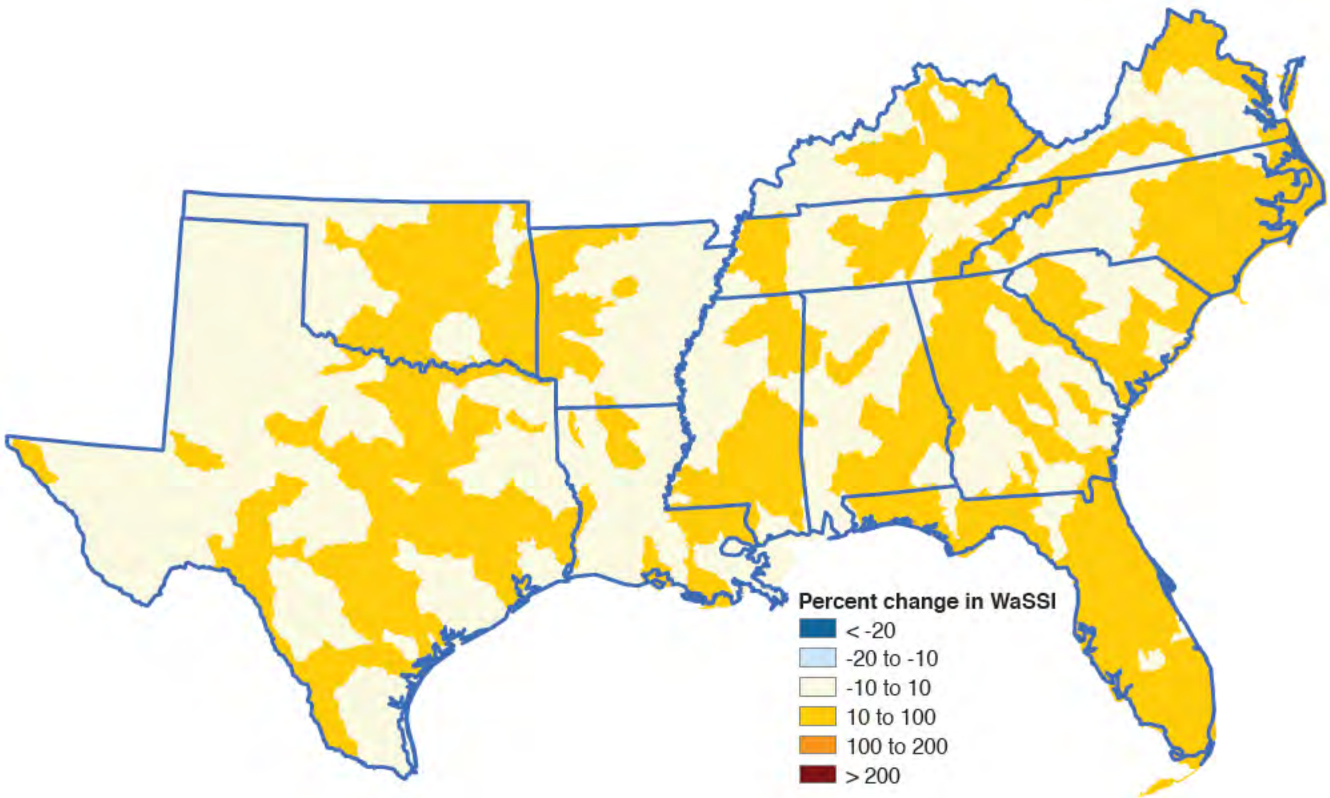


Figure 13.10—Percent change in water supply stress (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) caused by population change by 2050.

Figure 13.11—Percent change in water supply stress index (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) due to land use change by 2050.

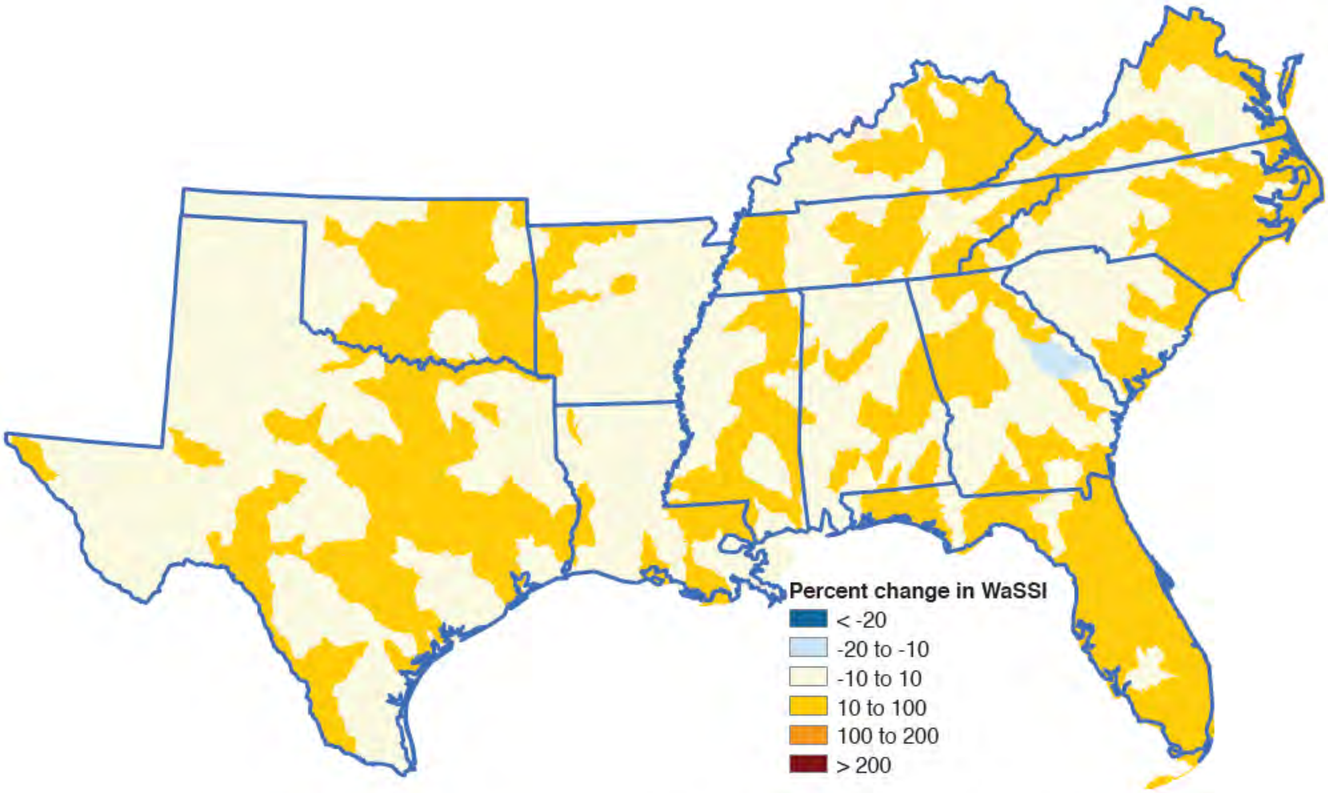


Figure 13.12—Percent change in water supply stress (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) by 2050 due to the combined effects of population and land use change.

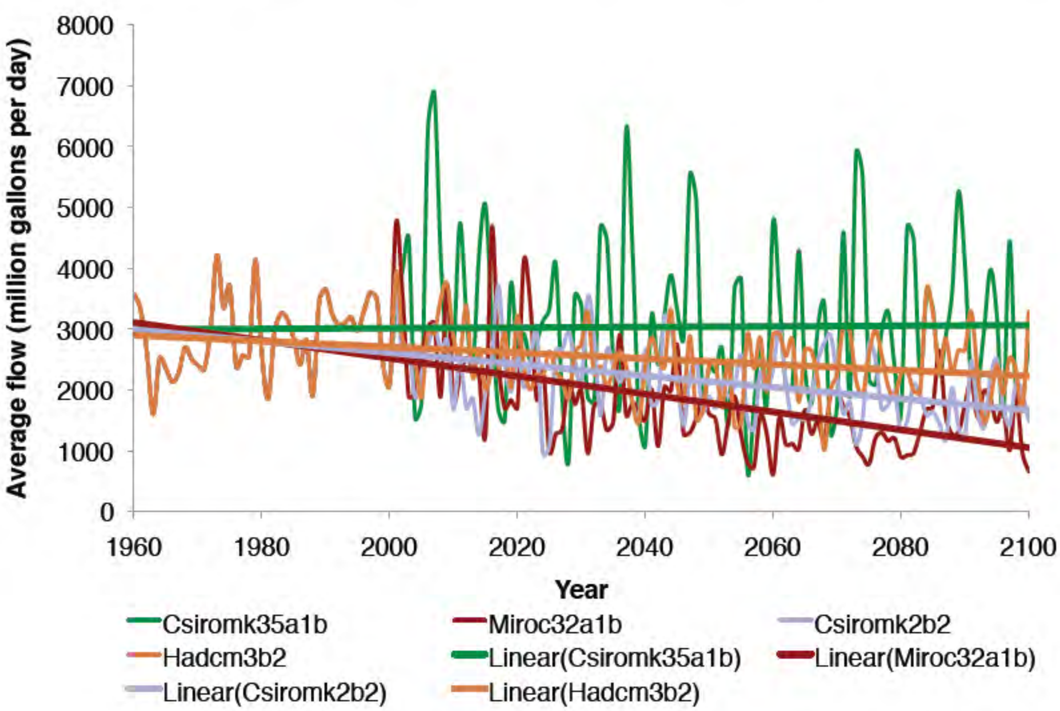


Figure 13.13—Projected average river flows among the 674 Natural Resources Conservation Service Watershed Boundary Dataset 8-digit Hydrologic Unit Code watersheds (HUCs) in the South under four future climate scenarios.

On average, water stress due to the combined effects of population and land use change will increase in the South by 10 percent.

6. All climate change scenarios predicted that the South would likely see increases in air temperature in the next 50 years but differed in predictions of precipitation change across the region. The combined effects of changing temperature and precipitation will generally decrease streamflow across the South (fig. 13.13). In addition, streamflow will likely become more variable with lower flows during drought periods and higher flows during wet periods than experienced in the past.
7. Water supply stress would likely increase significantly under all four climate change scenarios (fig. 13.14), largely caused by increases in water loss by evapotranspiration resulting from higher air temperatures, and also because of decreasing precipitation in some areas. The effects of changing climate on water stress will vary significantly across the region (fig. 13.15). For example, the WaSSI model projects that Frankfort, KY will have negligible change in water stress across the four future climate scenarios, while Oklahoma City, OK, Little Rock, AR, and Austin, TX are projected to have significant increases in water stress.

Implications of Sea Level Change on Coastal Areas

Sea-level may rise from 0.4 to 2.0 m by the end of the 21st century (table 13.5) (McMullen and Jabbour 2009, Rahmsorf 2007, Solomon and others 2009). Along the Atlantic Coast in the study region there is approximately 7,297 square miles (~4.6 million acres) of coastal land below an elevation of 1.5 meters (North Carolina and Florida have the most coastal area below 1.5 m), with an additional 5,573 square miles (~3.5 million acres) of coastal land between 1.5 and 3.5 m. Along the Gulf Coast there is approximately 13,605 square miles (~8.7 million acres) of land below an elevation of 1.5 m (Louisiana and Texas have the most coastal area below 1.5 m), with an additional 6,430 square miles (~4.1 million acres) of coastal land between 1.5 and 3.5 m (fig. 13.16). If sea level rose 1.5 m we estimate that 2,633 square miles (~1.6 million acres) of forests could be affected along the Atlantic Coast, and 3,352 square miles (~2.1 million acres) of forests could be impacted along the Gulf Coast. When physical processes are considered by the coastal vulnerability index, along the Atlantic Coast North Carolina and Virginia have the most coastline in the very high-risk class, and along the Gulf Coast, Louisiana and Texas have the most coastline in the very high-risk class (fig. 13.17).

Projections of sea level changes can help managers identify portions of the coastline that could be monitored more closely. For example, figure 13.18 shows that the entire Louisiana coastline is in the high risk category with coastal area below 1.5 m, but the Gulf coast portion of southern Florida is ranked in the moderate risk category even though its coastal area is also below 1.5 m, suggesting that its response to a rising sea may be slower than if predicted from elevation alone (Thieler and Hammar-Klose 2000). Figure 13.19 shows that portions of the North Carolina coastline and the Atlantic coast of Florida are in the high risk category, but because those coastal areas are between 1.5 and 3.5 m, a sea-level rise of 1 m may not affect those higher elevation areas.

DISCUSSION AND CONCLUSIONS

Forest conversion to agriculture or urban land uses consistently causes increases in discharge, peak flow, and velocity of streams. Differences in the nature of hydrologic responses to urbanization among subregions are substantial. As examples, the pronounced effect of urban development on peak flows and stream hydrographs found in the Appalachians and Piedmont may be obscured by natural precipitation regimes in arid regions, such as western Texas where hydrographs from less disturbed streams resemble those of urban streams (Grimm and others 2004). Similarly, the reductions in baseflow that are often observed following increases in impervious area in the Piedmont may not occur in the flatter terrain of the Coastal Plain.

Forest conversions also result in increases in sediment, water chemistry indices, fecal coliform and *E. coli*, and other substances. Because discharge and concentrations increase after urbanization, loads are generally higher. Physiographic characteristics such as slope and soil texture strongly influence hydrology and sediment export, but their impact on water chemistry is less than the impact of urbanization. Conversion of forest land to urban uses may result in health risks for humans as evidenced by large increases in fecal coliform and *E. coli*, heavy metals, pharmaceuticals, and other substances in stream water. While effective water treatment may overcome this risk to drinking water, there remains significant potential for direct contact with polluted water as streams flow through residential areas prior to treatment.

Each river basin has a unique land use history that may have long-lasting effects. Cuffney and others (2010) reported that the conversion of forest to urban land had more pronounced effects on benthic macroinvertebrates in Atlanta; Birmingham, AL; and Raleigh, NC than the conversion of agriculture to urban land had in Dallas, where natural grassland had already been degraded by agriculture in the recent past (an example antecedent land use impacts taking precedent over historical land use). In fact, their study found that antecedent agricultural land use masked the effects of urbanization in areas of historic forest use as well.

Physiographic characteristics could determine the threshold, or the resilience to change, that each subregion displays in

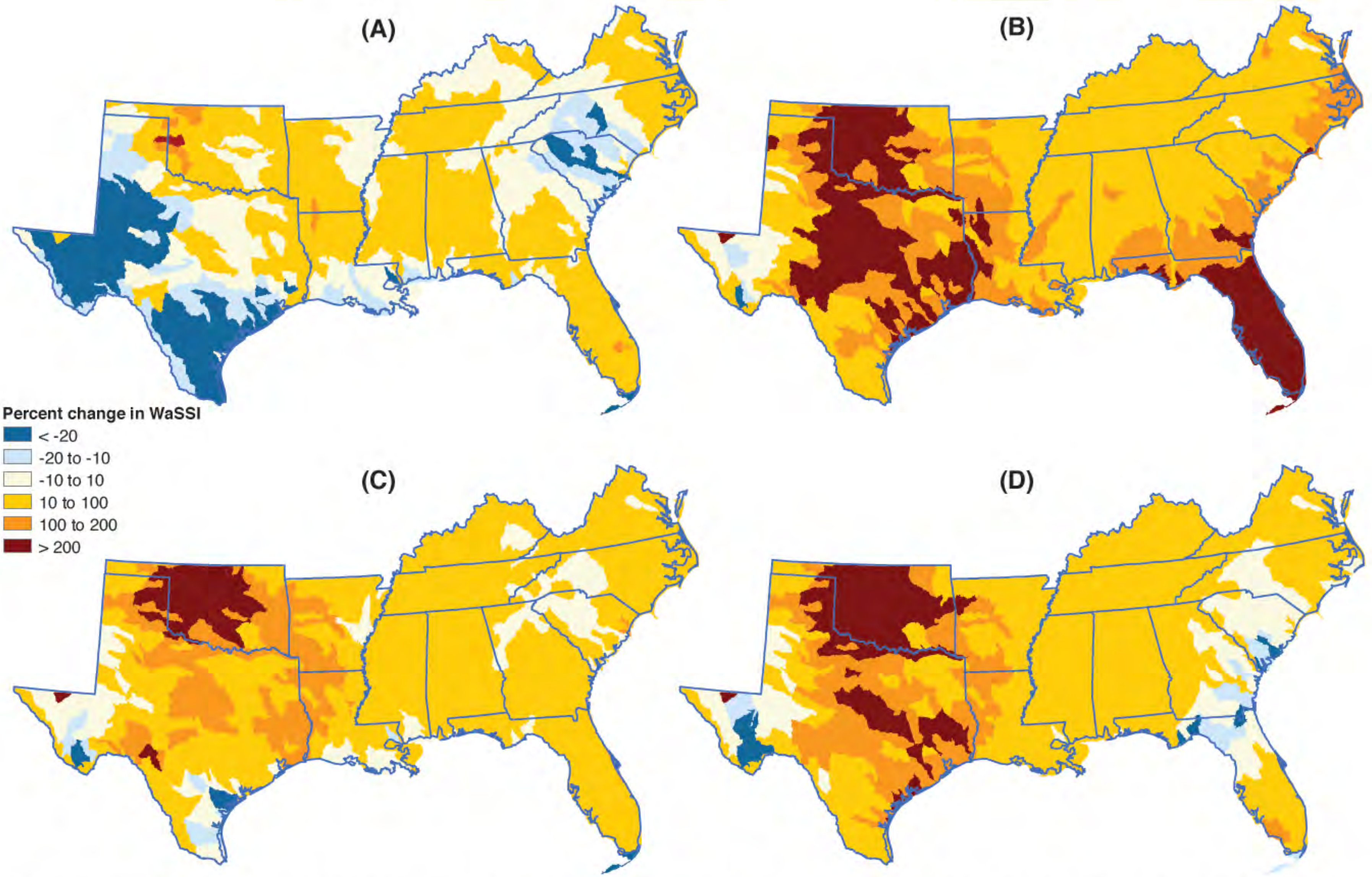


Figure 13.14—Percent change in water supply stress due to climate change (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) by 2050 under four climate scenarios: (A) csiromk35a1b, (B) miroc32a1b, (C) csiromk2b2, and (D) hadcm3b2.

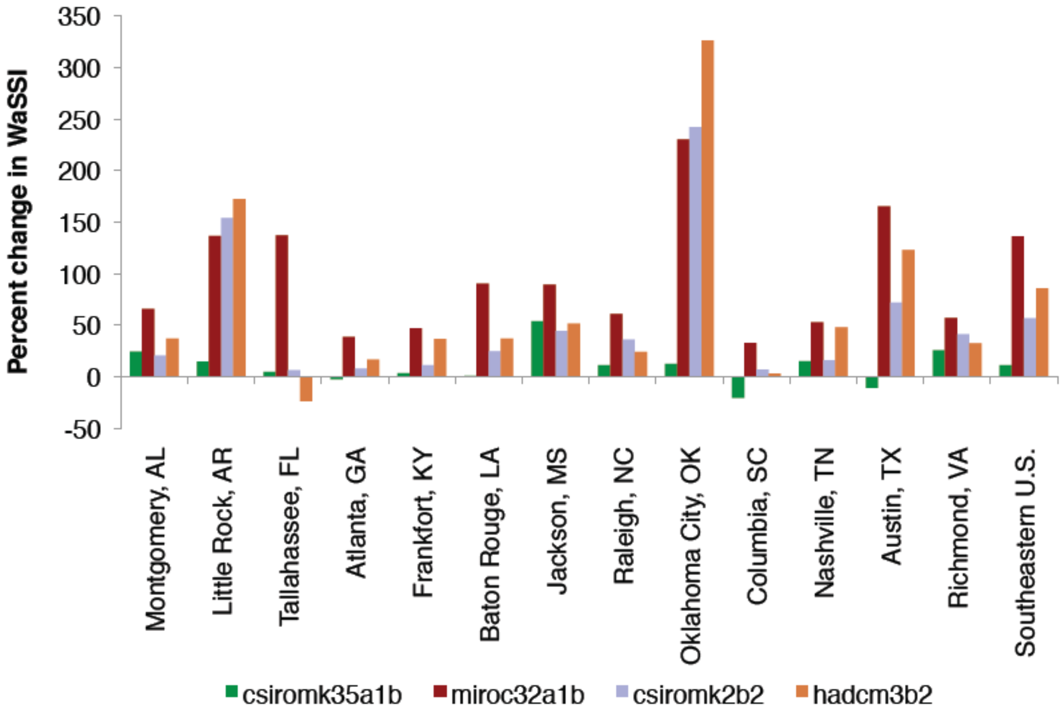
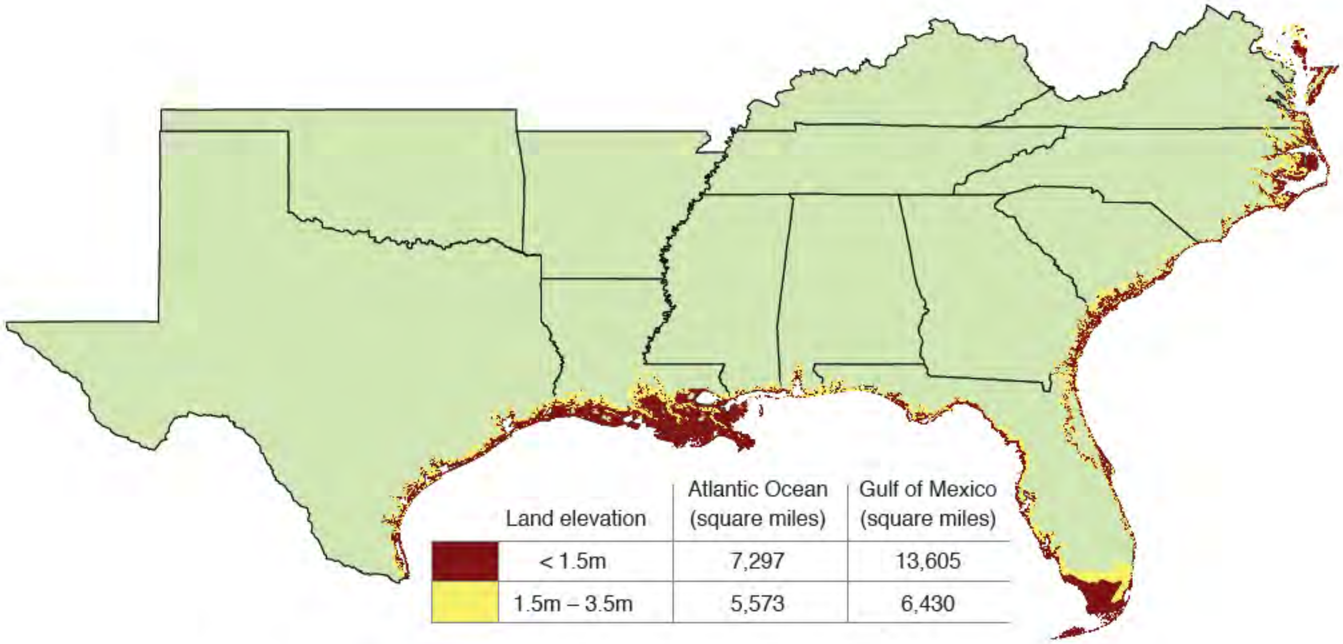


Figure 13.15—Percent change in water supply stress (defined by the Water Supply Stress Index (WaSSI) and calculated by dividing water supply into water demand) for Natural Resources Conservation Service Watershed Boundary Dataset 8-digit Hydrologic Unit Code watersheds (HUCs) containing State capital cities across the South under four future climate change scenarios between the baseline period (1995 to 2005) and the future condition (2045 to 2055).

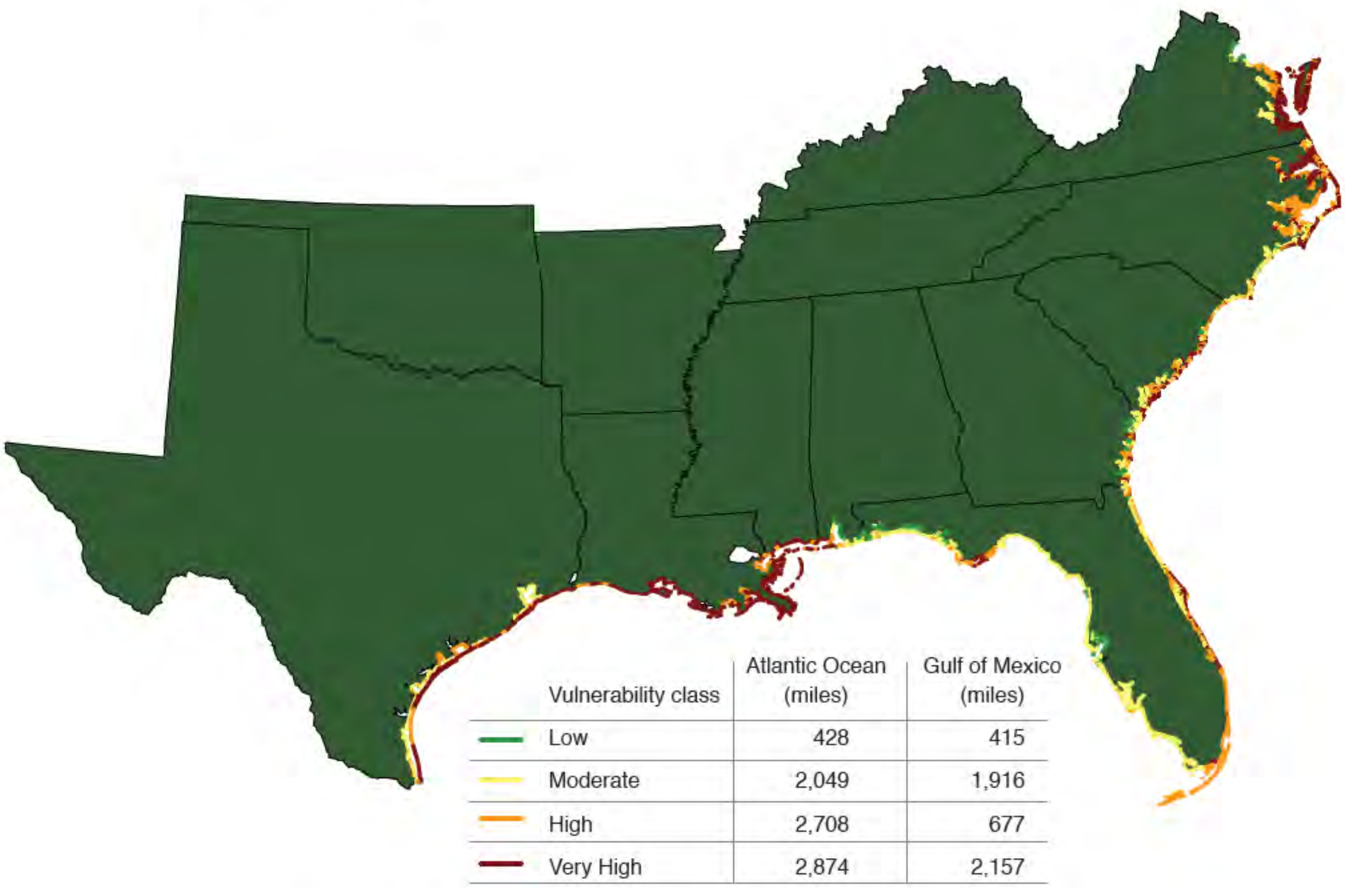
Table 13.5—Estimates of rise in the sea level by the end of the 21st century

Author	Estimated rise	Model characteristics
Parry and others 2007	0.28 m to 0.43 m	Excludes dynamic ice changes
Rahsmorf 2007	0.5 m to 1.4 m	Semi-empirical (relationship: sea-level rise and surface temperature)
Soloman and others 2009	0.4 m to 1.9 m	Limited to oceanic thermal expansion
	Could increase above estimate by several meters	Includes glacier melts and ice sheet melts
McCullen and Jabbour 2009	0.8 m to 2.0 m	Includes ice changes



	Land elevation	Atlantic Ocean (square miles)	Gulf of Mexico (square miles)
	< 1.5m	7,297	13,605
	1.5m – 3.5m	5,573	6,430

Figure 13.16—Land vulnerable to sea-level rise along the Atlantic Ocean and Gulf of Mexico. (Titus and Richman 2001)



Vulnerability class	Atlantic Ocean (miles)	Gulf of Mexico (miles)
Low	428	415
Moderate	2,049	1,916
High	2,708	677
Very High	2,874	2,157

Figure 13.17—Coastal vulnerability to sea-level rise along the Atlantic Ocean and Gulf of Mexico. (Hammar-Klose and Thieler 2001)

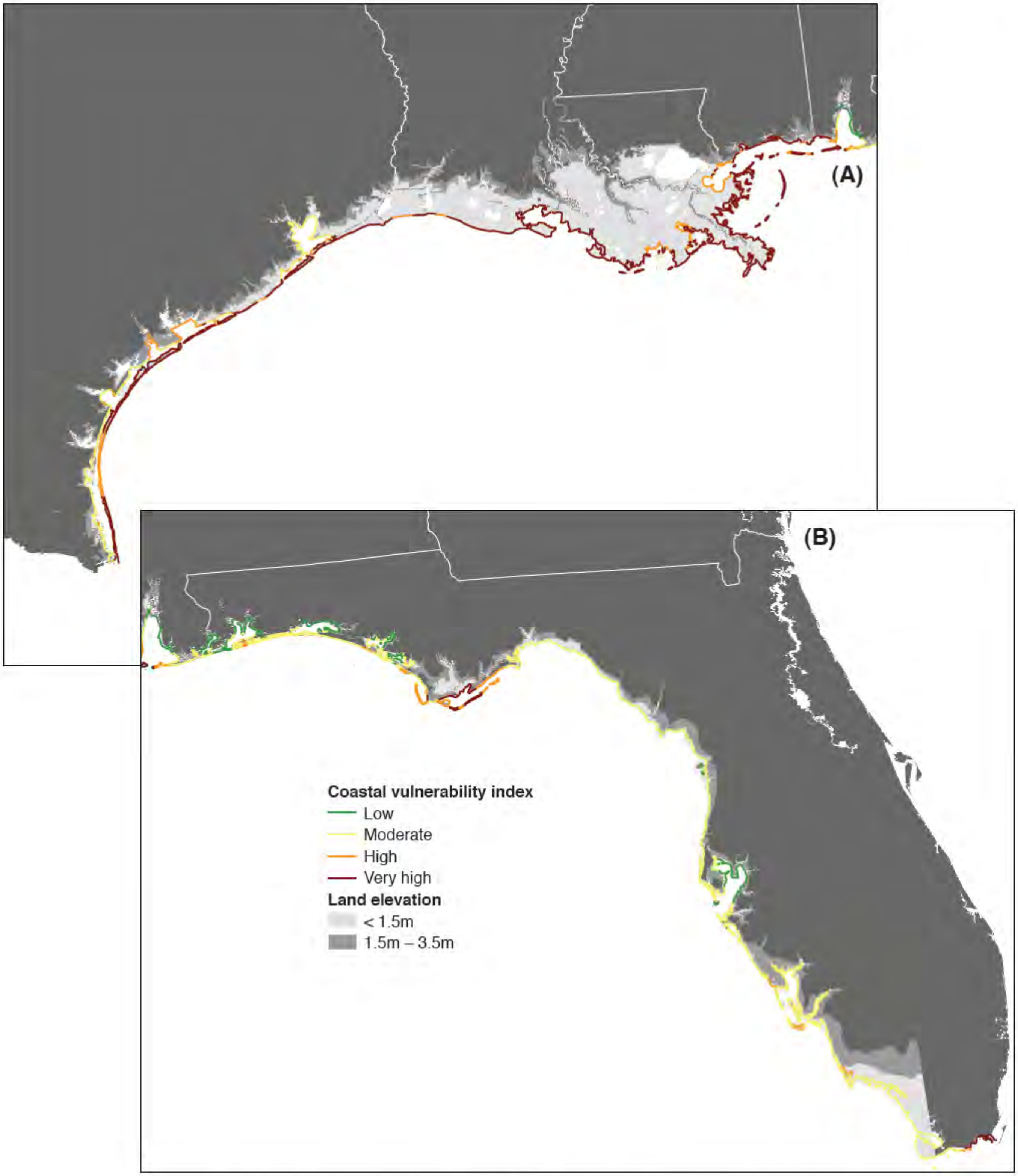


Figure 13.18—Vulnerability to sea-level rise along the Gulf of Mexico: (A) western coastal areas and (B) eastern coastal areas. (Hammar-Klose and Thieler 2001, Titus and Richman 2001)

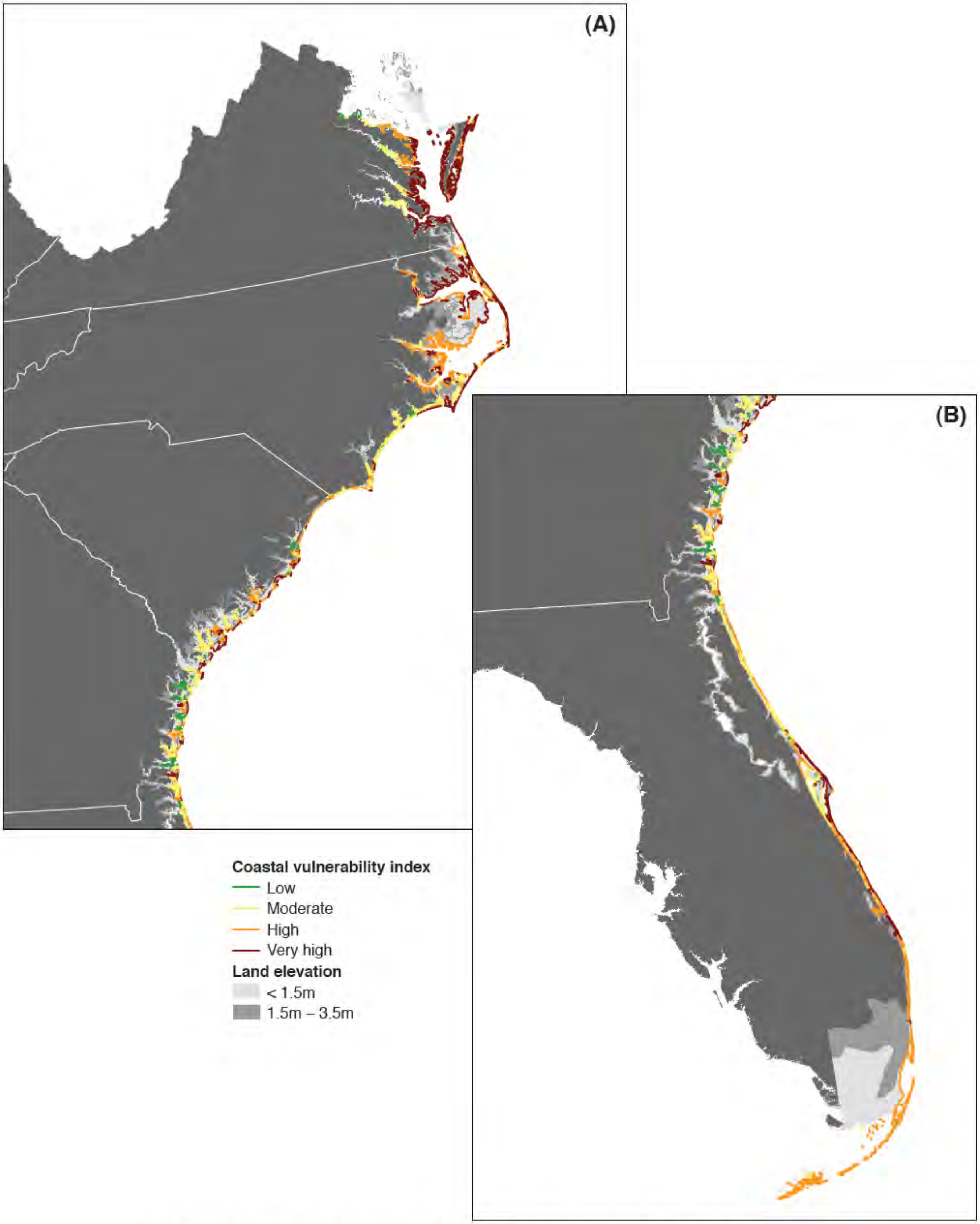


Figure 13.19—Vulnerability to sea-level rise along the Atlantic Ocean: (A) northern coastal areas and (B) southern coastal areas. (Hammar-Klose and Thieler 2001, Titus and Richman 2001)

response to changes in land use. For this reason, McMahon and Harned (1998) recommended incorporating measures of both natural physiographic variation and effects of human activity in watershed studies and management plans. Additionally, there have been some indications that impervious surface increases may have higher thresholds for significant water degradation in the Coastal Plain than the Piedmont or Southern Appalachians (Helms and others 2009, Morgan and Cushman 2005, Roy and others 2003, Stednick 1996, Utz and others 2009); but this does not appear to be true for all measures (Nagy and others 2012).

The concept of thresholds of imperviousness beyond which significant degradation of water quality occurs is vague and had previously been reported at 10-20 percent (Arnold and Gibbons 1996, Bledsoe and Watson 2001). However, some reports have noted significant changes in water quality at even lower levels of development, such as <5 percent impervious surface (Crim 2007, Cuffney and others 2010, Nagy and others 2012). For instance, at 5 percent impervious surface, Cuffney and others (2010) estimated a 13 to 23 percent degradation of macroinvertebrate assemblages compared to background conditions. This suggests that care must be taken from the first stages of development to limit impacts on water resources. Boggs and Sun (2011) suggest that maintaining high ET of vegetation in the growing season is key to reducing stormflow in urban watersheds. Furthermore, once impervious surface cover exceeds 30 percent, deterioration of water quality becomes severe (Calhoun and others 2003, Paul and Meyer 2001). In areas where development is planned or about to begin, it would be very useful to identify key bioindicators for detecting the onset of significant degradation.

Among the most dramatic impacts associated with forest conversion to urban or agriculture are changes in aquatic populations. The higher velocity and channel scouring associated with urban hydrology creates unstable habitat, and this is compounded by the effects of degraded water quality. Species richness and abundance generally decline; and some groups, such as mussels, may be eliminated from particular locations. These impacts tend to be most severe in the Appalachians. Also, species that are tolerant of the altered conditions may replace those that are intolerant. An example was observed in the Georgia Piedmont as reptile species richness increased after urbanization, while amphibian richness decreased (Barrett and Guyer 2008).

Increased intensification of forest management on a smaller land base could have impacts on quantity and quality of water, especially at local scales. In general, an increase in pine plantations or fast growing hardwood species may result in greater water use via transpiration (Ford and others 2011); however, the magnitude and significance of greater transpiration on water resources will depend on the community type that is being replaced and on site specific hydrologic processes. In addition, the impact of greater water use may be offset by a net reduction of forest cover. Increased intensification of forest management activities that create more severe or frequent soil disturbance—such as site preparation, increased harvest frequencies, a larger road network, or more traffic—may result in increased sediment and reduced water quality if Best Management Practices are bypassed.

Based on WaSSI model results under the four future climate scenarios considered in this chapter, streamflows and water supply will generally decrease and become more variable over the next 50 to 100 years. However, magnitudes and even the signs of changes in streamflows resulting from climate change will vary considerably across the region, with some small areas, such as western Texas, experiencing increases in water supply. Other areas will likely experience decreases in supply, particularly in Florida, Oklahoma, and northern Texas. Overall, climate-induced decreases in water supply and increased demand from a growing human population will likely result in an increase in water supply stress into the next century.

Considerable variability of water resource predictions among the future climate scenarios and the absence of overlapping predictions for any particular subregion confound the certainty of future projections. Despite these uncertainties, the importance of water resources for human and aquatic life argues for further research and active management.

Our projections indicate a greater risk of sea-level rise for many coastal areas in this century. Thermal inertia dictates that once the waters rise, curbs in future greenhouse gas emissions will not produce a quick reversal. Therefore, unlike precipitation driven flood events, flooding due to sea-level rise will have long-term consequences. Coastal inundation is one of the most visible impacts of rising sea levels. Areas that were once dry further inland will gradually shift to episodically inundated (during high tides and storms) and then to permanently inundated. The impact of sea level rise to the point of inundation is obvious, but other impacts may be less visible, such as the salt water marshes that exemplify an ecosystem in balance between fresh water and saline environments. These unique places provide important breeding habitat for many terrestrial and aquatic animal species. However, rapidly rising sea levels will permeate non-saline forests and grasslands, causing losses of existing vegetation without the possibility of replacement by more salt tolerant species. Once the existing vegetation is dead, the root structure that binds the soil system together and provides a buffer from incoming tides will also be lost, and coastal erosion is likely to accelerate. Although coastal erosion is a naturally occurring process in barrier islands and many other areas, the increase in rate and severity that is likely with rising sea levels could result in a greatly accelerated loss of valuable coastal property.

Finally, a combination of pressure on water resources from increasing human populations and rising sea levels could severely reduce fresh water supplies along coastal areas. As fresh water is drawn out of shallow ground water systems, adjacent brackish water would likely fill the void, thus raising the risk of salt water contamination to drinking water supplies. Rises in sea level will further increase the risk of contamination as saline water levels rise. The loss of ground water supplies in places like Florida would have enormous social and economic implications and may be more significant than coastal inundation in the near to medium future.

KNOWLEDGE AND INFORMATION GAPS

Past studies on forest-water relations that have been conducted primarily in forested watersheds are not sufficient to address issues in more complex, human dominated landscapes. A key issue is the relationship between increasing urbanization and diminishing available water supply for humans in the South. We need to understand more about the nature of this relationship and how it may change across the array of southern physiographic features. Complexity increases with the interactive effects of multiple drivers including land use change, climate change, population growth, and the natural variability in the hydrologic cycle. A better understanding is critically needed in advance of the next major drought, whose impacts may be exacerbated by expected increases in human populations and impervious surfaces in many areas of the South (chapter 4).

The ramifications of urbanization on surface water and subsequently, human health is another topic that deserves greater attention. Very high counts of fecal coliform and *E. coli* have been documented in urban streams, but the potential risks to human health have not yet been assessed. Research is needed on coastal areas, which have not been adequately studied and are expected to undergo high population growth and development rates in coming years. Also, the sensitivities of aquatic organisms to urbanization have been demonstrated but not quantified, and should be more fully understood so that they can serve as bioindicators of impending degradation to surface water resources. The focus of this chapter was on surface water impacts associated with land use conversion, but literature searches produced little information on the relationships of groundwater to land use and land cover. Because many southern communities are considering expanded use of aquifers, believing them to be "drought proof," they will need to understand the extent to which changes in land use might affect groundwater resources.

The WaSSI model provides a general summary of water supply and demand dynamics across large regions over extended periods of time, requiring assimilation and integration of large datasets and the use of extensive GIS and computing resources. These large data requirements necessitated development of simplifying assumptions to simulate water resource changes in response to climate change. For example, the WaSSI model used for this chapter does not include provisions for water supply reservoir storage or interbasin water transfers; it also assumes that all in-stream surface water is available for human use (no ecological flow is reserved) and that river flows are routed through the river network instantaneously during a given month. It is important to keep in mind that these assumptions may impact water supply stress predictions for some areas across the region. Future land use changes are likely to affect water quality and extreme hydrology such as peakflow rate, issues that are not addressed yet by the WaSSI model. The tradeoffs between water resources and carbon sequestration are not well understood and need to be quantified before embarking on bioenergy development and forest management to mitigate climate warming.

Compared to the physics of oceanic thermal expansion, relatively little is known about the rate of global warming, the changes in ocean surface albedo, or the input of water from snow and ice melts on land. Many of these unknowns are not a function of science gaps, but rather uncertainty about future increases in greenhouse gas emissions. Conversely, the physics of thermal expansion are well understood. As predictions of global warming rates improve, the accuracy of sea-level rise will also improve significantly. Finally, demographic changes and associated pressures on ground water resources are also unknown. These knowledge gaps need to be addressed before a more complete assessment of climate change on sea-level rise is possible.

LITERATURE CITED

Ainslie, W.B. 2002. Forested wetlands. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment: summary report. Gen. Tech, Rep. SRS–54. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 479–500.

Ainsworth, E.A.; Rogers, A. 2007. The response of photosynthesis and stomatal conductance to rising [CO_2]: mechanisms and environmental interactions. Plant, Cell and Environment. 30: 258–270.

Allen, M.R.; Ingram, W.J. 2002. Constraints on future changes in climate and the hydrologic cycle. Nature. 419: 224–232.

Amatya, D.M.; Callahan, T.J.; Radecki-Pawlik, A. [and others]. 2008. Hydrologic and water quality monitoring on Turkey Creek watershed, Francis Marion National Forest, SC. In: Proceedings of the South Carolina water resources conference. Clemson, SC: Clemson University. http://www.clemson.edu/restoration/events/past_events/sc_water_resources/t3_proceedings_presentations/t3_zip/williams.pdf. [Date accessed: October 28, 2010].

Amatya, D.M.; Sun, G.; Skaggs, R.W. [and others]. 2006. Hydrologic effects of global climate change on a large drained pine forest. In: Williams, T., ed. Hydrology and management of forested wetlands: Proceedings of the international conference. St. Joseph, MI: American Society of Agricultural and Biological Engineers: 583–594.

Anderson, S.A.; Masters, R.E. 1992. Riparian forest buffers. Fact Sheet 5034. Stillwater, OK: Oklahoma State University, Cooperative Extension Service. 7 p.

Andrews, W.J.; Becker, M.F.; Smith, S.J.; Tortorelli, R.L. 2009. Summary of surface-water quality data from the Illinois River basin in north Oklahoma, 1970–2007. Rev. Scientific Investigations Report. 2009–5182. Reston, VA: U.S. Geological Survey. 39 p.

Arnold, C.L., Jr.; Gibbons, C.J. 1996. Impervious surface cover: the emergence of a key environmental indicator. Journal of the American Planning Association. 62: 243–258.

Bailey, R.G. 1980. Description of the ecoregions of the United States. Misc. Publ. 1391. Washington, DC: U.S. Department of Agriculture Forest Service. 77 p.

Barrett, K.; Guyer, C. 2008. Differential responses of amphibians and reptiles in riparian and stream habitats to land use disturbances in western Georgia, USA. Biological Conservation. 141: 2290–2300.

Becker, C.J. 2006. Water quality and possible sources of nitrogen and bacteria to Rock and Travertine Creeks, Chickasaw National Recreation Area, Oklahoma, 2004. Scientific Investigations Report. 2005–5279. Reston, VA: U.S. Geological Survey. 24 p.

Beighley, R.E.; Melack, J.M.; Dunne, T. 2003. Impacts of California's climatic regimes and coastal land use change on streamflow characteristics. Journal of the American Water Resources Association. 39: 1419–1433.

Biggs, B.J.F. 1996. Patterns in benthic algae of streams. In: Stevenson, R.J.; Brothwell, M.L.; Lowe, R.L., eds. Algal ecology: freshwater benthic ecosystems. San Diego: Academic Press: 31-56.

Binkley, D.; Brown, T.C. 1993. Management impacts on water quality of forests and rangelands. Gen. Tech. Rep. RM–239. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station. 114 p.

Bledsoe, B.P.; Watson, C.C. 2001. Effects of urbanization of channel instability. Journal of the American Water Resources Association. 37: 255–270.

Blevins, D.W. 2004. Hydrology and cycling of nitrogen and phosphorous in Little Bean Marsh: a remnant riparian wetland along the Missouri River in Platte County, Missouri, 1996–97. Scientific Investigations Report 2004–5171. Reston, VA: U.S. Geological Survey. 78 p.

Boggs, J.; Sun, G. 2011. Urbanization alters watershed hydrology in the Piedmont of North Carolina. Ecohydology. 4: 256-264.

Bolstad, P.V.; Swank, W.T. 1997. Cumulative impacts of land use on water quality in a Southern Appalachian watershed. Journal of the American Water Resources Association. 33(3): 519–533.

Bosch, J.M.; Hewlett, J.D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology. 55: 3–23.

Brian, H.H.; Callaway, M.; Smith, J.; Karshen, P. 2004. Climate change and U.S. water resources: from modeled watershed impacts to national estimates. Journal of the American Water Resources Association. 40: 129–148.

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. Tech. Rep. WRP–DE–4. Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station. 101 p.

Brown, A.E.; Zhang, L.; McMahon, T.A. [and others]. 2005. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology. 310: 28–61.

Brown, T.C.; Hobbins, M.T.; Ramirez, J.A. 2008. Spatial distribution of water supply in the conterminous United States. Journal of the American Water Resources Association. 44: 1474–1487.

Calhoun, D.L.; Frick, E.A.; Buell, G.R. 2003. Effects of urban development on nutrient loads and streamflow, upper Chattahoochee River basin, Georgia, 1976–2001. In: Hatcher, K.J., ed. Proceedings of the 2003 Georgia water resources conference. Athens, GA: The University of Georgia, Institute of Ecology. [Unnumbered pages].

Casarim, F. 2009. Legacy sediments in Southeastern United States Coastal Plain streams. Auburn, AL: Auburn University. 155 p. M.S. thesis.

Chadwick, M.A.; Dobberfuhl, D.R.; Benke, A.C. [and others]. 2006. Urbanization affects stream ecosystem function by altering hydrology, chemistry, and biotic richness. Ecological Applications. 16: 1796–1807.

Chessman, B.; Growns, I.; Currey, J.; Plunkett-Cole, N. 1999. Predicting diatom communities at the genus level for the rapid biological assessment of rivers. Freshwater Biology. 41: 317–331.

Childers, D.L.; Gosselink, J.G. 1990. Assessment of cumulative impacts to water quality in a forested wetland landscape. Journal of Environmental Quality. 19: 455–464.

Clinton, B.D.; Vose, J.M. 2006. Variation in stream water quality in an urban headwater stream in the Southern Appalachians. Water, Air, and Soil Pollution. 169: 331–353.

Crim, J.F. 2007. Water quality changes across an urban-rural land use gradient in streams of the west Georgia piedmont. Auburn, AL: Auburn University. 130 p. M.S. thesis.

Cuffney, T.F.; Brightbill, R.A.; May, J.T.; Waite, I.R. 2010. Responses of benthic macroinvertebrates to environmental changes associated with urbanization in nine metropolitan areas. Ecological Applications. 20(5): 1384–1401.

Dale, V.H.; Joyce, J.A.; McNulty, S. [and others]. 2001. Climate change and forest disturbances. BioScience. 51: 723–734.

de la Cretaz, A.L.; Barten, P.K. 2007. Land use effects on streamflow and water quality in the Northeastern United States. New York: CRC Press. 319 p.

Dennis, J.V. 1988. The great cypress swamps. Baton Rouge, LA: Louisiana State University Press. 232 p.

DiDonato, G.T.; Stewart, J.R.; Sanger, D.M. [and others]. 2009. Effects of changing land use on the microbial water quality of tidal creeks. Marine Pollution Bulletin. 58: 97–106.

Domec J.C., Sun, G., Noormets, A. [and others]. 2012. A comparison of three methods to estimate evapotranspiration in two contrasting loblolly pine plantations: age-related changes in water use and drought sensitivity of evapotranspiration components. Forest Science. 58: 497-512.

Duryea, M.L.; Hermansen, A. 1997. Cypress: Florida's majestic and beneficial wetlands tree. CIR 1186. Gainesville, FL: University of Florida, Florida Cooperative Extension Service, Institute of Food and Agricultural Services. 12 p. http://edis.ifas.ufl.edu. [Date accessed: March 15, 2009].

Easterling, D.R.; Evans, J.L.; Groisman, P.Y. [and others]. 2000. Observed variability and trends in extreme climate events: a brief review. Bulletin of the American Meteorological Society. 81: 417–425.

Ernst, K.A.; Brooks, J.R. 2003. Prolonged flooding decreased stem density, tree size and shifted composition towards clonal species in a central Florida hardwood swamp. Forest Ecology and Management. 173: 261–279.

Exum, L.R.; Bird, S.L.; Harrison, J.; Perkins, C.A. 2005. Estimating and projecting impervious cover in the Southeastern United States. EPA/600/R–05/061. Athens, GA: U.S. Environmental Protection Agency, Ecosystems Research Division. 133 p.

Farley, K.; Jobbagy, E.; Jackson, R.B. 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. Global Change Biology. 11: 1565–1576.

Faulkner, S. 2004. Urbanization impacts on the structure and function of forested wetlands. Urban Ecosystems. 7: 89–106.

Ford, C.R.; Brooks, J.R. 2002. Detecting ecosystem response to increasing river flow in southwest Florida, USA. Forest Ecology and Management. 160: 45–64.

Ford, C.R.; Hubbard, R.M.; Vose, J.M. 2011. Quantifying structural and physiological controls on canopy transpiration of planted pine and hardwood stand species in the Southern Appalachians. Ecohydrology. 4(2): 183-195.

Ford, C.R.; Mitchell, R.J.; Teskey, R.O. 2008. Water table depth affects productivity, water use, and the response to nitrogen addition in a savanna system. Canadian Journal of Forest Research. 38: 2118–2127.

Fox, T.R.; Allen, H.L.; Albaugh, T.J. [and others]. 2007. Forest fertilization and water quality in the United States. Better Crops. 91: 5–7.

Gangloff, M.M.; Feminella, J.W. 2007. Stream channel geomorphology influences mussel abundance in Southern Appalachian streams, USA. Freshwater Biology. 52: 64–74.

Gillies, R.R.; Brim Box, J.; Symanzik, J.; Rodemaker, E.J. 2003. Effects of urbanization on the aquatic fauna of the Line Creek watershed, Atlanta—a satellite perspective. Remote Sensing of Environment. 86: 411–422.

Grace, J.M. 2005. Forest operations and water quality in the South. Transactions of the ASAE. 48(2): 871–880.

Gresham, C.A. 1989. A literature review on developing pocosins. In: Hook, D.D.; Lea, R., eds. Proceedings of the symposium: the forested wetlands of the Southern United States. Gen. Tech. Rep. SE–50. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 44–50.

Grimm, N.B.; Arrowsmith, J.R.; Eisinger, C. [and others]. 2004. Effects of urbanization on nutrient biogeochemistry of aridland streams. In: Defries, R.; Asner, G.; Houghton, R., eds. Ecosystem interactions with land use change. Geophys. Monogr. Ser. 153. Washington, DC: American Geophysical Union: 129–146.

Groffman, P.M.; Bain, D.J.; Band, L.E. [and others]. 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and the Environment. 1(6): 315–321.

Hagen, E.M.; Webster, J.R.; Benfield, E.F. 2006. Are leaf breakdown rates a useful measure of stream integrity along an agricultural landuse gradient? Journal of North American Benthological Society. 25(2): 330–343.

Hammar-Klose, E.S.; Thieler, E.R. 2001. Coastal vulnerability to sea-level rise: a preliminary database for the U.S. Atlantic, Pacific, and Gulf of Mexico Coasts. [CD–ROM]. Digital Data Ser. DDS–68. http://pubs.usgs.gov/dds/dds68. [Date accessed: October 28, 2010].

Helms, B.S. 2008. Response of aquatic biota to changing land use patterns in streams of west Georgia, USA. Auburn, AL: Auburn University. 224 p. Ph.D. dissertation.

Helms, B.S.; Feminella, J.W.; Pan, S. 2005. Detection of biotic responses to urbanization using fish assemblages from small streams of western Georgia, USA. Urban Ecosystems. 8: 39-57.

Helms, B.S.; Schoonover, J.E.; Feminella, J.W. 2009. Seasonal variability of landuse impacts on macroinvertebrate assemblages in streams of western Georgia, USA. Journal of the North American Benthological Society. 28(4): 991–1006.

Hibbert, A.R. 1967. Forest treatment effects on water yield. In: Sopper, W.E.; Lull, H.W., eds. Forest hydrology: Proceedings of a National Science Foundation advanced science seminar. New York: Pergamon Press: 527–543.

Holland, A.F.; Sanger, D.M.; Gawle, C.P. [and others]. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. Journal of Experimental Marine Biology and Ecology. 298: 151–178.

Houlahan, J.E.; Findlay, C.S. 2003. The effects of adjacent land use on wetland amphibian species richness and community composition. Canadian Journal of Fisheries and Aquatic Sciences. 60: 1078–1094.

Huntington, T.G. 2006. Evidence for intensification of the global water cycle: review and synthesis. Journal of Hydrology. 319: 83–95.

Intergovernmental Panel on Climate Change (IPCC). 2007. Contribution of working groups I, II, and III to the fourth assessment report of the intergovernmental panel on climate change. In: Pachauri, R.K.; Reisinger, A., eds. Geneva, Switzerland: Climate change 2007: Synthesis report. 104 p.

Jackson, C.R.; Martin, J.K.; Leigh, D.S.; West, L.T. 2005a. A southeastern piedmont watershed sediment budget: evidence for a multi-millennial agricultural legacy. Journal of Soil and Water Conservation. 60: 298–310.

Jackson, C.R.; Sun, G.; Amatya, D.M. [and others]. 2004. Fifty years of forest hydrology in the Southeast. In: Ice, G.G.; Stednick, J.D., eds. A century of forest and wildland watershed lessons. Bethesda, MD: Society of American Foresters: 33–112.

Jackson, R.B.; Jobbagy, E.G.; Avissar, R. [and others]. 2005b. Trading water for carbon with biological carbon sequestration. Science. 310: 1944–1947.

Jones, J.A.; Post, D.A. 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the Northwest and Eastern United States. Water Resources Research. 40: W05203.

Karl, T.R.; Knight, R.W. 1998. Secular trends of precipitation amount, frequency, and intensity in the USA. Bulletin of the American Meteorology Society. 79: 231–241.

Kenny, J.F.; Barber, N.L.; Hutson, S.S. [and others]. 2009. Estimated use of water in the United States in 2005. Circ. 1344. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 52 p.

Klapproth, J.C.; Johnson, J.E. 2000. Understanding the science behind riparian forest buffers: effects on water quality. Virginia Cooperative Extension Publ. Blacksburg, VA: Virginia Polytechnic Institute and State University: 420–451.

Kolpin, D.W.; Furlong, E.T.; Meyer, M.T. [and others]. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: a national reconnaissance. Environmental Science and Technology. 36: 1202–1211.

Koren, V.; Smith, M.; Duan, Q. 2003. Use of a priori parameter estimates in the derivation of spatially consistent parameter sets of rainfall-runoff models. In: Duan, Q.; Sorooshian, S.; Gupta, H. [and others], eds. Calibration of watershed models water science and applications. American Geophysical Union: 239–254. Vol. 6.

Lehrter, J.C. 2006. Effects of land use and land cover, stream discharge, and interannual climate on the magnitude and timing of nitrogen, phosphorus, and organic carbon concentrations in three Coastal Plain watersheds. Water Environment Research. 78(12): 2356–2368.

Lenat, D.R.; Crawford, J.K. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia. 294: 185–199.

Likens, G.E.; Bormann, F.H. 1995. Biogeochemistry of a forested ecosystem, 2d edition. New York: Springer-Verlag. 159 p.

Lins, H.; Slack, J.R. 1999. Streamflow trends in the United States. Geophysical Research Letters. 26: 227–230.

Lowrance, R.R.; Leonard, R.A.; Asmussen, L.E.; Todd, R.L. 1985. Nutrient budgets for agricultural watersheds in the southeastern Coastal Plain. Ecology. 66(1): 287–296.

Luce, C.H.; Holden, Z.A. 2009. Declining annual streamflow distributions in the Pacific Northwest United States, 1948–2006. Geophysical Research Letters. 36: L16401.

Mallin, M.A.; Williams, K.E.; Esham, E.C.; Lowe, R.P. 2000. Effect of human development on bacteriological water quality in coastal watersheds. Ecological Applications. 10: 1047–1056.

Maloney, K.O.; Feminella, J.W. 2006. Evaluation of single- and multi-metric benthic macroinvertebrate indicators of catchment disturbance over time at the Fort Benning Military Installation, Georgia, USA. Ecological Indicators. 6: 469–484.

Martin, W.H.; Boyce, S.G. 1993. Introduction: the southeastern setting. In: Martin, W.H.; Boyce, S.G.; Echternacht, A.C., eds. Biodiversity of the Southeastern United States: Lowland Terrestrial Communities (Vol. 2). New York: John Wiley: 1-46.

May, S.K.; Kimball, W.H.; Grady, N.; Dolan, R. 1982. CEIS: the coastal erosion information system. Shore and Beach. 50: 19–26.

McCullen, C.P.; Jabbour, J. 2009. Climate change science compendium. http://www.unep.org/compendium2009/. [Date accessed: October 28, 2010].

McMahon, G.; Bales, J.D.; Coles, J. [and others]. 2003. Use of stage data to characterize hydrologic conditions in an urbanizing environment. Journal of the American Water Resources Association. 39: 1529–1546.

McMahon, G.; Harned, D.A. 1998. Effect of environmental setting on sediment, nitrogen, and phosphorous concentrations in Albemarle-Pamlico Drainage Basin, North Carolina and Virginia, USA. Environmental Management. 22(6): 887–903.

Meyer, J.L. 1992. Seasonal patterns of water quality in Blackwater Rivers of the Coastal Plain, Southeastern United States. In: Becker, C.D.; Neitzel, D.A., eds. Water quality in North American river systems. Columbus, OH: Bartelle Press: 249–276.

Mielke, M.S.; Oliva, M.A.; deBarros, N.F. [and others]. 1999. Stomatal control of transpiration in the canopy of a clonal eucalyptus grandis plantation. Trees—Structure and Function. 13: 152–160.

Mitsch, W.J.; Day, J.W.; Gilliam, J.W. [and others]. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: strategies to counter a persistent ecological problem. BioScience. 51(5): 373–388.

Moore, G.W.; Bond, B.J.; Jones, J.A. [and others]. 2004. Structural and compositional controls on transpiration in 40- and 450-year-old riparian forests in western Oregon, USA. Tree Physiology. 24: 481–491.

Morgan, R.P.; Cushman, S.E. 2005. Urbanization effects on stream fish assemblages in Maryland, USA. Journal of the North American Benthological Society. 24: 643–655.

Nagy, R.C.; Lockaby, B.G.; Helms, B. 2011. Water resources and land use/cover in a humid region: The Southeastern United States. Journal of Environmental Quality. 40(3): 867-878.

Nagy, R.C.; Lockaby, B.G.; Kalin, L.; Anderson, C. 2012. Effects of urbanization on stream hydrology and water quality: the Florida Gulf Coast. Hydrological Processes. 26(13): 2019–2030.

Naiman, R.J.; Décamps, H.; McClain, M.E. 2005. Riparia: ecology, conservation, and management of streamside communities. Burlington, MA: Elsevier Academic Press. 430 p.

National Research Council. 1995. Wetlands: characteristics and boundaries. Washington, DC: National Academy Press. 328 p.

Novick, K.; Oren, R.; Stoy, P. [and others]. 2009. The relationship between reference canopy conductance and simplified hydraulic architecture. Advances in Water Resources. 32: 809–819.

Novotny, V. 2003. Water quality: diffuse pollution and watershed management. New York: John Wiley. 888 p.

NPA Data Services, Inc. 1999. Economic databases—mid-range growth projections 1967–2050. Arlington, VA: Regional Economic Projection Series.

Natural Resources Conservation Service (NRCS). 2009. Watershed boundary dataset. http://geo.data.gov/geoportal/catalog/search/resource/details.page?uuid=%7B5DE81693-574F-DB99-9B78-048D2B595498%7D. [Date accessed: January 9, 2009].

O'Gorman, P.A.; Schneider, T. 2009. The physical basis for increases in precipitation extremes in simulations of 21st-century climate change. Proceedings of the National Academy of Sciences. 106: 14,773–14,777.

Oki, T.; Kanae, S. 2006. Global hydrological cycles and world water resources. Science. 313: 1068–1072.

Olivera, F.; DeFee, B.B. 2007. Urbanization and its effect on runoff in the Whiteoak Bayou watershed, Texas. Journal of the American Water Resources Association. 43: 170–182.

Onorato, D.; Marion, K.R.; Angus, R.A. 1998. Longitudinal variations in the ichthyofaunal assemblages of the upper Cahaba River: possible effects of urbanization in a watershed. Journal of Freshwater Ecology. 13: 139–154.

Oren, R.; Pataki, D.E. 2001. Transpiration in response to variation in microclimate and soil moisture in southeastern deciduous forests. Oecologia. 127: 549–559.

Orser, P.N.; Shure, D.J. 1972. Effects of urbanization on the salamander *Desmognathus fuscus fuscus*. Ecology. 53: 1148-1154.

Palmer, T. 1994. Lifelines: the case for river conservation. Washington, DC: Island Press. 256 p.

Parry, M.L.; Canziani, O.F.; Palutikof, J.P. [and others], eds. 2007. Contribution of the working group II to the fourth assessment report of the intergovernmental panel on climate change, 2007. Cambridge, United Kingdom; New York: Cambridge University Press. 976 p.

Paul, M.J.; Meyer, J.L. 2001. Streams in the urban landscape. Annual Review of Ecology, Evolution, and Systematics. 32: 333–365.

Phillips, N.; Oren, R. 2001. Intra- and inter-annual variation in transpiration of a pine forest. Ecological Applications. 11: 385–396.

Powell, T.L.; Starr, G.; Clark, K.L. [and others]. 2005. Ecosystem and understory water and energy exchange for a mature, naturally regenerated pine flatwoods forest in north Florida. Canadian Journal of Forest Research. 35: 1568–1580.

Price, S.J.; Dorcas, M.E.; Gallant, A.L. [and others]. 2006. Three decades of urbanization: estimating the impact of land-cover change on stream salamander populations. Biological Conservation. 133: 436–441.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. Science. 315: 368–370.

Rose, S.; Peters, N.E. 2001. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. Hydrological Processes. 15: 1441–1457.

Ross, M.S.; O'Brien, J.J.; Sternberg, L.D.L. 1994. Sea-level rise and the reduction in pine forests in the Florida Keys. Ecological Applications. 4: 144–156.

Roy, A.H.; Freeman, M.C.; Freeman, B.J. [and others]. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. Journal of the North American Benthological Society. 24: 656–678.

Roy, A.H.; Rosemond, A.D.; Paul, M.J. [and others]. 2003. Stream macroinvertebrate response to catchment urbanisation (Georgia, U.S.A.). Freshwater Biology. 48: 329–346.

Schafer, K.V.R.; Oren, R.; Lai, C.; Katul, G. 2002. Hydrologic balance in an intact temperate ecosystem under ambient and elevated atmospheric CO_2 concentration. Global Change Biology. 8: 895–911.

Schafer, K.V.R.; Oren, R.; Tenhunen, J.D. 2000. The effect of tree height on crown level stomatal conductance. Plant Cell and Environment. 23: 365–375.

Schoonover, J.E.; Lockaby, B.G. 2006. Land cover impacts on stream nutrients and fecal coliform in the lower Piedmont of west Georgia. Journal of Hydrology. 331: 371–382.

Schoonover, J.E.; Lockaby, B.G.; Helms, B.S. 2006. Impacts of land cover on stream hydrology in the west Georgia Piedmont, USA. Journal of Environmental Quality. 35: 2123–2131.

Schoonover, J.E.; Lockaby, B.G.; Pan, S. 2005. Changes in chemical and physical properties of stream water across an urban-rural gradient in western Georgia. Urban Ecosystems. 8: 107–124.

Scott, M.C.; Helfman, G.S.; McTammany, M.E. [and others]. 2002. Multiscale influences on physical and chemical stream conditions across Blue Ridge landscapes. Journal of the American Water Resources Association. 38(5): 1379–1392.

Solley, W.B.; Pierce, R.R.; Perlman, H.A. 1998. Estimated use of water in 1995. Circ. 1200. Alexandria, VA: U.S. Geological Survey. http://water.usgs.gov/watuse/pdf1995/pdf/summary.pdf. [Date accessed: July, 2007].

Soloman, S.; Plattner, G-k.; Knutt, R.; Friedlingstein, P. 2009. Irreversible climate change due to carbon dioxide emissions. Proceedings of the National Academy of Sciences of the USA. 106(6): 1704–1709.

Sponseller, R.A.; Benfield, E.F.; Valett, H.M. 2001. Relationships between land use, spatial scale and stream macroinvertebrate communities. Freshwater Biology. 46: 1409–1424.

Stednick, J.D. 1996. Monitoring the effects of timber harvest on annual water yield. Journal of Hydrology. 176: 79–95.

Stoy, P.; Katul, G.; Siqueira, M. [and others]. 2006. Separating the effects of climate and vegetation on evapotranspiration along a successional chronosequence in the Southeastern United States. Global Change Biology. 12: 2115–2135.

Sun, G.; Alstad, K.; Chen, J. [and others]. 2011. A general predictive model for estimating monthly ecosystem evapotranspiration. Ecohydrology. 4(2): 245-255.

Sun, G.; McNulty, S.G.; Lu, J. [and others]. 2005. Regional annual water yield from forest lands and its response to potential deforestation across the Southeastern United States. Journal of Hydrology. 308: 258–268.

Sun, G.; McNulty, S.G.; Moore Myers, J.; Cohen, E.C. 2008. Impacts of multiple stresses on water demand and supply across the Southeastern United States. Journal of American Water Resources Association. 44(6): 1441–1457.

Sun, G., Noormets, A.; Gavazzi, M.J. [and others]. 2010. Energy and water balance of two contrasting loblolly pine plantations on the lower Coastal Plain of North Carolina, USA. Forest Ecology and Management. 259: 1299-1310.

Sun, G.; Riedel, M.; Jackson, R. 2004. Influences of management of Southern forests on water quantity and quality. In: Rauscher, H.M.; Johnsen, K., eds. Southern Forest Sciences: past, current, and future. Gen. Tech. Rep SRS-75. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 394 p. Chapter 3.

Sutherland, A.B.; Meyer, J.L.; Gardiner, E.P. 2002. Effects of land cover on sediment regime and fish assemblage structure in four Southern Appalachian streams. Freshwater Biology. 47: 1791–1805.

Swank, W.T.; Douglass, J.E. 1974. Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science. 185: 857–859.

Swank, W.T.; Douglass, J.E. 1977. Nutrient budgets for undisturbed and manipulated hardwood forest ecosystems in the mountains of North Carolina. In: Correll, D.L., ed. Watershed research in Eastern North America. Edgewater, MD: Smithsonian Institute: 343-362. Vol. 1.

Swift, L.W., Jr. 1988. Forest access roads: design, maintenance, and soil loss. In: Swank, W.T.; Crossley, D.A., Jr., eds. Ecological studies, forest hydrology and ecology at Coweeta. New York: Springer Verlag: 313–324. Vol. 66.

Thieler, E.R.; Hammar-Klose, E.S. 2000. National assessment of coastal vulnerability to future sea-level rise: preliminary results for the U.S. Gulf of Mexico Coast. Open-File Report 00-179, 1 sheet. U.S. Geological Survey.

Thomson, A.M.; Brown, R.A.; Rosenberg, N.J. [and others]. 2003. Simulated impacts of El Niño/southern oscillation on United States water resources. Journal of the American Water Resources Association. 39: 137–148.

Titus, J.G.; Richman, C. 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the U.S. Atlantic and gulf coasts. Climate Research. 18(2): 205–228.

Tomer, M.D.; Dosskey, M.G.; Burkart, M.R. [and others]. 2005. Placement of riparian forest buffers to improve water quality. [CD-ROM]. In: Brooks, K.N.; Folliot, P.F., eds. Moving agroforestry into the mainstream. Proceedings of the 9th North America agroforestry conference. St. Paul, MN: University of Minnesota, Department of Forest Resources.

Trimble, S.W. 2008. Man-induced soil erosion on the southern Piedmont. Ankey, IA: Soil and Water Conservation Society. 80 p.

Tufford, D.L.; Samarghitan, C.L.; McKellar, H.N., Jr. [and others]. 2003. Impacts of urbanization on nutrient concentrations in small southeastern coastal stream. Journal of the American Water Resources Association. 39(2): 301–312.

Ursic, S.J. 1986. Sediment and forestry practices in the South. In: Proceedings, fourth Federal interagency sedimentation conference. Washington, DC: U.S. Government Printing Office: 28–37. Vol. 1.

U.S. Census. 2001. Census 2000 summary file 1 United States, product ID V1–D00–S1S1–08–US1. http://www.census.gov/geo/www/gazetteer/places2k.html. [Date accessed: October 28, 2010].

U.S. Department of Agriculture (USDA), National Agroforestry Center. 2008. Working trees for water quality. http://www.unl.edu/nac/workingtrees.htm. [Date accessed: June 18, 2010].

U.S. Department of Agriculture (USDA), Natural Resource Conservation Service. 2009. Distribution maps of dominant soil orders. http://soils.usda.gov/technical/classification/orders/ultisols.html. [Date accessed: June 15, 2009].

Utz, R.M.; Hilderbrand, R.H.; Boward, D.M. 2009. Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients. Ecological Indicators. 9: 556–567.

Vellidis, G. 1999. Water quality function of riparian ecosystems in Georgia In: Hatcher, K.J., ed. Proceedings of the Georgia water resources conference. Athens, GA: The University of Georgia, Institute of Ecology: 207-210.

Vicars-Groening, J.; Williams, H.F.L. 2007. Impact of urbanization on storm response of White Rock Creek, Dallas, TX. Environmental Geology. 51: 1263–1269.

Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. Forest Science. 34(3): 547–563.

Vose, J.M.; Sun, G.; Ford, C.R. [and others]. 2011. Forest ecohydrological research in the 21st century: What are the critical needs? Ecohydrology. 4(2): 146-158.

Wahl, M.H.; McKellar, H.N.; Williams, T.M. 1997. Patterns of nutrient loading in forested and urbanized coastal streams. Journal of Experimental Marine Biology and Ecology. 213: 111–131.

Walbridge, M.R. 1993. Functions and values of forested wetlands in the Southern United States. Journal of Forestry. 91(5): 15–19.

Wallace, J.B.; Webster, J.R.; Lowe, R.L. 1992. High-gradient streams of the Appalachians. In: Hackney, C.T.; Adams, S.M.; Martin, W.A., eds. Biodiversity of the Southeastern United States: aquatic communities. New York: John Wiley: 133-192.

Walsh, C.J.; Roy, A.H.; Feminella, J.W. [and others]. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society. 24: 706–723.

Walters, D.M.; Leigh, D.S.; Bearden, A.B. 2003. Urbanization, sedimentation, and the homogenization of fish assemblages in the Etowah River basin, USA. Hydrobiologia. 494: 5–10.

Wang, L.; Lyons, J.; Kanehl, P.; Bannerman, R. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management. 28: 255–266.

Weaver, L.A.; Garman, G.C. 1994. Urbanization of a watershed and historical changes in a stream fish assemblage. Transactions of the American Fisheries Society. 123: 162–172.

Weston, N.B.; Hollibaugh, J.T.; Joyce, S.B. 2009. Population growth away from the coastal zone: thirty years of land use change and nutrient export in the Altamaha River, GA. Science of the Total Environment. 407(10): 3347–3356.

World Wildlife Fund. 2010. U.S. Southeast rivers and streams: safeguarding America's richest source of freshwater. http://wwf.panda.org/what_we_do/where_we_work/southeastern_rivers/. [Date accessed: June 18, 2010].

Wullschleger, S.D.; Hanson, P.J.; Todd, D.E. 2001. Transpiration from a multi-species deciduous forest as estimated by xylem sap flow techniques. Forest Ecology and Management. 143: 205–213.

CHAPTER 14.
Wildlife and Forest Communities

Margaret Trani Griep and Beverly Collins[1]

KEY FINDINGS

- The South has 1,076 native terrestrial vertebrates: 179 amphibians, 525 birds, 176 mammals, and 196 reptiles. Species richness is highest in the Mid-South (856) and Coastal Plain (733), reflecting both the large area of these subregions and the diversity of habitats within them.
- The geography of species richness varies by taxa. Amphibians flourish in portions of the Piedmont and Appalachian-Cumberland highlands and across the Coastal Plain. Bird richness is highest along the coastal wetlands of the Atlantic Ocean and Gulf of Mexico, mammal richness is highest in the Mid-South and Appalachian-Cumberland highlands, and reptile richness is highest across the southern portion of the region.
- The South has 142 terrestrial vertebrate species considered to be of conservation concern (e.g., global conservation status rank of critically imperiled, imperiled, or vulnerable), 77 of which are listed as threatened or endangered by the U.S. Fish and Wildlife Service. More than 900 plant species are of concern, 141 of which are threatened or endangered. Threats to biodiversity are occurring throughout the region.
- The proportion of species at risk varies among taxonomic groups: 46 percent of imperiled vertebrate species are amphibians, followed by reptiles (25 percent), mammals (16 percent), and birds (13 percent). The Coastal Plain (64) and Mid-South (55) lead in the numbers of imperiled vertebrate species, followed by the Appalachian-Cumberland highlands (31), Piedmont (29), and Mississippi Alluvial Valley (9).
- Hotspots of vertebrate species of conservation concern include the Atlantic and Gulf coasts, Peninsular Florida, and Southern Gulf. Emerging areas of concern include sections within the Appalachian-Cumberland highlands (Blue Ridge, Southern Ridge and Valley, Cumberland Plateau and Mountain, Interior Low Plateau) and Mid-South (Ozark-Ouachita Highlands, West Texas Basin and Range, and Cross Timbers).
- Hotspot areas for plants of concern are Big Bend National Park; the Apalachicola area of the Southern Gulf Coast; Lake Wales Ridge and the area south of Lake Okeechobee in Peninsular Florida; and coastal counties of North Carolina in the Atlantic Coastal Plain. The Appalachian-Cumberland highlands also contain plants identified by States as species of concern.
- Species, including those of conservation concern, are imperiled by habitat alteration, isolation, introduction of invasive species, environmental pollutants, commercial development, human disturbance, and exploitation. Conditions predicted by the forecasts will magnify these stressors. Each species varies in its vulnerability to forecasted threats, and these threats vary by subregion. Key areas of concern arise where hotspots of vulnerable species coincide with forecasted stressors.
- There are 614 species that are presumed extirpated from selected States in the South; 64 are terrestrial vertebrates and 550 are vascular plants. Over 50 percent of the terrestrial vertebrates are new to this list since the Southern Forest Resource Assessment. Factors contributing to their demise include urban growth, industrial development, incompatible agricultural practices, degradation of wetlands, alteration of natural hydrological conditions, pesticide contamination, natural and human-caused disturbance, and destruction of locally unique habitats.
- **Mid-South:** Forest loss and urban growth in the Ozark-Ouachita Highlands threatens concentrations of plant and animal species. Urban development along southern borders of Texas and Louisiana in the Cross Timbers and Western Gulf sections could impact a large number of reptiles and birds.
- **Appalachian-Cumberland highlands:** Forecasted changes in the Interior Low Plateau of central Kentucky and Tennessee threaten bats and plants associated with limestone glades. Urban development in the Southern Appalachians could imperil the diversity of salamanders. Recreational use may add additional pressure on rare communities, and climate change threatens species endemic to high elevation areas.
- **Piedmont:** Substantial urban growth and forest loss could degrade the diversity of amphibians, mammals, and plants, although species in inaccessible sites (such as rock outcrops) may be less at risk. Management on public land

[1]Margaret Trani Griep is the Regional Wildlife Ecologist, Southern Region, U.S. Department of Agriculture Forest Service, Atlanta, GA 30309. Beverly Collins is an Associate Professor, Department of Biology, Western Carolina University, Cullowhee, NC 28734.

may become difficult due to the population pressure in surrounding counties. Species in areas transitional to other subregions may also be threatened by climate change.

- **Mississippi Alluvial Valley:** Urban growth forecasts for the Deltaic Plain could degrade the richness of shorebirds and waterfowl in the wetlands of the Mississippi Flyway as well as habitat for the Louisiana black bear. Sea level rise could inundate the coastal habitat inhabited by numerous species.
- **Coastal Plain:** Urban development could threaten species along both coasts and within the Florida Peninsula, which serves as stopover habitat in the Atlantic Flyway and nesting habitat for imperiled sea turtles. The flora of inland ecosystems is threatened by changing fire regimes. Projected inundation of mangrove and coastal live oak forests from sea level rise would reduce habitat for several taxa.
- **High elevation forests:** Spruce-fir forests in the Southern Appalachians are subject to air pollution, acid deposition, and natural disturbances. Climate warming and further housing development may result in the loss of endemic species or changes in species ranges.
- **Upland hardwood forests:** Declines are predicted at 14 percent throughout the region under the Cornerstone that forecasts higher levels of urbanization and lower timber prices. Predicted northward shifts in species distributions could threaten forest interior species and reassemble forest types, including the widely distributed oak-hickory forest.
- **Longleaf pine forests:** Portions of the Coastal Plain are expected to lose acreage under the Cornerstone that forecasts higher urbanization and higher timber prices, while south-central Florida and northwest Alabama are predicted to gain acreage of this forest type.
- **Early successional forests:** Under the Cornerstone that forecasts higher urbanization and higher timber prices, the greatest losses are expected in the Northern Ridge and Valley section, southern Florida and associated Keys, and scattered locations in coastal Virginia and North Carolina. Gains are expected in the Ridge and Valley of east Tennessee, Cumberland Plateau and Mountains, Apalachicola region of Florida, Ozark-Ouachita Highlands, and adjacent northern area of the Mississippi Alluvial Valley.
- Climate change is an additional source of stress on terrestrial species and ecosystems. Projections of temperature increase and variability in precipitation patterns may change the future distribution of many species, influencing seasonal movement, recruitment, and mortality. Species may move into the habitats of others, creating new assemblages; changes in phenology will affect the timing of resource availability.
- Species at risk from climate change include those with restricted geographic ranges, patchy distributions, and those that occur at the margins of their ranges. Other characteristics include limited dispersal ability, low genetic diversity, affinity to aquatic habitats, narrow physiological tolerance, and late maturation.
- Communities at high elevations, grassland communities, and wetland ecosystems may be particularly susceptible to climate change. Species whose ranges are limited to coastal areas will be vulnerable to projected changes in sea level. Sea level rise may inundate barrier islands, coastal wetlands, and marshes of the Coastal Plain, as well as along the eastern Atlantic and Gulf coasts.
- The forecasts pose challenges on how best to implement future conservation and management strategies. New tools and approaches to managing uncertainty (e.g., scenario planning, sensitivity analysis, or ecological risk analysis) may become routine.
- Integrating climate science into management planning will be important, accompanied by monitoring strategies that identify patterns in disturbance, phenology, and range changes. As future impacts occur across large areas, the appropriate decision-making level may shift to cover landscape or regional scales; temporal scales will be longer than typically considered.
- An awareness of the relationship between the forecasts and the geographic pattern of species occurrence will foster planning efforts. The implications for the conservation of southern species are significant: in the midst of a growing region, the provision of biological diversity will become a critical conservation issue.

INTRODUCTION

The diversity of plant and animal communities in the South ranges from high elevation forests to coastal wetlands, barrier islands, and arid regions of west Texas. Factors contributing to the diversity of these communities include regional gradients in climate, geologic and edaphic site conditions, topographic variation, and natural disturbance processes (Boyce and Martin 1993, Delcourt and others 1993, Healy 1985). These factors have contributed to the diversity of several species groups: salamanders, snakes, and turtles (White and others 1998). Throughout the South, the evolution of plants and animals combines with the isolation that characterizes some habitats to produce many pockets of endemism. Endemic species are unique to a given geographic area or locale (http://en.wikipedia.org/wiki/Cosmopolitan_distribution); physical, climatic, and biological factors can contribute to endemism.

Centuries of land use change have modified the southern landscape, resulting in the disappearance and endangerment of species communities. Habitat loss and degradation have become serious threats (Buckner 1989, Noss and others 1995, Williams 1989). Rapid population growth has resulted in land-use conversion (such as wetland drainage and channelization), urban sprawl, and habitat fragmentation (White and others 1998). Landscape modification has led to habitat isolation, water and air pollution, and altered disturbance regimes (Lorimer 2001, Trani and others 2001).

The introduction of nonnative invasive species (Wilcove and others 1998) is a major concern, as is the proliferation of the illegal pet trade (Bailey and others 2006).

The fragmentation of forests that occurs with the conversion of forest habitats often eliminates or displaces species from a site simply because less habitat occurring in smaller and more isolated patches supports fewer species (MacArthur and Wilson 1967). This effect has been shown in fragments of globally imperiled pine rockland forest scattered within urban South Florida (Possley and others 2008), where the result has been fewer plant species and high variance in species richness. Reduced population size can decrease genetic diversity and outcrossing rates (Aguilar and others 2008, Godt and others 1996), while microclimate gradients from edge to interior habitats alter species composition (Honu and others 2009, Matlack 1994). Forest edge provides habitat for invasive species, and decreases habitat for interior species (Fridley and others 2009, Guirado and others 2006).

Another concern is the effect of changing climate on plant and animal communities. Species that are rare because of restrictive or specialized needs are especially at risk. Climate change is one of the factors attributed to amphibian declines (Trani 2002b) and is a special concern for high elevation communities. Along with suffering the direct effects of sea level rise—changes in temperature, precipitation, and coastal inundation—species are indirectly affected by changes in fire regimes and species interactions.

Although the future of these species and the communities they inhabit is uncertain, human population expansion over the next five decades raises the possibility of substantial impacts. The objective of this chapter is to examine how changes in forest environmental and social conditions affect terrestrial wildlife, their habitats, and forest vegetation communities in the South. It is organized into six major discussion topics:

- The geographic patterns of richness for amphibian, bird, mammal, and reptile species, along with a description of the differences in richness among taxa and subtaxa
- The geographic patterns of terrestrial wildlife species formally listed as threatened or endangered under the Endangered Species Act of 1973 (Flather and others 2008) along with a discussion of the environmental factors that imperil them
- The geographic patterns of other at-risk plant and terrestrial wildlife species—those ranked as species of conservation concern by State Heritage Agencies (Trani 2002b)—along with a discussion of the environmental factors that imperil them
- The extent of species extirpation that have already occurred, along with a discussion of the factors that contributed to their extirpation. Comparisons are made with the state lists of extirpated wildlife species presented in the Southern Forest Resource Assessment
- The potential impact on southern species from forecasts of urban development, forest loss, and climate change, and the key areas of concern that coincide with forecasted changes
- The potential effects of anticipated futures on selected forest communities: longleaf pine forests, high elevation forests, early successional communities, and upland hardwood forests

Each topic is addressed for the region as a whole and by subregion and section. The focus is on terrestrial vertebrate species, vascular plants, and select forest communities identified during public meetings held throughout the region (Wear and others 2009). Additional information on forest communities is provided in chapter 4 (land uses), chapter 5 (forest conditions), chapter 3 (climate change), chapter 16 (invasive insects and diseases), and chapter 15 (invasive plant species). Terrestrial species of non-forest habitats, such as arid west Texas, are included. However, because aquatic species were examined in extensive detail in Herrig and Shute (2002) and were not identified as a concern during the public meetings, they are not covered here.

METHODS

Species Criteria

The major species groups included in this analysis consist of the following: birds, mammals, reptiles, amphibians, and vascular plants. The analysis includes forest or non-forest dwelling species that are native to the South.

Species with a conservation status rank of G1-G5 were selected for the richness analyses; G1-G3 and federal status species for the areas of conservation concern analyses; and SX-SH for the State extirpation analyses (table 14.1). Species that were not assessed, unranked or not yet ranked were not included due to the incompleteness of location data for those species. The following filters were applied to the global species data (McNees 2010):

- The species occurs in one or more of the 13 Southern States;
- The species has a rounded G-Rank of G1, G2, G3, G4, or G5, creating a full-species analysis;
- Infrataxa records were rolled up to the full species level for the G-Rank counts. However, infrataxa were tallied individually in the Federal status analyses if that was the relevant taxonomic level that the listing applied to (i.e., often a subspecies has Federal listing status but not the species in entirety);
- A data record was excluded if it was not mappable or had a last observed date prior to 1970;
- For analyses using range maps, the following were excluded: historic, introduced, and extirpated/extinct portions of a species range.

Table 14.1—Conservation status ranks used by NatureServe and its network of Natural Heritage Programs (NatureServe 2011)

Status Rank	Definition
G1	**Critically imperiled**—At a very high risk of extirpation due to extreme rarity (often five or fewer occurrences), very steep declines, or other factors. Critically imperiled globally because of extreme rarity or because of some factor(s) the organism especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000) or acres (<2,000) or linear miles (<10).
G2	**Imperiled**—At high risk of extirpation due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors. Imperiled globally because of rarity or because of some factor(s) the organism very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) or linear miles (10 to 50).
G3	**Vulnerable**—At moderate risk of extirpation due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors. Vulnerable globally either because the organism is very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	**Apparently secure**—Uncommon but not rare; some cause for long-term concern due to declines or other factors—although the organism may be rare in parts of its range, particularly on the periphery—and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5	**Secure**—Common, widespread, and abundant—although the organism may be rare in parts of its range, particularly on the periphery. Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.
SH	**Possibly Extirpated**—Known from only historical records; evidence that the species may no longer be present, but not enough to state this with certainty. A species has been searched for unsuccessfully, but not thoroughly enough to presume that it is no longer present.
SX	**Presumed Extirpated**—Species is believed to be extirpated from the state. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.

Geographic analysis

Geographic shapefiles for each section, subregion, and region boundary used for the Futures analyses (fig. 14.1) were obtained from the Forest Service, U.S. Department of Agriculture. (Further description of these areas, and the process of their delineation, can be found in chapter 1).

Shapefiles of the occurrence and range records were extracted from NatureServe's central databases for species matching project criteria. The species shapefiles were separately intersected against the county, section, and subregion GIS layers using a series of spatial join processes to attribute each individual occurrence record and range polygon to appropriate county, section, and subregion polygons (McNees 2010). The county boundaries layer was downloaded from the U.S. Geological Survey.

The attribute table from the output layer of each spatial join process in the step above was imported into Microsoft Access. The results tables were combined so that there was a single table for the county, section, and subregion results; these were then summarized to create unique lists of species within each area. Crosstab queries generated counts by taxonomic groupings and conservation rank categories.

A series of map image files were produced in .gif format (200 dpi resolution) using ArcMap showing the various counts of species by county for the South. Areas of unique species richness or rarity were identified and representative species occurring in these areas described. Legend categories were determined using the natural breaks method for dividing a range of numeric values into categories, an iterative process to minimize within-category variance.

Biodiversity-forecast analyses

Cornerstone scenarios were selected for the analysis of biodiversity-forecast stressors based on their potential for future impacts in the South. The spatial products created during the initial geographic analysis (patterns of species richness and rarity) were then analyzed in contrast with the

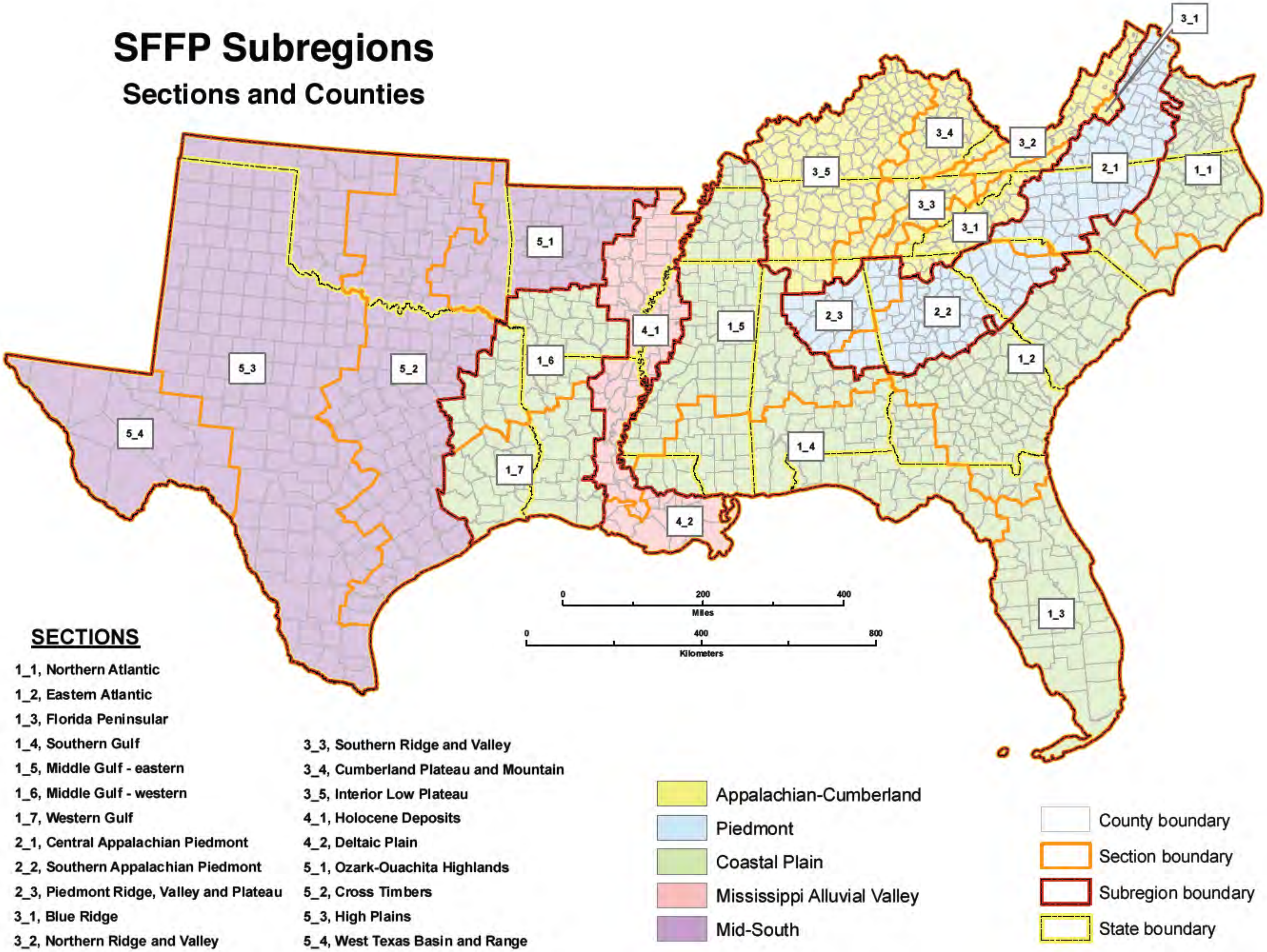


Figure 14.1—The subregion and section boundaries of the Southern Forest Futures analysis.

forecast maps generated for urban growth (chapter 4), forest loss (chapter 5), and climate change (chapter 3). Patterns of coincidence were identified and examined; selected areas of particular concern were described where forecasted stressors coincided with species richness and rarity by subregion and section. A synthesis of the published literature further described how anticipated land use change, human population growth, urbanization, and related infrastructure development could affect species in the South.

GIS maps of special forest communities under selected forecasts were developed from Forest Inventory and Analysis data (chapter 5). Distributions for 2010 and 2060 and percentage changes were described for longleaf pine, early successional forest, and upland hardwood forest along with a discussion of potential impacts on the species that inhabit these communities.

DATA SOURCES

The foundation of this analysis consists of global (range-wide) tracking data developed by NatureServe (2010, 2011) and State-level tracking data provided by Natural Heritage Programs across the South. Use of standard ranking criteria and definitions makes Natural Heritage ranks comparable across taxa groups and across jurisdictions. Standardized criteria include population size, area of occupancy, population trends, suspected threats, environmental specificity, and viability of extant populations. Species data are updated annually, incorporating new information provided by field surveys, monitoring activities, and literature reviews. Systematic surveys for imperiled and other species occurrence vary across counties in the South. These data gaps and other limitations are discussed in the Knowledge and Information Gaps section.

The species locations were derived from element of occurrence and range map data sources. For species considered at-risk (G1-G3) or those having Federal listing status, the data were based on NatureServe's element of occurrence database which is based on observed locations of species (for G3 species that lack occurrence records, range map data were substituted). The threatened or endangered species listed by the U.S. Fish and Wildlife Service were verified from the U.S. Department of the Interior (2011).

For species considered secure or apparently secure (G4-G5), the data were based on NatureServe's range maps for birds, mammals, reptiles, and amphibians. (Because NatureServe does not maintain range maps for plant species, data were not available for G4 to G5 plants.) Unlike element of occurrence data, this information is coarsely mapped and intended to represent the entire range of a species. While often based on element occurrence data, the ranges for species are also based on published literature, expert opinion, and consultations with other organizations. The following are the sources of the range map data specific to this analysis:

- Digital Distribution Maps of the Birds of the Western Hemisphere (Ridgely and others 2007). ArcView shapefiles contain the known range of each species depicted as polygons where a species is widespread, or as points where there are isolated records. Not all vagrant occurrences are depicted. Data were provided by NatureServe in collaboration with Robert Ridgely, James Zook, The Nature Conservancy Migratory Bird Program, Conservation International Center for Applied Biodiversity Science (CABS), World Wildlife Fund US, and Environment Canada WILDSPACE.
- Digital Distribution Maps of the Mammals of the Western Hemisphere (Patterson and others 2007). ArcView shape files contain the known range of each species depicted as polygons where a species is widespread, or as points where there are isolated records. Data were provided by NatureServe in collaboration with The Nature Conservancy, Conservation International CABS, World Wildlife Fund US, and Environment Canada WILDSPACE.
- Digital Distribution Maps of the Reptiles of the United States and Canada (NatureServe 2007). This dataset contains distribution information for terrestrial and aquatic reptiles, crocodilians, and turtles occurring in the United States and Canada. Distribution maps accompany Red List Assessments and species accounts in NatureServe Explorer (www.natureserve.org/Explorer/). Annotated maps indicate scale, sources, taxonomic decisions, current range, origin, and island distributions where applicable.
- Digital Distribution Maps of the International Union for Conservation of Nature Red List of Threatened Species: Amphibian Range Maps (International Union for Conservation of Nature 2009). Part of a global biodiversity assessment, the dataset contains spatial data for approximately 20,000 species including amphibians. The data are held in shapefiles; the known range of each species is depicted in polygon format.

RESULTS

Geographic Patterns of Vertebrate Richness

The terrestrial vertebrates of the South consist of 1,076 native species (NatureServe 2011): 179 amphibians, 525 birds, 176 mammals, and 196 reptiles. Species richness is highest in the Mid-South (856) and Coastal Plain (733). It is evident that species richness is influenced by a species-area relationship among the subregions. Richness reflects the large area of these subregions (chapter 1) and the diversity of habitats within them. The remaining, smaller subregions support fewer vertebrate species: 528 for the Piedmont, 501 for the Mississippi Alluvial Valley, and 484 for the Appalachian-Cumberland highlands.

To support this relationship further, NatureServe Explorer (2010) lists 153 ecosystems in the Coastal Plain and 115 ecosystems in the Mid-South. In comparison, the other subregions support 77 (Appalachian-Cumberland highlands), 22 (Piedmont), and 22 (Mississippi Alluvial Valley) ecosystems, respectively. Here, ecosystem is used in its traditional sense and represents recurring groups of communities found in comparable environments that are influenced by similar ecological processes such as fire or flooding (NatureServe 2011).

The variation in species richness is influenced by differences in geographic location and environmental complexity (fig. 14.2). The most diverse locations follow the coastal areas, starting at the Southern Gulf and moving westward across the Mid-South to the West Texas Basin and Range. These areas support numerous tropical species that reach their northern limits at this latitude (Stein and others 2000). The Ozark-Ouachita Highlands and Cross Timbers areas north of this band also support habitat for an impressive number of amphibian and reptile species, respectively. Areas of richness also occur along the Atlantic Coast from northern Florida to Virginia.

Although figure 14.2 highlights the geographic patterns that cross the four taxonomic groupings, there are differences that are not evident from the composite map. These are reported by subregion and section in table 14.2.

Amphibians—This taxon reaches its uppermost species richness in the South (Bailey and others 2006). Of the 179 amphibian species that occur in the region, the majority are salamanders (113): mole salamanders, hellbenders, lungless salamanders, mudpuppies, and sirens. Frogs and toads (66 species) constitute the second group. Characteristic species include true frogs, tree frogs, chorus frogs, cricket frogs, true toads, narrowmouth toads, and spadefoot toads. Amphibians are an increasing important consideration in many issues of conservation concern.

Amphibians use ephemeral pools, seeps, bogs, caves, forests, floodplain and isolated wetlands, small ponds, and other habitats. The longleaf pine/wiregrass community,

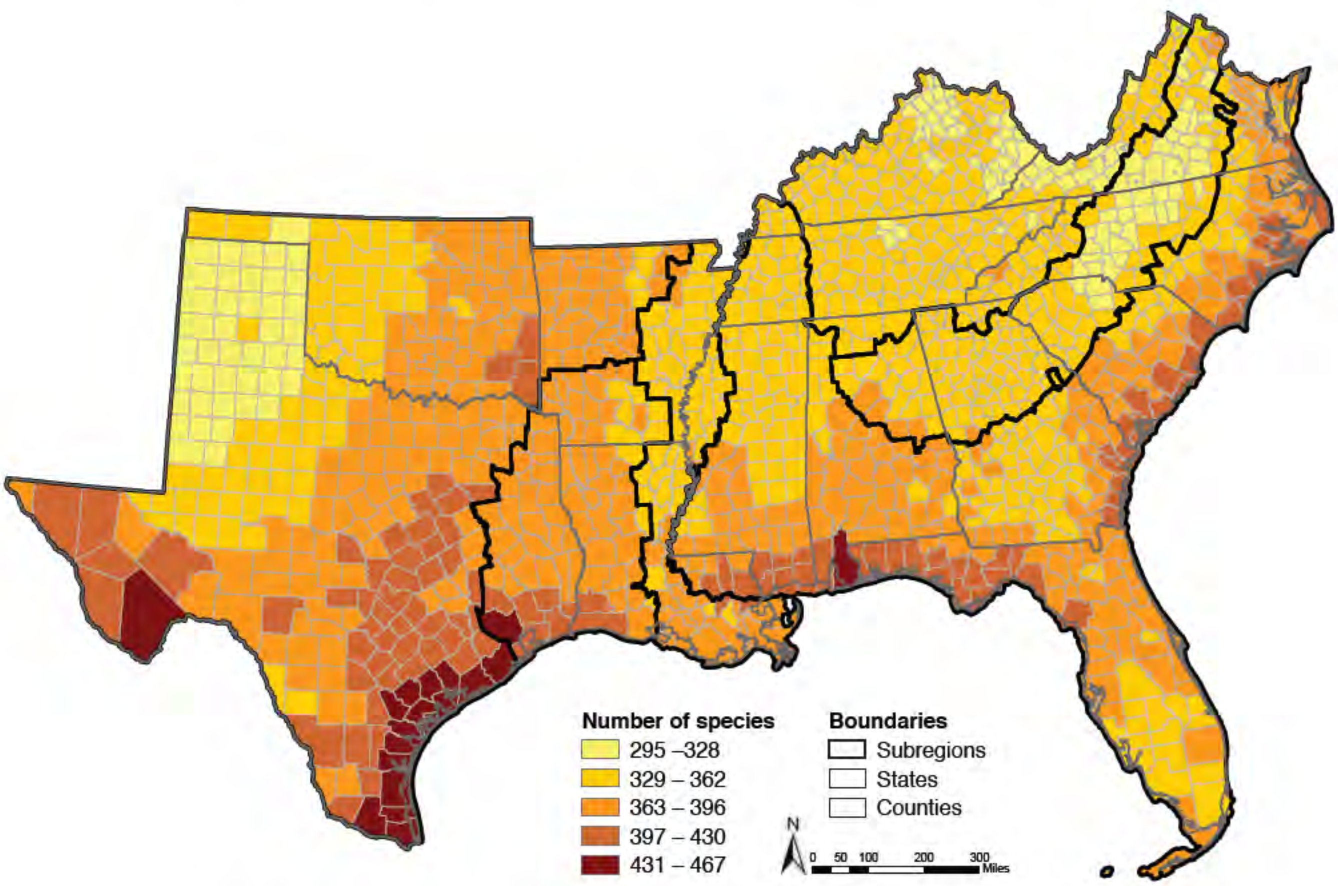


Figure 14.2—County-level counts of native terrestrial vertebrate species in the South. (Source: NatureServe 2011)

Table 14.2—Vertebrate species richness by ecological subregion and section (NatureServe 2011).

		Subtaxa																
Subregion	Section	Frogs and toads	Salamanders	Other birds	Perching birds	Raptors	Shorebirds	Wading birds	Waterfowl	Bats	Carnivores	Other mammals	Rodents	Crocodilians	Lizards	Snakes	Turtles	Worm lizards
Appalachian-Cumberland	Blue Ridge	17	54	42	132	13	17	11	21	16	11	18	26		9	26	13	
	Cumberland Plateau and Mountain	20	35	43	135	14	17	11	22	16	11	15	25		9	24	12	
	Interior Low Plateau	25	32	45	139	15	16	11	24	16	12	16	23		9	29	15	
	Northern Ridge and Valley	16	41	42	130	14	17	7	24	11	12	16	23		7	21	13	
	Southern Ridge and Valley	15	41	43	130	12	16	8	20	14	11	16	26		9	21	11	
Coastal Plain	Eastern Atlantic	29	31	70	131	16	35	16	28	14	10	14	20	1	13	42	23	1
	Florida Peninsular	21	18	81	128	20	33	19	25	13	12	13	18	2	14	40	21	1
	Middle Gulf-Eastern	32	35	52	139	16	22	15	24	15	13	11	21	1	11	40	23	
	Middle Gulf-Western	26	21	54	140	14	24	13	24	13	13	12	21	1	13	38	17	
	Northern Atlantic	29	22	75	134	17	35	13	32	11	11	13	20	1	10	35	18	
	Southern Gulf	34	33	71	136	15	32	19	27	13	11	11	25	1	12	48	34	1
	Western Gulf	27	16	80	142	18	37	16	31	13	15	13	22		12	41	18	
Mid-South	Cross Timbers	38	26	86	184	21	37	17	34	16	17	18	41		25	58	24	
	High Plains	37	18	92	208	28	38	17	31	25	20	16	57		38	64	21	
	Ozark-Ouachita Highlands	29	29	49	143	15	20	12	25	16	12	14	27	1	13	38	17	
	West Texas Basin and Range	19	4	66	171	21	22	10	25	24	14	15	46		35	43	10	
Mississippi Alluvial Valley	Deltaic Plain	25	18	69	127	15	32	15	27	8	10	10	14		10	36	16	
	Holocene Deposits	30	29	61	141	16	31	14	24	14	12	11	23	1	11	38	17	
Piedmont	Central Appalachian Piedmont	29	48	61	133	17	25	10	27	13	12	20	24		10	33	13	
	Piedmont Ridge, Valley, and Plateau	24	36	43	127	13	16	11	22	14	10	11	23		11	30	17	
	Southern Appachian Piedmont	31	43	43	128	13	17	13	20	15	12	17	22		11	38	21	

cypress-gum swamps, and mixed hardwood-pine habitats support a variety of species. Coastal bayous and slow-moving rivers provide habitat for sirens and amphiumas, while hellbenders prefer cool, fast-flowing upland rivers. Some amphibians have geographic ranges that are restricted to specific physiographic regions. For example, Coastal Plain forests are important for mole salamanders, while other amphibians occur in small, isolated populations in high elevation areas that retain northern climates (Gibbons and Buhlmann 2001). Moisture is a limiting factor: several terrestrial species migrate to aquatic habitats for egg deposition, while aquatic species use terrestrial habitat for dispersal of juveniles and other seasonal activity. Leaf litter, fallen logs, moist soils, and other surface debris serve as refugia from drying conditions.

The Coastal Plain (106 species) leads in amphibian richness, followed closely by the Piedmont (94), Mid-South (91), and Appalachian-Cumberland highlands (90). Sixty-two species of amphibians inhabit the Mississippi Alluvial Valley (fig. 14.3). Salamander richness is highest in the Appalachian-Cumberland highlands (64) and Piedmont (61), and frog and toad richness is greatest in the Coastal Plain (50) and Mid-South (46).

The distribution of amphibians across the South is far reaching, encompassing mountains, highlands, and coastal areas along the Atlantic Ocean and Gulf of Mexico (fig. 14.4). The Southern Appalachians support notable richness levels of salamander species in the Blue Ridge (54), Central Appalachian Piedmont (48), Southern Appalachian Piedmont (43), and both Ridge and Valley sections (41). Characteristic species include the cave salamander (*Eurycea lucifuga*), dusky salamander (*Desmognathus fuscus*), eastern newt (*Notophthalmus viridescens*), lesser siren (*Siren intermedia*), marbled salamander (*Ambystoma opacum*), and mudpuppy (*Necturus maculosus*).

Frog and toad richness is highest in the Cross Timbers (38) and High Plains (37) sections of the Mid-South and Southern Gulf (34) section of the Coastal Plain (table 14.2). The two Mid-South areas provide habitat for the Cajun chorus frog (*Pseudacris fouquettei*), Cope's gray treefrog (*Hyla chrysoscelis*), southern leopard frog (*Rana sphenocephala),* eastern narrow-mouthed toad (*Gastrophryne carolinensis*), Hurter's spadefoot (*Scaphiopus hurterii*), and red-spotted toad (*Bufo punctatus*). The Southern Gulf supports the barking treefrog (*Hyla gratiosa*), Coastal Plain toad (*Bufo nebulifer*), and spring peeper (*Pseudacris crucifer*).

The areas that support a diversity of both amphibian assemblages form an arc across the southern portion of the Northern Atlantic (51 species), Eastern Atlantic (60 species), westward across the Southern Gulf (67 species), and northwest across the Middle Gulf-Eastern (67 species), the Holocene Deposits section of the Mississippi River (59 species), and the Ozark-Ouachita Highlands (58 species). The two Atlantic sections provide habitat for the four-toed salamander (*Hemidactylium scutatum*), northern dwarf siren (*Pseudobranchus striatus*), and spotted salamander (*Ambystoma maculatum*). The Southern and Middle Gulf-Eastern locations provide habitat for the three-lined salamander (*Eurycea guttolineata*) and Woodhouse's toad (*Bufo woodhousii*). Numerous frogs, toads, and salamanders inhabit the Holocene Deposits including the Gulf Coast waterdog (*Necturus beyeri complex*), Louisiana slimy salamander (*Plethodon kisatchie*), and Ozark zigzag salamander (*Plethodon angusticlavius*). Characteristic

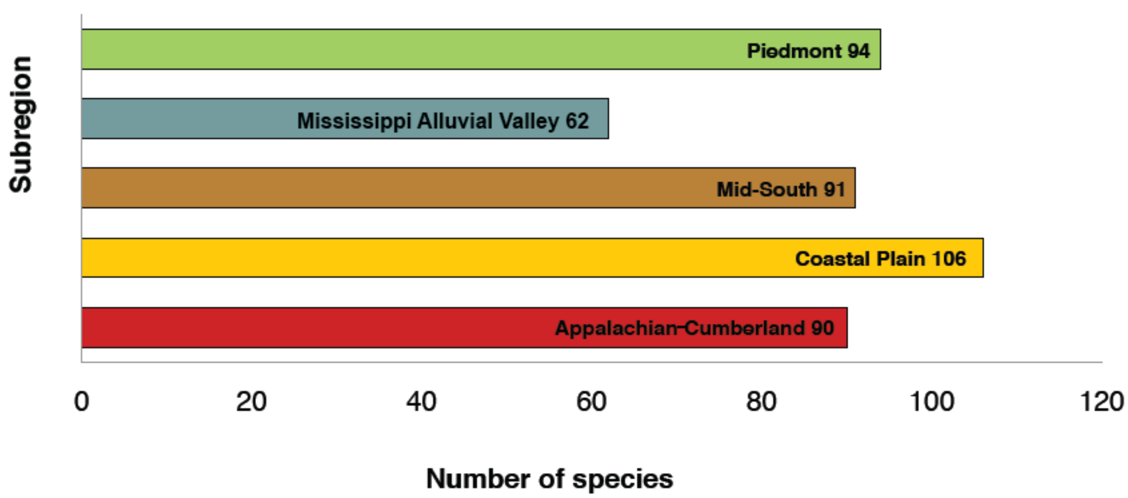


Figure 14.3—Richness of amphibian species by subregion in the South.

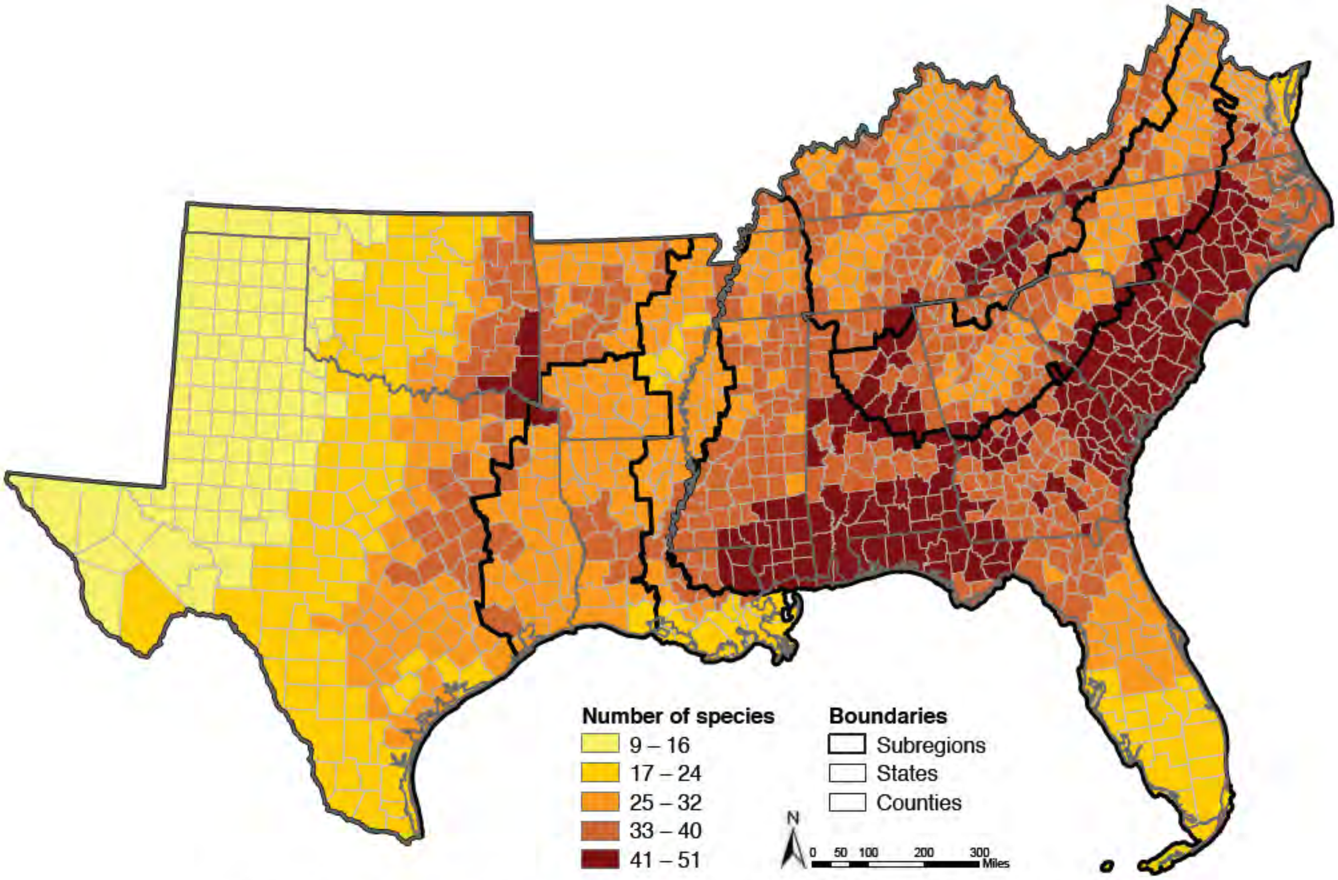


Figure 14.4—County-level counts of all native amphibian species in the South. (Source: NatureServe 2011)

species occurring in the Ozark-Ouachita Highlands include the pickerel frog (*Rana palustris*), Plains leopard frog (*Rana blairi*), Ozark hellbender (*Cryptobranchus alleganiensis bishopi*), and three-toed amphiuma (*Amphiuma tridactylum*).

Birds—The moderate climate and diverse forests across the South sustain abundant and diverse communities of breeding, wintering, and migrating birds. The region supports 525 avian species (NatureServe 2011), which include perching birds, shorebirds, wading birds, waterfowl, and raptors. Perching birds comprise the majority of bird species (256 species). Included in this subgroup are flycatchers, crows, swallows, jays, wrens, vireos, grackles, orioles, finches, sparrows, and warblers. The NatureServe category of "Other Birds" includes 137 species represented by several gamebirds, woodpeckers, and open ocean birds such as cormorants, petrels, and pelicans. There are 41 species classified as waterfowl; representative birds include mottled ducks, Canada geese, wood ducks, and mallards. Shorebird examples (41 species) include plovers and curlews, and wading bird examples (20 species) include sandhill cranes and flamingos. The 30 raptors occurring in the South include eagles, hawks, kites, and vultures.

The distribution of birds is influenced by a combination of local and landscape conditions. Local features include habitat composition, structural diversity, and successional stage. Landscape conditions include habitat patch size, interspersion of vegetative communities, edge length, interpatch distance, interior forest, adjacent land use, and spatial heterogeneity. The South provides habitat for summer breeding populations, overwintering birds, and birds that migrate to South America. Coastal and maritime forest communities provide important habitat for these species.

The peak number of bird species (469) occurs in the Mid-South (fig. 14.5), where perching bird (241) and raptor (28) diversity occur in highest numbers. The Mid-South's impressive diversity is due to its extent, habitat heterogeneity, and central placement along the Nation's southern border. Second to the Mid-South is the Coastal Plain (395), which supports the majority of waterfowl (38), shorebirds (40), and wading birds (21). The next tier is led by the Mississippi

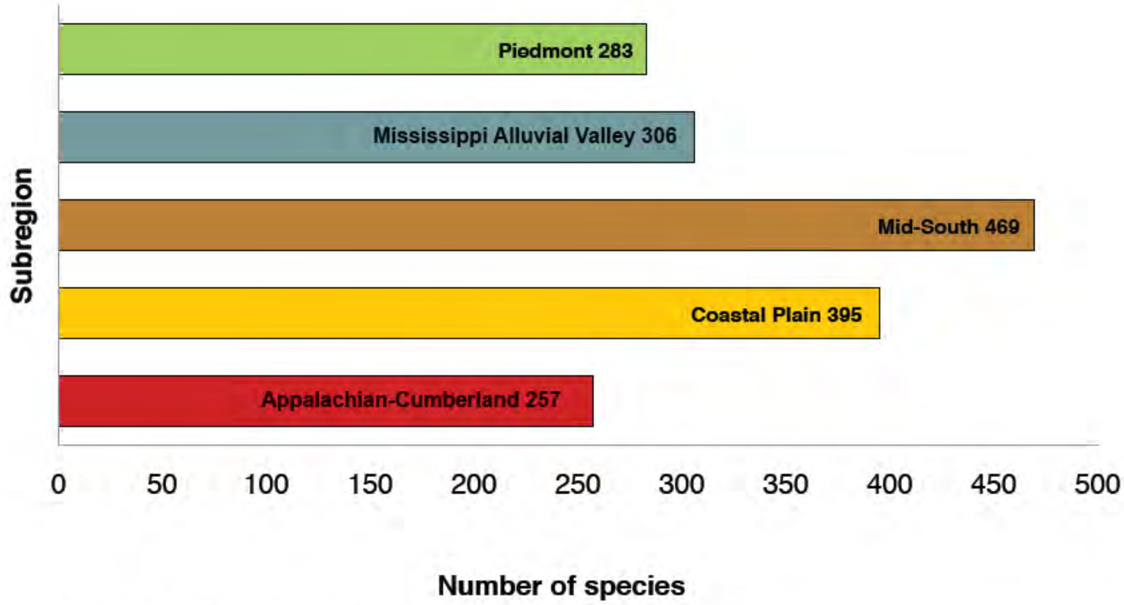


Figure 14.5—Richness of bird species by subregion in the South.

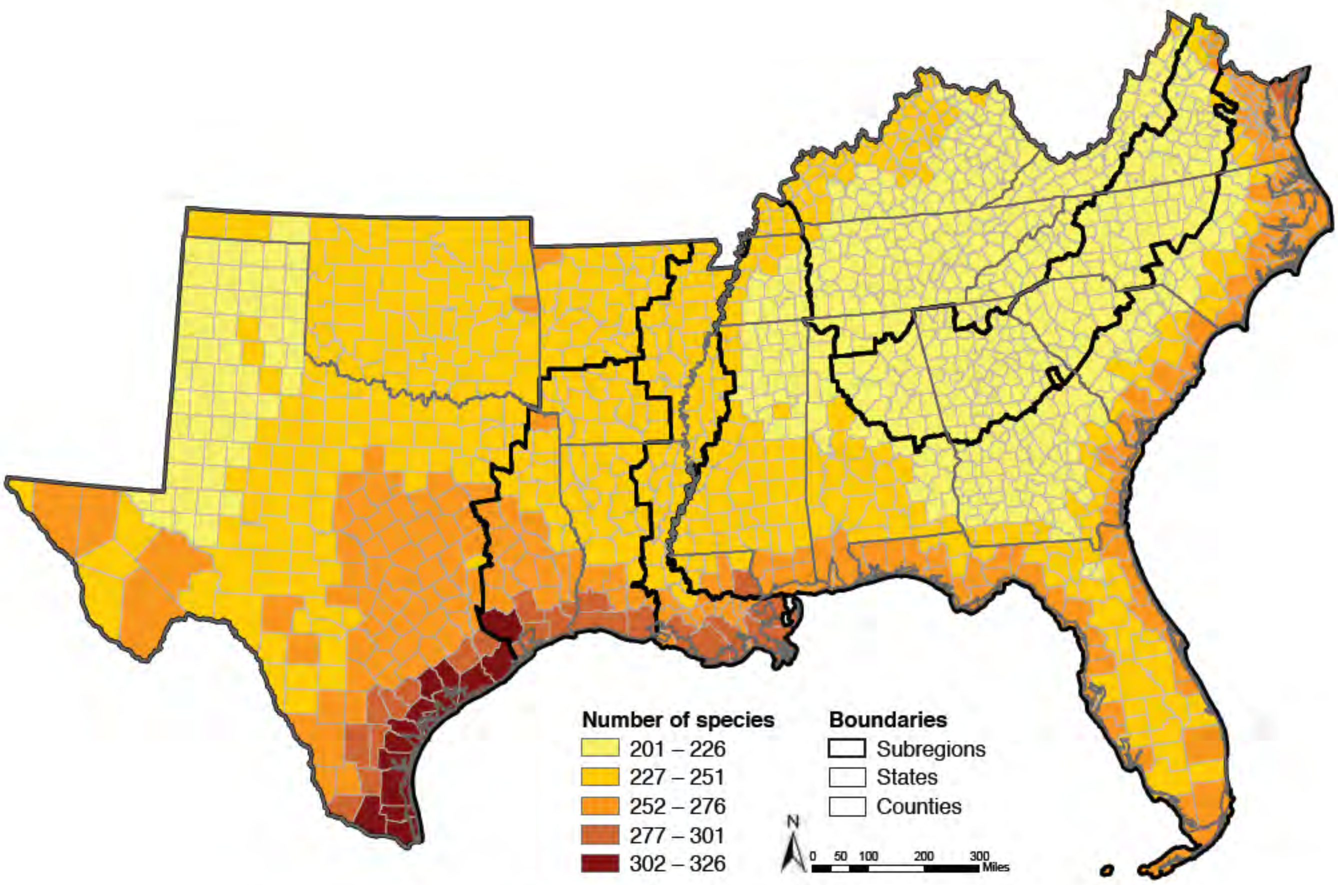


Figure 14.6—County-level counts of all native bird species in the South. (Source: NatureServe 2011)

Alluvial Valley (306), Piedmont (283), and Appalachian-Cumberland highlands (257).

Bird richness along the coastal areas and wetlands of the Atlantic Ocean and Gulf of Mexico points to the importance of this habitat (fig. 14.6). The pattern across the southernmost portions of Texas and Peninsular Florida reflects those species typical of Latin America and the Caribbean (Stein and others 2000). Of particular prominence are the Southern Gulf; the portions of the Cross Timbers and High Plains that form the Texas eastern coastline; and the Western Gulf and Deltaic Plain at the mouth of the Mississippi River. The two Mid-South sections each support habitat for over 360 species; these include Cooper's hawk (*Accipiter cooperii*), golden eagle (*Aquila chrysaetos*), white-tailed kite (*Elanus leucurus*), Le Conte's sparrow (*Ammodramus leconteii*), juniper titmouse (*Baeolophus ridgwayi*), and canyon wren (*Catherpes mexicanus*).

The Northern Atlantic and Western Gulf provide habitat for a diversity of waterfowl including American wigeon (*Anas americana*), blue-winged teal (*Anas discors*), bufflehead (*Bucephala albeola*), hooded merganser (*Lophodytes cucullatus*), and lesser scaup (*Aythya affinis*). The salt marshes of the Northern Atlantic also support important breeding and wintering populations of the American black duck (*Anas rubripes*) and black rail (*Laterallus jamaicensis*). Numerous wading birds inhabit the Southern Gulf and Florida Peninsula including the great egret (*Ardea alba*), little blue heron (*Egretta caerulea*), and white-faced ibis (*Plegadis chihi*). Thirty-three species of shorebirds occur in the Eastern Atlantic, Northern Atlantic, and Western Gulf; characteristic species include the American oystercatcher (*Haematopus palliatus*), dunlin (*Calidris alpina*), greater yellowlegs (*Tringa melanoleuca*), and upland sandpiper (*Bartramia longicauda*).

Mammals—Terrestrial, marine, and freshwater habitats in the South are home to 176 native mammals (NatureServe 2011) including rodents, bats, and carnivores. Rodents (79 species) are the largest group, with representative species including squirrels, pocket gophers, voles, jumping and harvest mice, and muskrats. There are 39 species of bats inhabiting the region. Foxes, weasels, canids, and skunks are among the 25 species of carnivores. The relative absence of large, native carnivores reflects the history of European settlement (Trani and others 2007). The American black bear (*Ursus americanus*) is the largest carnivore currently inhabiting the South. The NatureServe category of "other mammals" includes 33 species represented by ungulates, lagomorphs, shrews, moles, and others.

Mammals are associated with specific habitats that offer suitable forage and refuge; patterns of use vary with seasonal food availability. Areas are diverse in composition, structure, and ecological succession stage; mosaics of cover types and the ecotones between them enhance prey density and other food opportunities. Most hollow logs, snags, brush piles, or rock outcrops are acceptable dens for rodents and carnivores, but the caves used by some bats must meet precise temperature and humidity conditions. Mammals associated with aquatic habitats use estuaries, marshes, and streams. Terrestrial habitats include desert, prairie, savanna, and agricultural fields. In the mountains, high-elevation habitats (such as spruce-fir and northern hardwood forests) are important to the long-tailed shrew (*Sorex dispar*); in coastal areas, bottomland hardwoods and cypress swamps support the swamp rabbit (*Sylvilagus aquaticus*).

The peak number of mammal species (148) occurs in the Mid-South, where rodent (68), bat (38), and carnivore (22) diversity occur in highest numbers (fig. 14.7). Second is the Coastal Plain (103 species), which supports the most species categorized as "other mammals" (24 species) by NatureServe. The next tier is led by the Appalachian-Cumberland highlands (77 species), Piedmont (76 species), and Mississippi Alluvial Valley (61 species).

The distribution of mammal diversity across the region highlights patterns in two quite different subregions: the Mid-South and the Appalachian-Cumberland highlands (fig. 14.8). Of particular importance is the West Texas Basin and Range section, which is located on the Mexican border and provides habitat for 99 mammal species. Together, the four Mid-South sections support the highest richness of rodents ranging from 57 species in the High Plains to 27 species in the Ozark-Ouachita Highlands. Characteristic rodents from these sections include the cactus deermouse (*Peromyscus eremicus*), Chihuahuan pocket mouse (*Chaetodipus eremicus*), Mexican ground squirrel (*Spermophilus mexicanus*), Southern Plains woodrat (*Neotoma micropus*), and Texas antelope squirrel (*Ammospermophilus interpres*). Bat richness is also greatest in the Mid-South, with the High Plains (25 species) and West Texas Basin and Range (24 species) supporting the southern yellow bat (*Lasiurus ega*), spotted bat (*Euderma maculatum*), Yuma myotis (*Myotis yumanensis*), and other species. Carnivore richness is highest in the band from southcentral Texas (17 species) expanding westward through the Western Gulf (15 species). Unique western carnivores include the ocelot (*Leopardus pardalis*), western spotted skunk (*Spilogale gracilis*), and white-nosed coati (*Nasua narica*). Each remaining area in the South supports a range of 10 to 12 carnivores.

Mammal richness is also notable in the Appalachian-Cumberland highlands, which encompasses a much smaller area than the Mid-South but supports 16 bat species including the eastern small-footed myotis (*Myotis leibii*), gray myotis (*Myotis grisescens*), and Virginia big-eared

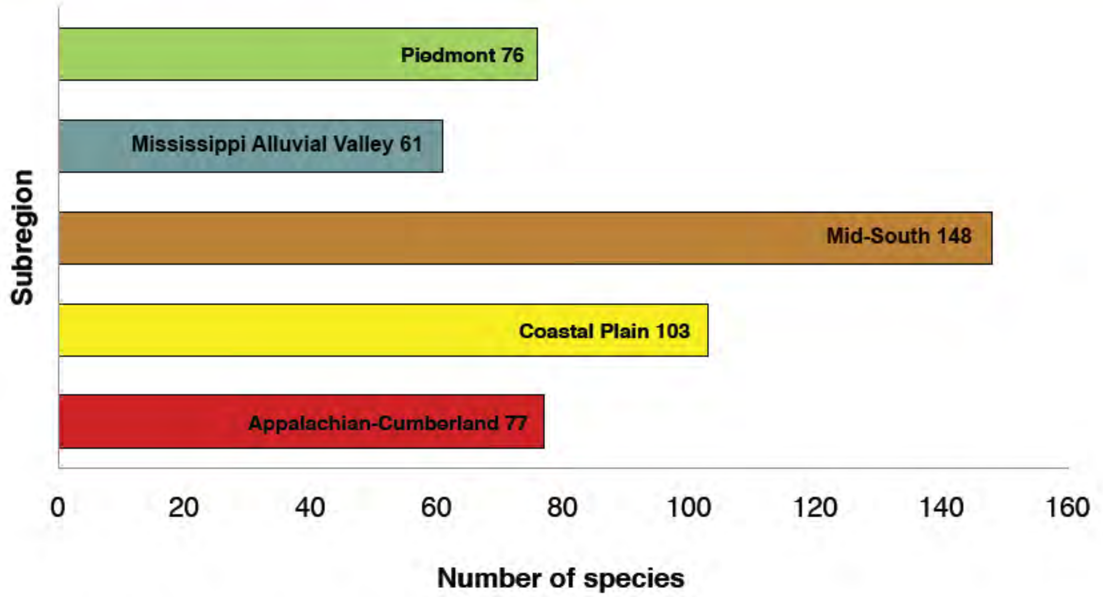


Figure 14.7—Richness of mammal species by subregion in the South.

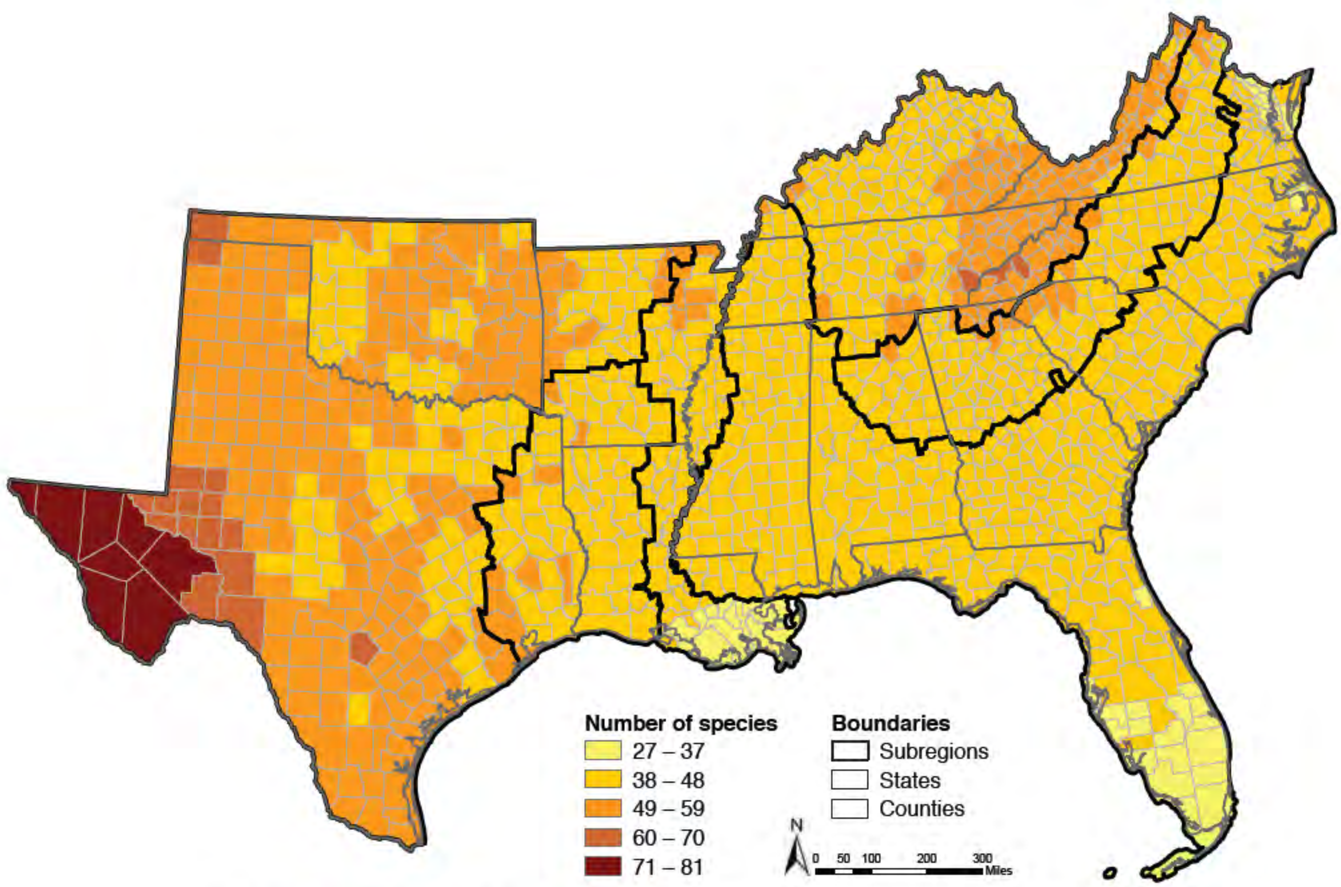


Figure 14.8—County-level counts of all native mammal species in the South. (Source: NatureServe 2011)

bat (*Corynorhinus townsendii virginianus*). There are 28 rodent species within mountainous areas providing habitat for the Allegheny woodrat (*Neotoma magister*), red squirrel (*Tamiasciurus hudsonicus*), and southern bog lemming (*Synaptomys cooperi*). The Central Appalachian Piedmont (20 species) and Blue Ridge (18 species) support the largest number of "other mammals," which include the American water shrew (*Sorex palustris*), Appalachian cottontail (*Sylvilagus obscurus*), hairy-tailed mole (*Parascalops breweri*), and long-tailed shrew among others.

Reptiles—The South supports 196 reptile species (NatureServe 2011), including snakes (90), lizards (53), turtles (50), crocodilians (2), and worm lizards (1). The major subgroups of snakes are nonvenomous snakes, coral snakes, and pit vipers; species that inhabit the water are especially prevalent. Two of the largest snakes in North America occur in the region: the eastern indigo snake (*Drymarchon couperi*) and eastern diamond-backed rattlesnake (*Crotalus adamanteus*). The four lizard subgroups include anole lizards, fence lizards, collared lizards, horned lizards, whiptails, skinks, and glass lizards. The turtle group consists of sea turtles, snapping turtles, box turtles, mud and musk turtles, tortoises, and soft-shell turtles. The two crocodilians are quite well-known: the American alligator (*Alligator mississippiensis*) and American crocodile (*Crocodylus acutus*). The fossorial worm lizard (*Rhineura floridana*), despite its name and appearance, is an Amphisbaenian and does not belong in either the snake or the lizard group.

With the exception of lizards, the all reptiles reach their maximum species richness in the South (Bailey and others 2006). As with amphibians, ecological importance of lizards has become recognized in the past decade as resource objectives focus on biodiversity conservation, landscape perspectives, and their role in ecosystem functioning.

Reptiles occupy a variety of habitats including mesic and xeric hardwood forests, sandhills, grasslands, prairies, barrens, outcrops, beaches and dunes, agricultural and urban areas (Bailey and others 2006). Rivers, streams, swamps, lakes, and marshes figure prominently in aquatic turtle occurrence. Groups such as mud turtles (*Kinosternon* spp.) use terrestrial habitat for nesting and winter dormancy, spending the summer in wetland areas. The forested mountain areas support an abundance of reptiles including the bog turtle (*Glyptemys muhlenbergii*), while the longleaf pine-wiregrass community is vital habitat for the gopher tortoise (*Gopherus polyphemus)* and glass lizard (*Ophisaurus* spp.). Cypress-gum swamps support several species (Gibbons and Buhlmann 2001) including the rainbow snake (*Farancia erytrogramma*) and striped crawfish snake (*Regina alleni*). Leaf litter and fallen logs provide shelter and foraging opportunities; friable soils are an important habitat component for many.

The Mid-South (148 species) leads in reptile richness (fig. 14.9), where snake (74) and lizard (45) species occur in the highest numbers. The diversity of this subregion reflects its large size and strategic location at the crossroads of several distinct reptilian fauna (Stein and others 2000). Many eastern reptiles reach their westernmost distribution in the Mid-South, while the converse is also true for western reptiles. Second in reptile richness is the Coastal Plain (129), which supports the most turtle species (43) in its abundant coastal and freshwater habitats. The third tier is comprised of the Piedmont (75), Mississippi Alluvial Valley (72), and Appalachian-Cumberland highlands (60).

The distribution of reptile diversity is concentrated across the southern portion of the region, with notable differences among the various groups (fig. 14.10). Lizard richness is highest in the western sections of three Mid-South sections—High Plains (38), West Texas Basin and Range (35), and Cross Timbers (25)—reflecting availability of arid habitats. These three sections provide habitat for the Texas spotted whiptail (*Aspidoscelis gularis*), eastern collared lizard (*Crotaphytus collaris),* round-tailed horned lizard (*Phrynosoma modestum*), and canyon lizard (*Sceloporus merriami*). Snakes are quite diverse in both the eastern and western portions of the region. The High Plains (64), Cross Timbers (58), and West Texas Basin and Range (43) sections support the Chihuahuan hook-nosed snake (*Gyalopion canum*), prairie rattlesnake (*Crotalus viridis*), and Texas threadsnake (*Leptotyphlops dulcis*). The Southern Gulf (48), Eastern Atlantic (42), and Florida Peninsular (40) sections are inhabited by the cottonmouth (*Agkistrodon piscivorus*), Florida crowned snake (*Tantilla relicta*), and southern watersnake (*Nerodia fasciata*). The Southern Gulf supports the maximum diversity of turtles (34) including the Alabama map turtle (*Graptemys pulchra*), Pascagoula map turtle (*Graptemys gibbonsi*), and Peninsula cooter (*Pseudemys peninsularis).* Other notable Coastal Plain areas inhabited by a variety of turtles include the Eastern Atlantic (23), Middle Gulf-Eastern (23), and Florida Peninsular (21). Characteristic species include the common musk turtle (*Sternotherus odoratus*), eastern box turtle (*Terrapene carolina*), southern painted turtle (*Chrysemys dorsalis*), and spiny softshell (*Apalone spinifera*).

Geographic Patterns of Species Listed as Threatened or Endangered

Figure 14.11 displays the distribution of 77 vertebrate species listed as threatened or endangered by the U.S. Fish and Wildlife Service in the South. There is an evident pattern of endangerment along the Atlantic Ocean coast extending from North Carolina to Florida and along the Gulf of Mexico westward to Louisiana, with pockets along the southern coast of Texas.

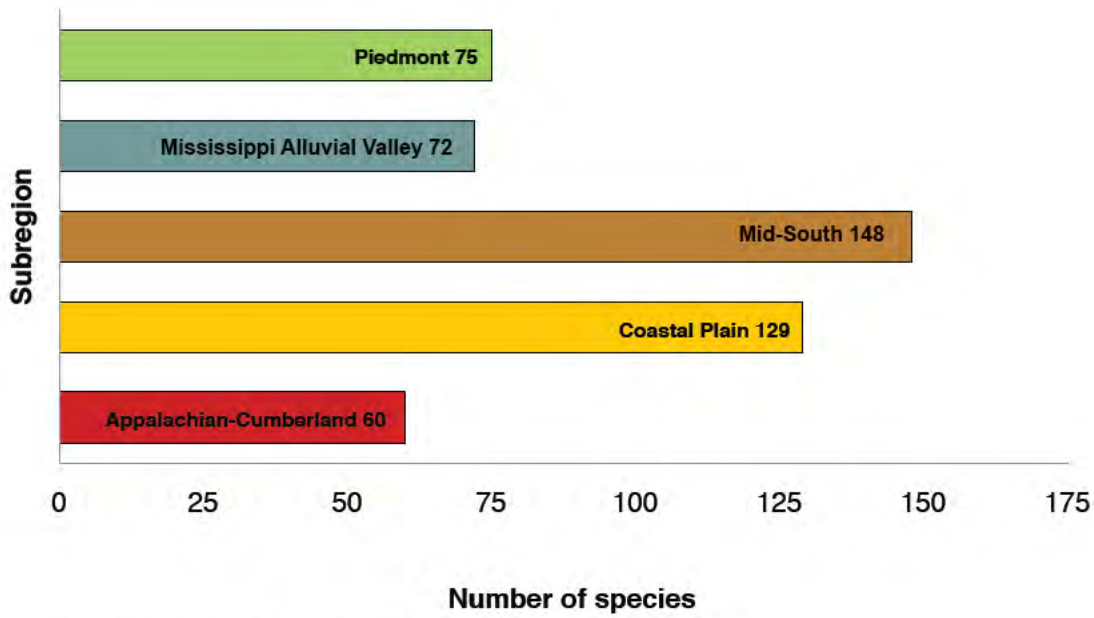


Figure 14.9—Richness of reptile species by subregion in the South.

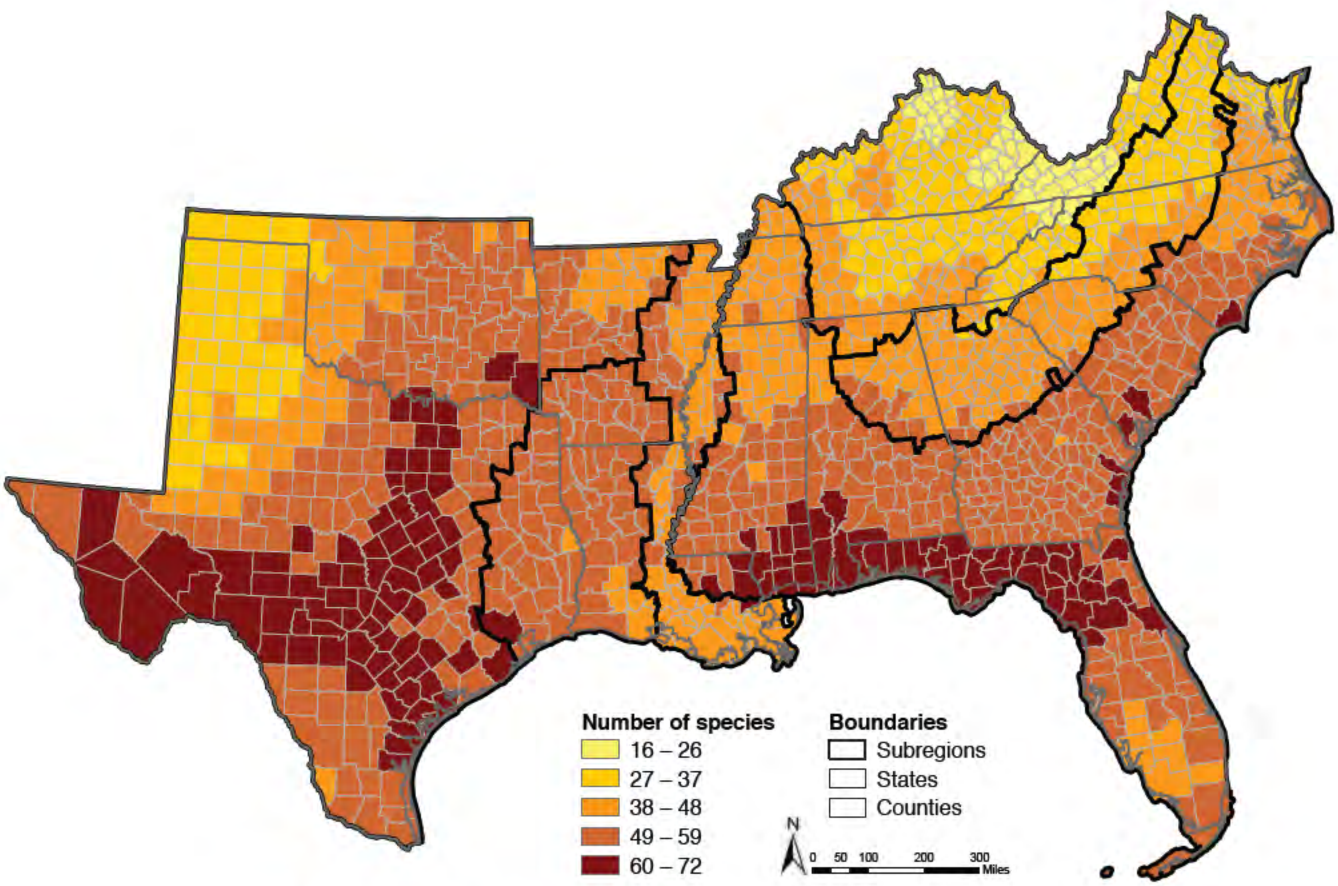


Figure 14.10—County-level counts of all native reptile species in the South. (Source: NatureServe 2011)

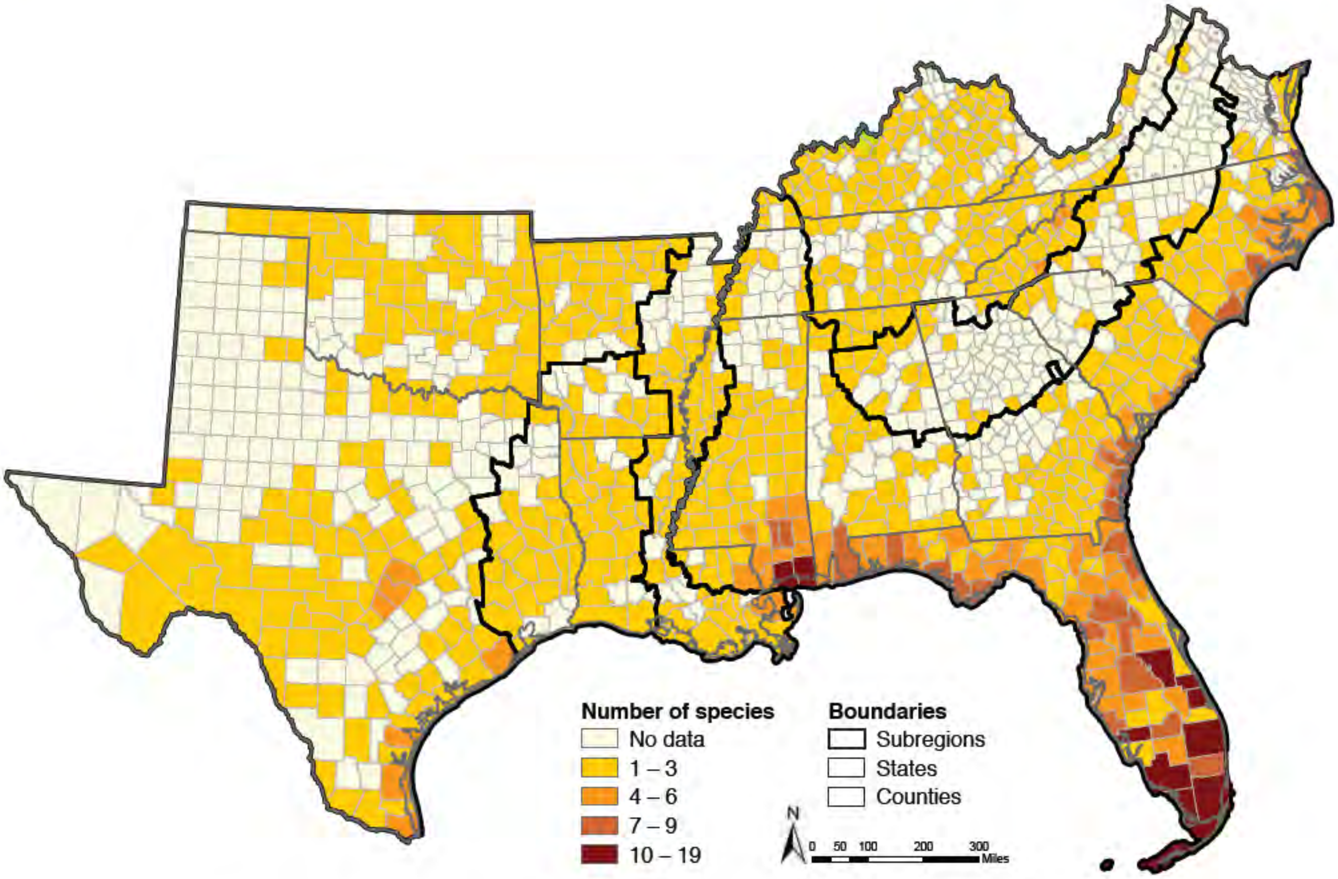


Figure 14.11—County-level counts for Federal-status terrestrial vertebrate species in the South. (Source: NatureServe 2011)

The Coastal Plain leads with the number of threatened or endangered vertebrates (62 species), with heaviest concentrations occurring in Peninsular Florida, Southern Gulf, and Eastern Atlantic areas (table 14.3). The Mid-South is second, with 33 listed species, the majority occurring within the High Plains and Cross Timbers sections. The remaining subregions have 10 or fewer vertebrate species with Federal status. They are described by taxa in the next section of this chapter.

Coastal regions, especially the Cape Fear area of North Carolina, the tip of Florida, and the Gulf of Mexico from Florida westward to Louisiana, also have concentrations of the 141 threatened or endangered vascular plant species (fig. 14.12). In addition, pockets of listed plant species occur in the Lake Wales Ridge in central Florida, Southern Blue Ridge and escarpment in the Carolinas, and the Big Bend region of the West Texas Basin and Range.

With 60 species, the Coastal Plain leads in threatened or endangered vascular plants (table 14.4). The Appalachian-Cumberland highlands are second (35 species), followed by the Piedmont (24), Mid-South (21), and Mississippi Alluvial Valley (1).

Amphibians—Nine species of amphibians are listed as threatened or endangered; the list is dominated by salamanders in the Coastal Plain and Mid-South (table 14.3). Species of special concern include the Houston toad (*Bufo houstonensis*), Barton Springs salamander (*Eurycea sosorum*), reticulated flatwoods salamander (*Ambystoma bishopi*), Shenandoah Mountain salamander (*Plethodon shenandoah*), and Texas blind salamander (*Eurycea rathbuni*).

These species have physiological constraints and complex life cycles that limit them to moist habitats, restricted geographic ranges, and site fidelity. Contributing to their imperilment are thermal changes, water pollution, and excessive siltation in their aquatic habitats (Wilson 1995). Wetland alteration from dredging, channelization, and impoundment is also detrimental to many of these species. Other factors include invasive animal species, acid precipitation, and ultraviolet radiation. Population isolation inhibits dispersal; many amphibians are adapted to travel only short distances,

Table 14.3—Terrestrial vertebrate species that are federally listed as threatened or endangered in the South (U.S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
AMPHIBIANS				
Frogs and Toads				
Bufo houstonensis	Houston toad	E	Coastal Plain, Mid-South	1_7, 5_2
Rana sevosa	Dusky gopher frog	E	Coastal Plain	1_4
Salamanders				
Eurycea nana	San Marcos salamander	T	Mid-South	5_3
Eurycea rathbuni	Texas blind salamander	E	Mid-South	5_3
Eurycea sosorum	Barton Springs salamander	E	Mid-South	5_3
Plethodon shenandoah	Shenandoah salamander	E	Piedmont, Appalachian-Cumberland	2_1, 3_2
Ambystoma bishopi	Reticulated flatwoods salamander	E	Coastal Plain	1_4
Ambystoma cingulatum	Frosted flatwoods salamander	T	Coastal Plain	1_2, 1_3, 1_4
Phaeognathus hubrichti	Red Hills salamander	T	Coastal Plain	1_4
BIRDS				
Wading Birds				
Grus americana	Whooping crane	E	Coastal Plain, Mid-South	*1_3, 5_2, 5_3*
Grus canadensis pulla	Mississippi sandhill crane	E	Coastal Plain	*1_4*
Raptors				
Falco femoralis septentrionalis	Northern Aplomado falcon	E	Mid-South	5_3
Polyborus plancus audubonii	Audubon's crested caracara	T	Coastal Plain	1_3
Rostrhamus sociabilis plumbeus	Snail kite	E	Coastal Plain	1_3
Shorebirds				
Charadrius melodus	Piping plover	T	Coastal Plain, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 1_7, 4_2, 5_2, 5_3
Mycteria americana	Wood stork	E	Coastal Plain, Piedmont	1_2, 1_3, 1_4, 1_5, 2_2
Numenius borealis	Eskimo curlew	E	Coastal Plain, Mid-South	1_2, 5_4
Perching Birds				
Ammodramus maritimus mirabilis	Cape Sable sparrow	E	Coastal Plain	1_3
Ammodramus savannarum floridanus	Florida grasshopper sparrow	E	Coastal Plain	1_3
Aphelocoma coerulescens	Florida scrub-jay	T	Coastal Plain	1_2, 1_3, 1_4
Dendroica chrysoparia	Golden-cheeked warbler	E	Mid-South	5_2, 5_3
Dendroica kirtlandii	Kirtland's warbler	E	Coastal Plain	1_2, 1_3, 1_4
Vermivora bachmanii	Bachman's warbler	E	Coastal Plain, Mid-South, Mississippi Alluvial Valley, Appalachian-Cumberland	1_1, 1_2, 1_4, 1_6, 1_7, 3_5, 4_1, 4_2, 5_2
Vireo atricapilla	Black-capped vireo	E	Mid-South	5_2, 5_3, 5_4
Other Birds				
Campephilus principalis	Ivory-billed woodpecker	E	Coastal Plain, Mississippi Alluvial Valley	1_3, 1_4, 1_6, 4_1

(Continued)

Table 14.3—(continued) Terrestrial vertebrate species that are federally listed as threatened or endangered in the South (U.S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
Picoides borealis	Red-cockaded woodpecker	E	Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 1_5, 1_6, 1_7, 2_1, 2_2, 2_3, 3_3, 3_4, 3_5, 4_1, 5_1, 5_2
Sternula antillarum	Least tern	E	Coastal Plain, Mid-South	1_6, 5_1, 5_2, 5_3
Sternula antillarum athalassos	Interior least tern	E	Coastal Plain, Appalachian-Cumberland, Mississippi Alluvial Valley. Mid-South	1_5, 1_6, 1_7, 3_5, 4_1, 4_2, 5_1, 5_2, 5_3
Sterna dougallii dougallii	Roseate tern	E	Coastal Plain	1_2, 1_3
Strix occidentalis lucida	Mexican spotted owl	T	Mid-South	5_4
Tympanuchus cupido attwateri	Attwater's greater prairie chicken	E	Coastal Plain, Mid-South, Mississippi Alluvial Valley	1_7, 5_2, 4_2, 5_2, 5_3
MAMMALS				
Bats				
Corynorhinus townsendii ingens	Ozark big-eared bat	E	Mid-South	5_1
Corynorhinus townsendii virginianus	Virginia big-eared bat	E	Appalachian-Cumberland	3_1, 3_2, 3_4, 3_5
Leptonycteris nivalis	Mexican long-nosed bat	E	Mid-South	5_4
Myotis sodalis	Indiana myotis	E	Coastal Plain, Piedmont, Appalachian-Cumberland, Mid-South	1_5, 2_1, 2_2, 2_3, 3_1, 3_2, 3_3, 3_4, 3_5, 5_1
Myotis grisescens	Gray myotis	E	Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, Mid-South	1_2, 1_4, 1_5, 2_1, 2_3, 3_1, 3_2, 3_3, 3_4, 3_5, 4_1, 5_1
Rodents				
Glaucomys sabrinus coloratus	Carolina northern flying squirrel	E	Appalachian-Cumberland	3_1
Glaucomys sabrinus fuscus	Virginia northern flying squirrel	E	Appalachian-Cumberland	3_2
Microtus pennsylvanicus dukecampbelli	Duke's salt marsh vole	E	Coastal Plain	1_4
Neotoma floridana smalli	Key Largo woodrat	E	Coastal Plain	1_3
Oryzomys palustris natator	Key Oryzomys	E	Coastal Plain	1_3
Peromyscus gossypinus population 1	Key Largo cotton deermouse	E	Coastal Plain	1_3
Peromyscus polionotus allophrys	Choctawhatchee beach deermouse	E	Coastal Plain	1_4
Peromyscus polionotus ammobates	Alabama beach deermouse	E	Coastal Plain	1_4
Peromyscus polionotus niveiventris	Southeast beach deermouse	T	Coastal Plain	1_3
Peromyscus polionotus peninsularis	St. Andrews beach deermouse	E	Coastal Plain	1_4
Peromyscus polionotus phasma	Anastasia beach deermouse	E	Coastal Plain	1_3
Peromyscus polionotus trissyllepsis	Perdido Key beach deermouse	E	Coastal Plain	1_4
Sciurus niger cinereus	Delmarva fox squirrel	E	Coastal Plain	1_1
Carnivores				
Canis rufus	Red wolf	E	Coastal Plain	1_2, 1_4
Leopardus pardalis	Ocelot	E	Mid-South	5_3
Puma concolor coryi	Florida panther	E	Coastal Plain	1_3
Puma concolor (all except *coryi*)	Mountain lion	SAT	Mid-South	5_2, 5_3, 5_4

(Continued)

Table 14.3—(continued) Terrestrial vertebrate species that are federally listed as threatened or endangered in the South (U.S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
Puma yagouaroundi cacomitli	Gulf Coast jaguarundi	E	Mid-South	5_2, 5_3
Ursus americanus	American black bear	SAT	Coastal Plain, Mid-South	1_5, 5_4
Ursus americanus luteolus	Louisiana black bear	T	Coastal Plain, Mississippi Alluvial Valley	1_4, 1_5, 1_7, 4_1, 4_2
Other Mammals				
Odocoileus virginianus clavium	Key deer	E	Coastal Plain	1_3
Sylvilagus palustris hefneri	Lower Keys rabbit	E	Coastal Plain	1_3
Trichechus manatus	West Indian manatee	E	Coastal Plain, Mississippi Alluvial Valley	1_1, 1_2, 1_3, 1_4, 4_2
REPTILES				
Crocodilians				
Alligator mississippiensis	American alligator	SAT	Coastal Plain, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 1_5, 1_6, 4_1, 5_1
Crocodylus acutus	American crocodile	T	Coastal Plain	1_3
Snakes				
Drymarchon couperi	Eastern indigo snake	T	Coastal Plain	1_2, 1_3, 1_4
Nerodia clarkii taeniata	Atlantic saltmarsh snake	T	Coastal Plain	1_3
Nerodia paucimaculata	Concho watersnake	T	Mid-South	5_2, 5_3
Turtles				
Caretta caretta	Loggerhead	T	Coastal Plain, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 4_2, 5_2, 5_3
Chelonia mydas	Green turtle	E[e]	Coastal Plain	1_1, 1_2, 1_3, 1_4
Dermochelys coriacea	Leatherback	E	Coastal Plain	1_1, 1_2, 1_3
Eretmochelys imbricata	Hawksbill	E	Coastal Plain	1_1, 1_3
Glyptemys muhlenbergii	Bog turtle	T	Piedmont, Appalachian-Cumberland	2_1, 2_2, 3_1
Gopherus polyphemus	Gopher tortoise	T	Coastal Plain, Piedmont	1_2, 1_3, 1_4, 1_5, 2_2
Graptemys flavimaculata	Yellow-blotched map turtle	T	Coastal Plain	1_4, 1_5
Graptemys oculifera	Ringed map turtle	T	Coastal Plain	1_4, 1_5
Lepidochelys kempii	Kemp's Ridley sea turtle	E	Coastal Plain, Mid-South, Mississippi Alluvial Valley	1_1, 1_2, 1_3, 1_4, 4_2, 5_3
Pseudemys alabamensis	Alabama redbelly turtle	E	Coastal Plain	1_4
Sternotherus depressus	Flattened mask turtle	T	Coastal Plain, Piedmont	1_5, 2_3

[a]Names follow NatureServe (2011).
[b]T = Threatened; E = Endangered; SAT = Similarity of Appearance to a Threatened taxon.
[c]Location data from NatureServe (2010).
[d]1_1 (Northern Atlantic); 1_2 (Eastern Atlantic); 1_3 (Florida Peninsular); 1_4 (Southern Gulf); 1_5 (Middle Gulf-Eastern); 1_6 (Middle Gulf-Western); 1_7 (Western Gulf); 2_1 (Central Appalachian Piedmont); 2_2 (Southern Appalachian Piedmont); 2_3 (Piedmont Ridge, Valley and Plateau); 3_1 (Blue Ridge); 3_2 (Northern Ridge and Valley); 3_3 (Southern Ridge and Valley); 3_4 (Cumberland Plateau and Mountain); 3_5 (Interior Low Plateau); 4_1 (Holocene Deposits); 4_2 (Deltaic Plain); 5_1 (Ozark-Ouachita Highlands); 5_2 (Cross Timbers); 5_3 (High Plains); 5_4 (West Texas Basin and Range).
[e]Listed endangered in the breeding colony population in Florida; threatened elsewhere.

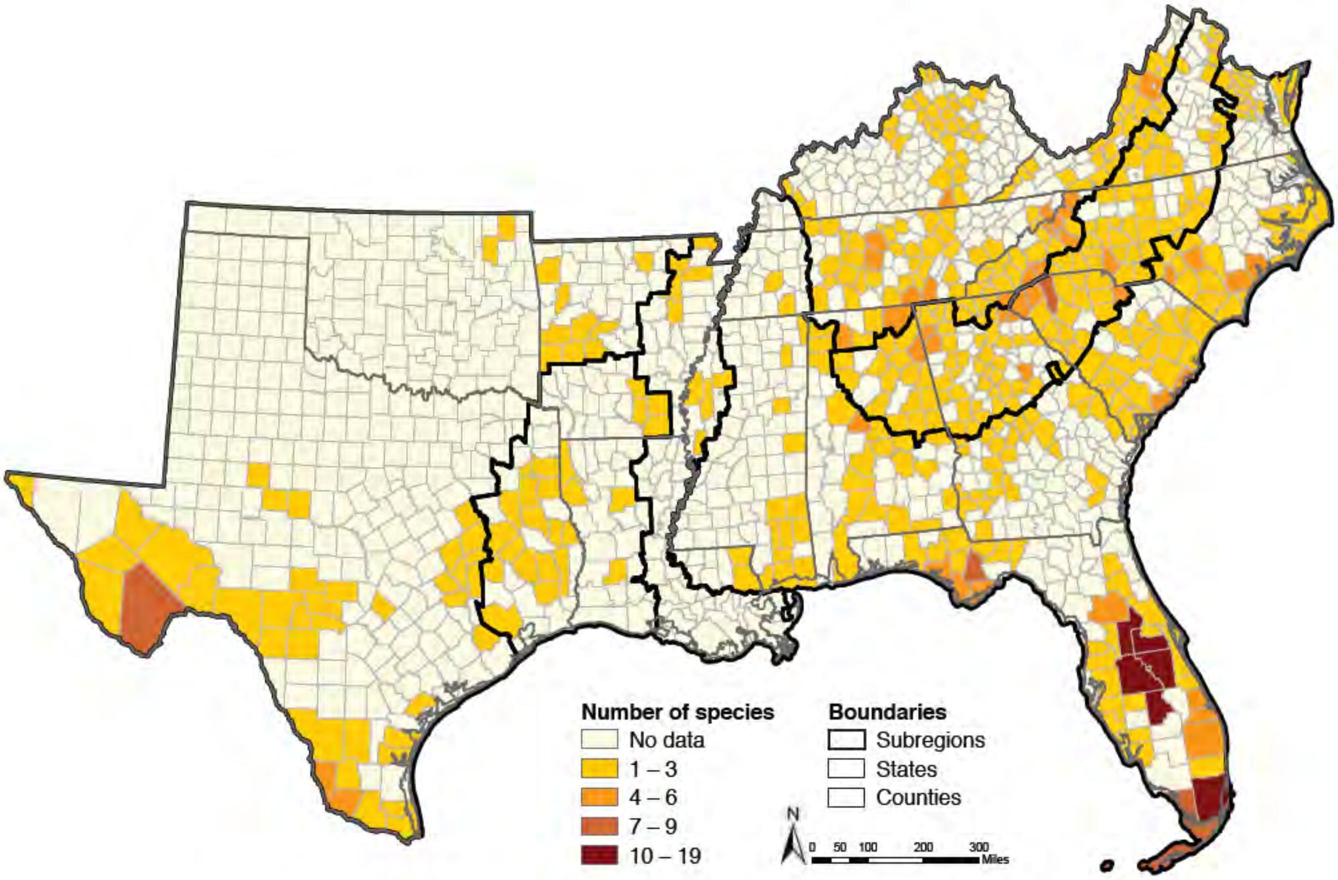


Figure 14.12—County-level counts for Federal-status vascular plant species in the South. (Source: NatureServe 2011)

limiting their ability to find similar locales in response to habitat alteration (Gibbons and Buhlmann 2001).

Birds—Twenty-two species of birds are listed as threatened or endangered (table 14.3). Seventeen of these species inhabit the Coastal Plain and 12 in the Mid-South. Species of concern include the Cape Sable sparrow (*Ammodramus maritimus mirabilis*) and the Eskimo curlew (*Numenius borealis*).

Many of these species are experiencing habitat loss, habitat fragmentation, and coastal development (Trani 2002a). Habitat for Audubon's crested caracara (*Polyborus plancus audubonii*) is being degraded by large-scale conversion of native range and pasture to citrus groves. The dependence on breeding and stopover habitats along migration routes has placed several bird species at risk in areas where habitat alteration is occurring. Drainage and channelization projects impact wetland species such as the wood stork (*Mycteria americana)* and snail kite (*Rostrhamus sociabilis plumbeus)*.

Mammals—Twenty-eight species of mammals are listed as threatened or endangered (table 14.3). Twenty listed mammals occur in the Coastal Plain, eight in the Mid-South. The list is dominated by 13 rodents, including Carolina and Virginia northern flying squirrels (*Glaucomys sabrinus coloratus, G. s. fuscus*) and southeast beach deermouse (*Peromyscus polionotus niveiventris)*. Other species of concern include the Louisiana black bear (*Ursus americanus luteolus*) and Indiana myotis (*Myotis sodalis*).

These species are experiencing habitat fragmentation, land-use conversion, population isolation, road mortality, and coastal development (Harvey and Saugey 2001, Trani and others 2007). Human disturbance to hibernation and maternity colonies is a major factor in bat declines (Trani 2002a). Some rodent species have narrow distributions such as beach habitats, where feral cats represent a significant threat (McCay 2007, White and others 1998). Habitat destruction and the paucity of large tracts of land free from human harassment threaten large, far-ranging mammals such

Table 14.4—Vascular plant species that are Federally listed as threatened or endangered in the South (U. S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
Ferns and Relatives				
Asplenium scolopendrium var. *americanum*	Hart's-tongue Fern	T	Appalachian-Cumberland	3_4, 3_5
Isoetes louisianensis	Louisiana Quillwort	E	Coastal Plain	1_4
Isoetes melanospora	Black-spored Quillwort	E	Piedmont	2_2
Isoetes tegetiformans	Merlin's-grass	E	Piedmont	2_2
Conifers and Relatives				
Torreya taxifolia	Florida Torreya	E	Coastal Plain, Piedmont	1_4, 2_2
Flowering Plants				
Graminoids				
Carex lutea	Sulphur Sedge	E	Coastal Plain	1_2
Scirpus ancistrochaetus	Northeastern Bulrush	E	Appalachian-Cumberland	3_2
Zizania texana	Texas Wild Rice	E	Mid-South	5_3
Cacti				
Astrophytum asterias	Star Cactus	E	Mid-South	5_3
Coryphantha scheeri var. *robustispina*	Pima Pineapple Cactus	E	Mid-South	5_4
Echinocereus chisoensis var. *chisoensis*	Chisos Hedgehog Cactus	T	Mid-South	5_2, 5_3, 5_4
Echinocereus viridiflorus var. *davisii*	Davis' Green Pitaya	E	Mid-South	5_4
Escobaria minima	Nellie Cory Cactus	E	Mid-South	5_4
Escobaria sneedii var. *sneedii*	Sneed Pincushion Cactus	E	Mid-South	5_4
Harrisia fragrans	Fragrant Prickly-apple	E	Coastal Plain	1_3
Pilosocereus robinii	Key Tree Cactus	E	Coastal Plain	1_3
Sclerocactus brevihamatus ssp. *tobuschii*	Shorthook Fishhook Cactus	E	Mid-South	5_3, 5_4
Sclerocactus mariposensis	Lloyd's Mariposa Cactus	T	Mid-South	5_4
Vines				
Apios priceana	Price's Potato-bean	T	Coastal Plain, Piedmont, Appalachian-Cumberland	1_5, 2_3, 3_4, 3_5
Bonamia grandiflora	Florida Lady's-nightcap	T	Coastal Plain	1_3
Clematis morefieldii	Morefield's Leatherflower	E	Appalachian-Cumberland	3_4, 3_5
Clematis socialis	Alabama Leather-flower	E	Piedmont	2_3
Cucurbita okeechobeensis	Okeechobee Gourd	E	Coastal Plain	1_3
Galactia smallii	Small's Milkpea	E	Coastal Plain	1_3
Jacquemontia reclinata	Reclined Clustervine	E	Coastal Plain	1_3
Herbs				
Abronia macrocarpa	Large-fruit Sand-verbena	E	Mid-South	5_2
Aeschynomene virginica	Sensitive Joint-vetch	T	Coastal Plain, Piedmont	1_1, 2_1
Amaranthus pumilus	Seabeach Amaranth	T	Coastal Plain	1_1, 1_2
Ambrosia cheiranthifolia	South Texas Ragweed	E	Mid-South	5_2
Amorpha herbacea var. *crenulata*	Crenulate Leadplant	E	Coastal Plain	1_3
Amphianthus pusillus	Little Amphianthus	T	Piedmont	2_1, 2_2
Arabis perstellata	Braun's Rockcress	E	Appalachian-Cumberland	3_5
Arabis serotina	Shalebarren Rockcress	E	Appalachian-Cumberland	3_2
Astragalus bibullatus	Pyne's Ground-plum	E	Appalachian-Cumberland	3_5
Baptisia arachnifera	Hairy Rattleweed	E	Coastal Plain	1_2
Callirhoe scabriuscula	Texas Poppy-mallow	E	Mid-South	5_3

(Continued)

Table 14.4—(continued) Vascular plant species that are Federally listed as threatened or endangered in the South (U. S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
Campanula robinsiae	Robins' Bellflower	E	Coastal Plain	1_3
Cardamine micranthera	Small-anther Bittercress	E	Piedmont	2_1
Chamaesyce deltoidea ssp. *adhaerens*	Wedge Spurge	E	Coastal Plain	1_3
Chamaesyce garberi	Garber's Spurge	T	Coastal Plain	1_3
Chrysopsis floridana	Florida Goldenaster	E	Coastal Plain	1_3
Clitoria fragrans	Pigeon Wings	T	Coastal Plain	1_3
Crotalaria avonensis	Avon Park Rabbit-bells	E	Coastal Plain	1_3
Cryptantha crassipes	Terlingua Creek Cat's-eye	E	Mid-South	5_4
Dalea foliosa	Leafy Prairie-clover	E	Coastal Plain, Appalachian-Cumberland	1_5, 3_5
Echinacea laevigata	Smooth Purple Coneflower	E	Coastal Plain, Piedmont, Appalachian-Cumberland	1_2, 2_1, 2_2, 3_1, 3_2
Echinacea tennesseensis	Tennessee Coneflower	E	Appalachian-Cumberland	3_5
Eriogonum longifolium var. *gnaphalifolium*	Scrub Wild Buckwheat	T	Coastal Plain	1_3
Eryngium cuneifolium	Wedgeleaf Button-snakeroot	E	Coastal Plain	1_3
Euphorbia telephioides	Telephus Spurge	T	Coastal Plain	1_4
Geocarpon minimum	Tiny Tim	T	Coastal Plain, Mid-South	1_6, 1_7, 5_1
Geum radiatum	Spreading Avens	E	Appalachian-Cumberland	3_1
Halophila johnsonii	Johnson's Sea-grass	T	Coastal Plain	1_3
Harperocallis flava	Harper's Beauty	E	Coastal Plain	1_4
Helenium virginicum	Virginia Sneezeweed	T	Appalachian-Cumberland	3_2
Helianthus paradoxus	Pecos Sunflower	T	Mid-South	5_4
Helianthus schweinitzii	Schweinitz's Sunflower	E	Piedmont	2_1, 2_2
Helonias bullata	Swamp-pink	T	Coastal Plain, Piedmont, Appalachian-Cumberland	1_1, 2_2, 3_1, 3_2
Hexastylis naniflora	Dwarf-flower Heartleaf	T	Piedmont, Appalachian-Cumberland	2_1, 2_2, 3_1
Hoffmannseggia tenella	Slender Rushpea	E	Mid-South	5_2
Houstonia purpurea var. *montana*	Mountain Bluet	E	Appalachian-Cumberland	3_1
Hymenoxys texana	Prairie Dawn	E	Coastal Plain, Mid-South	1_7, 5_2
Hypericum cumulicola	Highlands Scrub St. John's-wort	E	Coastal Plain	1_3
Iliamna corei	Peters Mountain Mallow	E	Appalachian-Cumberland	3_2
Isotria medeoloides	Small Whorled Pogonia	T	Coastal Plain, Piedmont, Appalachian-Cumberland	1_1, 2_1, 2_2, 3_1, 3_2, 3_3, 3_4
Justicia cooleyi	Cooley's Water-willow	E	Coastal Plain	1_3
Lesquerella filiformis	Missouri Bladderpod	T	Mid-South	5_1
Lesquerella lyrata	Lyrate Bladderpod	T	Coastal Plain, Appalachian-Cumberland	1_5, 3_5
Lesquerella pallida	White Bladderpod	E	Coastal Plain	1_7
Lesquerella perforata	Spring Creek Bladderpod	E	Appalachian-Cumberland	3_5
Lesquerella thamnophila	Zapata Bladderpod	E	Mid-South	5_3
Liatris helleri	Heller's Blazingstar	T	Appalachian-Cumberland	3_1
Liatris ohlingerae	Florida Gayfeather	E	Coastal Plain	1_3
Lupinus westianus var. *aridorum*	Scrub Lupine	E	Coastal Plain	1_3

(Continued)

Table 14.4—(continued) Vascular plant species that are Federally listed as threatened or endangered in the South (U. S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
Lysimachia asperulifolia	Roughleaf Loosestrife	E	Coastal Plain	1_1, 1_2
Manihot walkerae	Walker's Manihot	E	Mid-South	5_3
Marshallia mohrii	Mohr's Barbara's-buttons	T	Coastal Plain, Piedmont	1_5, 2_3
Minuartia cumberlandensis	Cumberland Sandwort	E	Appalachian-Cumberland	3_4, 3_5
Nolina brittoniana	Britton's Bear-grass	E	Coastal Plain	1_3
Oxypolis canbyi	Canby's Dropwort	E	Coastal Plain	1_2, 1_4
Phlox nivalis ssp. *texensis*	Texas Trailing Phlox	E	Coastal Plain	1_7
Pinguicula ionantha	Violet-flowered Butterwort	T	Coastal Plain	1_4
Pityopsis ruthii	Ruth's Silk-grass	E	Appalachian-Cumberland	3_1
Platanthera leucophaea	Eastern Prairie White-fringed Orchid	T	Appalachian-Cumberland	3_2
Platanthera praeclara	Western Prairie White-fringed Orchid	T	Mid-South	5_2
Polygala lewtonii	Lewton's Polygala	E	Coastal Plain	1_3
Polygala smallii	Tiny Polygala	E	Coastal Plain	1_3
Polygonella basiramia	Wireweed	E	Coastal Plain	1_3
Polygonella myriophylla	Small's Jointweed	E	Coastal Plain	1_3
Potamogeton clystocarpus	Little Aguja Pondweed	E	Mid-South	5_4
Ptilimnium nodosum	Harperella	E	Coastal Plain, Piedmont, Mid-South	1_2, 2_1, 2_2, 2_3, 5_1
Sagittaria fasciculata	Bunched Arrowhead	E	Piedmont, Appalachian-Cumberland	2_2, 3_1
Sagittaria secundifolia	Little River Arrowhead	T	Piedmont	2_2, 2_3
Sarracenia oreophila	Green Pitcherplant	E	Piedmont, Appalachian-Cumberland	2_3, 3_1, 3_4
Sarracenia rubra ssp. *alabamensis*	Alabama Canebrake Pitcherplant	E	Coastal Plain	1_5
Sarracenia rubra ssp. *jonesii*	Mountain Sweet Pitcherplant	E	Piedmont, Appalachian-Cumberland	2_2, 3_1
Schwalbea americana	Chaffseed	E	Coastal Plain	1_2, 1_4, 1_7
Scutellaria floridana	Florida Skullcap	T	Coastal Plain	1_4
Scutellaria montana	Large-flower Skullcap	T	Piedmont, Appalachian-Cumberland	2_3, 3_3, 3_4
Silene polypetala	Fringed Campion	E	Coastal Plain, Piedmont	1_2, 1_4, 2_2
Sisyrinchium dichotomum	Reflexed Blue-eyed-grass	E	Piedmont, Appalachian-Cumberland	2_1, 2_2, 3_1
Solidago albopilosa	White-haired Goldenrod	T	Appalachian-Cumberland	3_4, 3_5
Solidago shortii	Short's Goldenrod	E	Appalachian-Cumberland	3_5
Solidago spithamaea	Blue Ridge Goldenrod	T	Appalachian-Cumberland	3_1
Spigelia gentianoides	Gentian Pinkroot	E	Coastal Plain	1_4
Spiranthes parksii	Navasota Ladies'-tresses	E	Coastal Plain, Mid-South	1_7, 5_2
Thalictrum cooleyi	Cooley's Meadowrue	E	Coastal Plain	1_2, 1_4
Thymophylla tephroleuca	Ashy Dogweed	E	Mid-South	5_3
Trifolium stoloniferum	Running Buffalo Clover	E	Appalachian-Cumberland	3_4, 3_5
Trillium persistens	Persistent Trillium	E	Piedmont, Appalachian-Cumberland	2_2, 3_1
Trillium reliquum	Relict Trillium	E	Coastal Plain, Piedmont	1_2, 1_4, 1_5, 2_2

(Continued)

Table 14.4—(continued) Vascular plant species that are Federally listed as threatened or endangered in the South (U. S. Department of Interior 2011)

Scientific name[a]	Common name	ESA[b]	Subregion name	Section[c,d]
Warea amplexifolia	Wide-leaf Warea	E	Coastal Plain	1_3
Warea carteri	Carter's Mustard	E	Coastal Plain	1_3
Xyris tennesseensis	Tennessee Yellow-eyed-grass	E	Coastal Plain, Piedmont, Appalachian-Cumberland	1_5, 2_3, 3_5
Trees and Shrubs				
Asimina tetramera	Four-petal Pawpaw	E	Coastal Plain	1_3
Ayenia limitaris	Texas Ayenia	E	Mid-South	5_3
Betula uber	Virginia Roundleaf Birch	T	Appalachian-Cumberland	3_2
Chionanthus pygmaeus	Pygmy Fringetree	E	Coastal Plain	1_1
Conradina brevifolia	Shortleaf Rosemary	E	Coastal Plain	1_3
Conradina etonia	Etonia Rosemary	E	Coastal Plain	1_3
Conradina glabra	Apalachicola Rosemary	E	Coastal Plain	1_4
Conradina verticillata	Cumberland False Rosemary	T	Appalachian-Cumberland	3_4
Deeringothamnus pulchellus	Beautiful Pawpaw	E	Coastal Plain	1_3
Deeringothamnus rugelii	Rugel's Pawpaw	E	Coastal Plain	1_3
Dicerandra christmanii	Yellow Scrub Balm	E	Coastal Plain	1_3
Dicerandra cornutissima	Longspurred Mint	E	Coastal Plain	1_3
Dicerandra frutescens	Scrub Mint	E	Coastal Plain	1_3
Dicerandra immaculata	Lakela's Mint	E	Coastal Plain	1_3
Frankenia johnstonii	Johnston's Frankenia	E	Mid-South	5_3
Hudsonia montana	Mountain Golden-heather	T	Appalachian-Cumberland	3_1
Lindera melissifolia	Pondberry	E	Coastal Plain, Mississippi Alluvial Valley	1_1, 1_2, 1_4, 1_6, 4_1
Prunus geniculata	Scrub Plum	E	Coastal Plain	1_3
Quercus hinckleyi	Hinckley's Oak	T	Mid-South	5_4
Rhododendron chapmanii	Chapman's Rhododendron	E	Coastal Plain	1_3, 1_4
Rhus michauxii	Michaux's Sumac	E	Coastal Plain, Piedmont	1_2, 2_1, 2_2,
Ribes echinellum	Miccosukee Gooseberry	T	Coastal Plain, Piedmont	1_4, 2_2
Spiraea virginiana	Virginia Spiraea	T	Piedmont, Appalachian-Cumberland	2_3, 3_1, 3_3, 3_4, 3_5
Styrax platanifolius ssp. *texanus*	Texas Snowbell	E	Mid-South	5_3, 5_4
Ziziphus celata	Scrub Ziziphus	E	Coastal Plain	1_3

[a]Species names follow USDA NRCS Plants Database (2010).
[b]T = Threatened; E = Endangered; SAT = Similarity of Appearance to a threatened taxon.
[c]Location data from NatureServe (2010).
[d]1_1 (Northern Atlantic); 1_2 (Eastern Atlantic); 1_3 (Florida Peninsular); 1_4 (Southern Gulf); 1_5 (Middle Gulf-Eastern); 1_6 (Middle Gulf-Western); 1_7 (Western Gulf); 2_1 (Central Appalachian Piedmont); 2_2 (Southern Appalachian Piedmont); 2_3 (Piedmont Ridge, Valley and Plateau); 3_1 (Blue Ridge); 3_2 (Northern Ridge and Valley); 3_3 (Southern Ridge and Valley); 3_4 (Cumberland Plateau and Mountain); 3_5 (Interior Low Plateau); 4_1 (Holocene Deposits); 4_2 (Deltaic Plain); 5_1 (Ozark-Ouachita Highlands); 5_2 (Cross Timbers); 5_3 (High Plains); 5_4 (West Texas Basin and Range).

as American black bear and Florida panther (*Puma concolor coryi)* that require extensive home ranges (Crawford and others 2001, Pelton 2001).

Reptiles—Table 14.3 lists 18 species of reptiles as threatened or endangered including 14 in the Coastal Plain and six inhabiting the Mid-South. The list is dominated by 11 turtles. Reptiles of concern include the leatherback (*Dermochelys coriacea*), eastern indigo snake, and sand skink (*Plestiodon reynoldsi*). The American alligator is designated as threatened due to "Similarity of Appearance" to the American crocodile (U. S. Department of the Interior 2011).

Due to an ectothermic physiology and seasonal inactivity, reptiles have relatively slow growth rates and advanced ages at maturity, factors that exacerbate environmental risks. Imperilment factors include illegal and unregulated collecting of reptiles, land development, intentional killing, degradation of aquatic habitats, and fire suppression (Ernst and others 1994, Gibbons and Buhlmann 2001, Rudolph and Burgdorf 1997, Semlitsch and Bodie 1998, White and others 1998).

Geographic Patterns of Other At Risk Species

The 77 threatened or endangered vertebrates and 141 threatened or endangered plants represent a portion of southern species considered to be at risk. The databases of the State Heritage Agencies contributed to an additional regional list of species of conservation concern; this list was based on rarity throughout the complete range where a species occurs (table 14.1).

The list consists of 142 vertebrates and 942 plant species (fig. 14.13). Among terrestrial vertebrates, 32 species (22 percent) are classified as critically imperiled, 45 species (32 percent) as imperiled, and 65 species (46 percent) as vulnerable. The proportion of species at risk varies among taxonomic groups, with amphibians comprising 46 percent of imperiled species, followed by reptiles (25 percent), mammals (16 percent), and birds (13 percent). Among vascular plants, 181 (19 percent) are critically imperiled, 306 (32 percent) are imperiled, and 455 (46 percent) are vulnerable.

Figures 14.14 and 14.15 display the geographic distribution of species of concern across the South. For vertebrates (fig. 14.14), there appears to be geographic coincidence with the Federal status map, particularly in the importance of areas along the Atlantic and Gulf coasts, with Peninsular Florida and Southern Gulf sections as locations of serious conservation concern. However, it also provides an additional perspective on the geography of risk, pointing to locations that are emerging as new areas of concern. These include the Appalachian-Cumberland highlands (Blue Ridge, Southern Ridge and Valley, Cumberland Plateau and Mountain, and Interior Low Plateau sections) and the Mid-South (Ozark-Ouachita Highlands and West Texas Basin and Range sections, and Edwards Plateau in central Texas).

In terms of subregion, the Coastal Plain (64 vertebrate and 532 plant species) and Mid-South (55 vertebrate and 321 plant

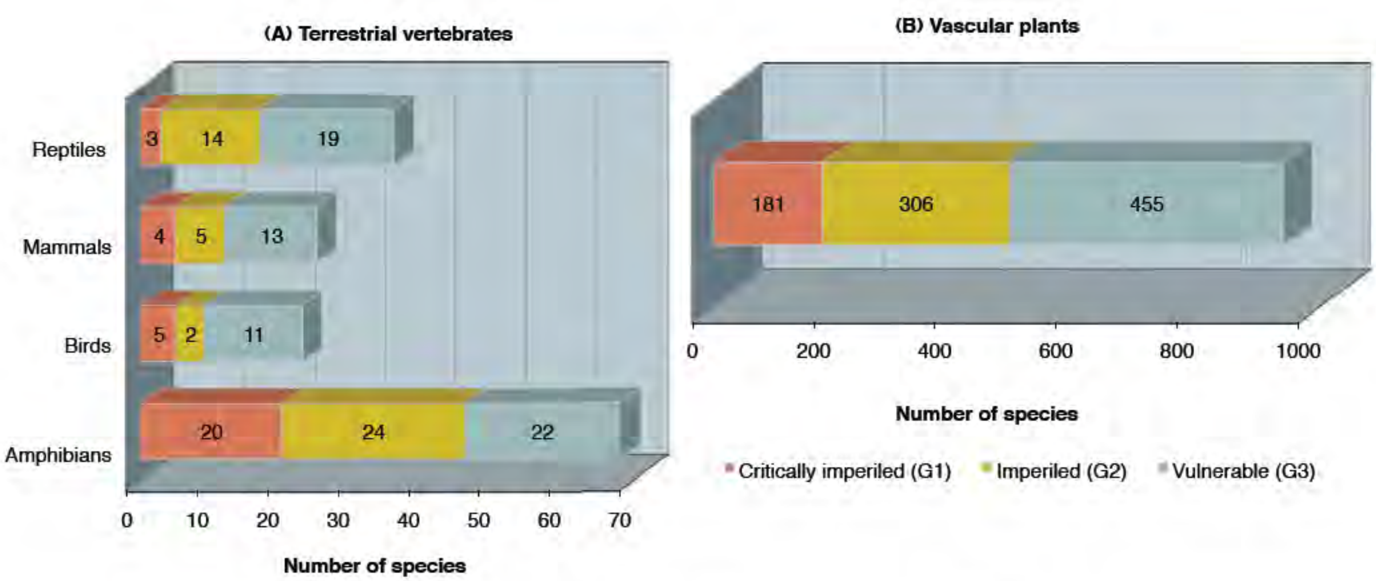


Figure 14.13—Number of species at risk in the South for (A) terrestrial vertebrates and (B) vascular plants.

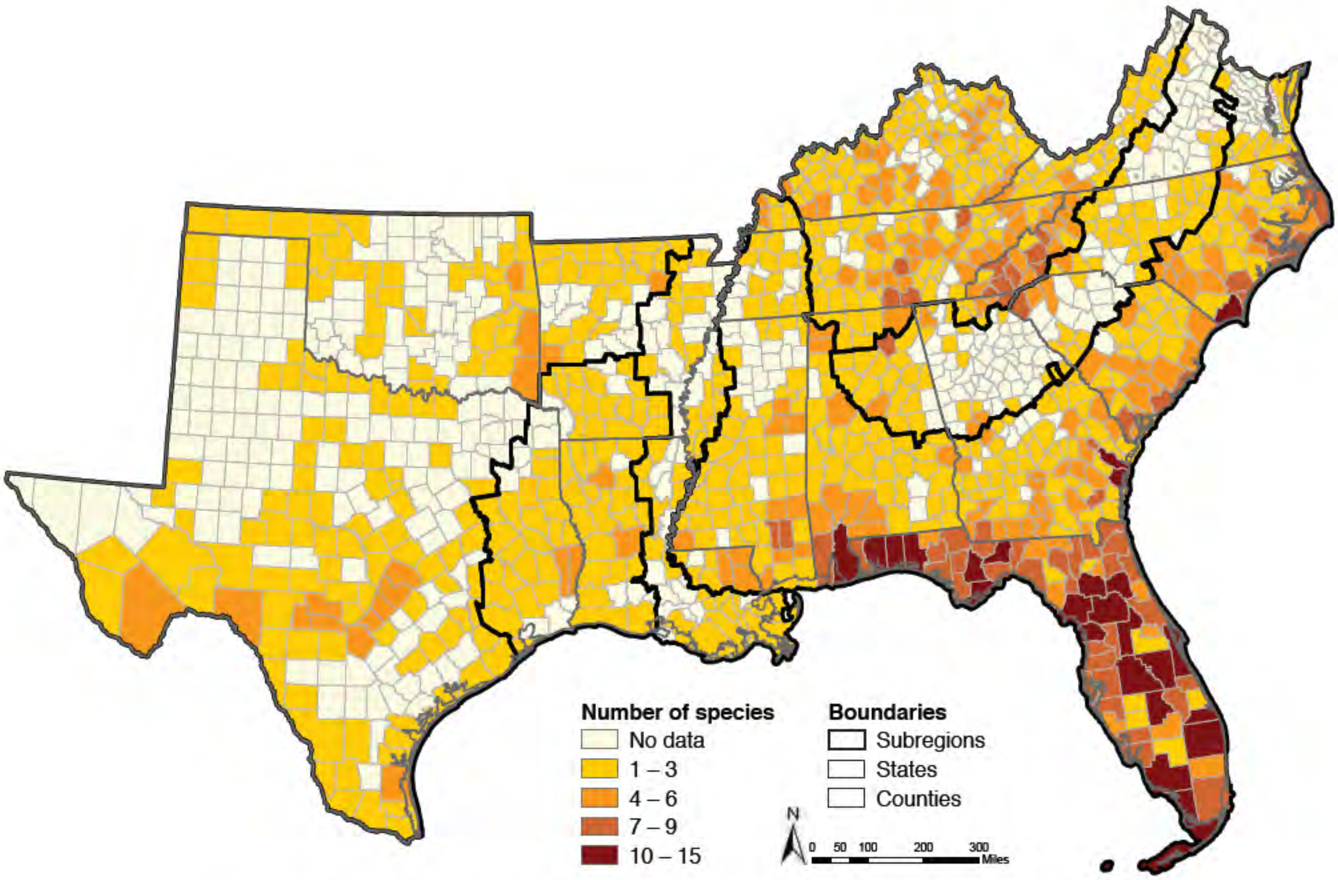


Figure 14.14—County-level counts for terrestrial vertebrate species of conservation concern in the South. (Source: NatureServe 2011)

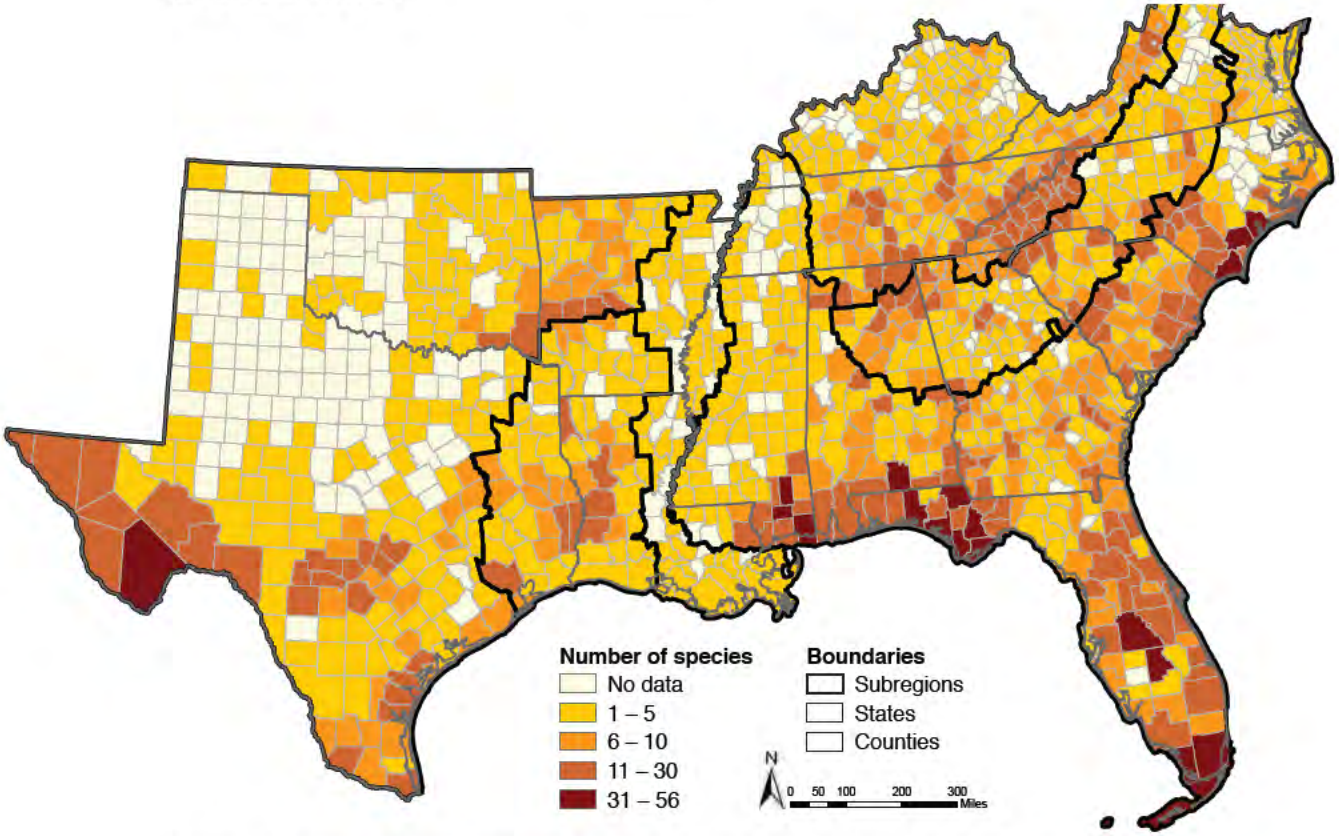


Figure 14.15—County-level counts for vascular plant species of conservation concern in the South. (Source: NatureServe 2011)

Table 14.5—Amphibian species of global conservation concern within the South (NatureServe 2011)[a]

Scientific name	Common name	Subregion name	Section[b]
Frogs and Toads			
G1			
Bufo houstonensis	Houston toad	Coastal Plain, Mid-South	1_7, 5_2
Rana sevosa	Dusky gopher frog	Coastal Plain	1_4
G2			
Rana okaloosae	Florida bog frog	Coastal Plain	1_4
G3			
Rana capito	Carolina gopher frog	Coastal Plain, Piedmont, Appalachian-Cumberland	1_1, 1_2, 1_3, 1_4, 2_2, 2_3, 3_5
Salamanders			
G1			
Eurycea chisholmensis	Salado salamander	Mid-South	5_2
Eurycea nana	San Marcos salamander	Mid-South	5_3
Eurycea naufragia	Georgetown salamander	Mid-South	5_2
Eurycea neotenes	Texas salamander	Mid-South	5_3
Eurycea rathbuni	Texas blind salamander	Mid-South	5_3
Eurycea robusta	Blanco blind salamander	Mid-South	5_3
Eurycea sosorum	Barton Springs salamander	Mid-South	5_3
Eurycea species 6	Pedernales River Springs salamander	Mid-South	5_3
Eurycea species 8	Comal Springs salamander	Mid-South	5_3
Eurycea species 10	Dolan Falls salamander	Mid-South	5_4
Eurycea tonkawae	Jollyville Plateau salamander	Mid-South	5_2, 5_3
Eurycea tridentifera	Comal blind salamander	Mid-South	5_3
Eurycea waterlooensis	Austin blind salamander	Mid-South	5_3
Gyrinophilus gulolineatus	Berry Cave salamander	Appalachian-Cumberland	3_3
Notophthalmus meridionalis	Black-spotted newt	Mid-South	5_2, 5_3
Plethodon amplus	Blue Ridge gray-cheeked salamander	Piedmont, Appalachian-Cumberland	2_1, 3_1
Plethodon meridianus	South Mountain gray-cheeked salamander	Appalachian-Cumberland, Piedmont	2_1, 3_1
Plethodon shenandoah	Shenandoah salamander	Piedmont, Appalachian-Cumberland	2_1, 3_2
G2			
Ambystoma bishopi	Reticulated flatwoods salamander	Coastal Plain	1_4
Ambystoma cingulatum	Frosted flatwoods salamander	Coastal Plain	1_2, 1_3, 1_4
Desmognathus abditus	Cumberland dusky salamander	Appalachian-Cumberland	3_4
Desmognathus folkertsi	Dwarf black-bellied salamander	Appalachian-Cumberland	3_1
Eurycea pterophila	Blanco River springs salamander	Mid-South	5_3
Eurycea species 7	Edwards Plateau spring salamander	Mid-South	5_3, 5_4
Gyrinophilus palleucus	Tennessee cave salamander	Coastal Plain, Piedmont, Appalachian-Cumberland	1_5, 2_3, 3_3, 3_4, 3_5
Haideotriton wallacei	Georgia blind salamander	Coastal Plain	1_4
Necturus alabamensis	Black Warrior waterdog	Coastal Plain, Piedmont	1_5, 2_3
Notophthalmus perstriatus	Striped newt	Coastal Plain	1_2, 1_3, 1_4
Phaeognathus hubrichti	Red Hills salamander	Coastal Plain	1_4
Plethodon aureolus	Tellico salamander	Appalachian-Cumberland	3_1

(Continued)

Table 14.5—(continued) Amphibian species of global conservation concern within the South (NatureServe 2011)[a]

Scientific name	Common name	Subregion name	Section[b]
Plethodon caddoensis	Caddo Mountain salamander	Coastal Plain, Mid-South	1_6, 5_1
Plethodon cheoah	Cheoah Bald salamander	Appalachian-Cumberland	3_1
Plethodon fourchensis	Fourche Mountain salamander	Mid-South	5_1
Plethodon hubrichti	Peaks of Otter salamander	Piedmont, Appalachian-Cumberland	2_1, 3_2
Plethodon kiamichi	Kiamichi slimy salamander	Mid-South	5_1
Plethodon ouachitae	Rich Mountain salamander	Mid-South	5_1
Plethodon petraeus	Pigeon Mountain salamander	Piedmont	2_3
Plethodon sequoyah	Sequoyah slimy salamander	Mid-South	5_1
Plethodon sherando	Big Levels salamander	Piedmont	2_1
Plethodon shermani	Red-legged salamander	Appalachian-Cumberland	3_1
Plethodon virginia	Shenandoah Mountain salamander	Appalachian-Cumberland	3_2
G3			
Amphiuma pholeter	One-toed amphiuma	Coastal Plain	1_3, 1_4
Aneides aeneus	Green salamander	Coastal Plain, Piedmont, Appalachian-Cumberland	1_5, 2_1, 2_2, 2_3, 3_1, 3_3, 3_4, 3_5
Cryptobranchus alleganiensis	Hellbender	Coastal Plain, Piedmont, Appalachian-Cumberland	1_5, 2_2, 2_3, 3_1, 3_2, 3_3, 3_4, 3_5
Desmognathus aeneus	Seepage salamander	Coastal Plain, Piedmont, Appalachian-Cumberland	1_5, 2_2, 2_3, 3_1, 3_3
Desmognathus apalachicolae	Apalachicola dusky salamander	Coastal Plain	1_4
Desmognathus imitator	Imitator salamander	Appalachian-Cumberland	3_1
Desmognathus santeetlah	Santeetlah dusky salamander	Appalachian-Cumberland	3_1
Desmognathus wrighti	Pygmy salamander	Appalachian-Cumberland	3_1, 3_2, 3_3
Eurycea junaluska	Junaluska salamander	Appalachian-Cumberland	3_1, 3_3
Eurycea latitans	Cascade Caverns salamander	Mid-South	5_3
Eurycea troglodytes	Eurycea troglodytes complex	Mid-South	5_3
Eurycea tynerensis	Oklahoma salamander	Mid-South	5_1
Necturus lewisi	Neuse River waterdog	Coastal Plain, Piedmont	1_1, 2_1
Plethodon jordani	Red-cheeked salamander	Appalachian-Cumberland	3_1
Plethodon kisatchie	Louisiana slimy salamander	Coastal Plain, Mississippi Alluvial Valley	1_7, 4_1
Plethodon metcalfi	Southern gray-cheeked salamander	Piedmont, Appalachian-Cumberland	2_2, 3_1
Plethodon montanus	Northern gray-cheeked salamander	Piedmont, Appalachian-Cumberland	2_2, 3_1
Plethodon punctatus	White-spotted salamander	Appalachian-Cumberland	3_2
Plethodon teyahalee	Southern Appalachian salamander	Piedmont, Appalachian-Cumberland	2_2, 3_1
Plethodon websteri	Webster's salamander	Coastal Plain, Piedmont	1_4, 1_5, 2_2, 2_3
Plethodon welleri	Weller's salamander	Appalachian-Cumberland	3_1, 3_2

[a]G1 = Critically imperiled; G2 = Imperiled; G3 = Vulnerable.
[b]1_1 (Northern Atlantic); 1_2 (Eastern Atlantic); 1_3 (Florida Peninsular); 1_4 (Southern Gulf); 1_5 (Middle Gulf-Eastern); 1_6 (Middle Gulf-Western); 1_7 (Western Gulf); 2_1 (Central Appalachian Piedmont); 2_2 (Southern Appalachian Piedmont); 2_3 (Piedmont Ridge, Valley and Plateau); 3_1 (Blue Ridge); 3_2 (Northern Ridge and Valley); 3_3 (Southern Ridge and Valley); 3_4 (Cumberland Plateau and Mountain); 3_5 (Interior Low Plateau); 4_1 (Holocene Deposits); 4_2 (Deltaic Plain); 5_1 (Ozark-Ouachita Highlands); 5_2 (Cross Timbers); 5_3 (High Plains); 5_4 (West Texas Basin and Range).

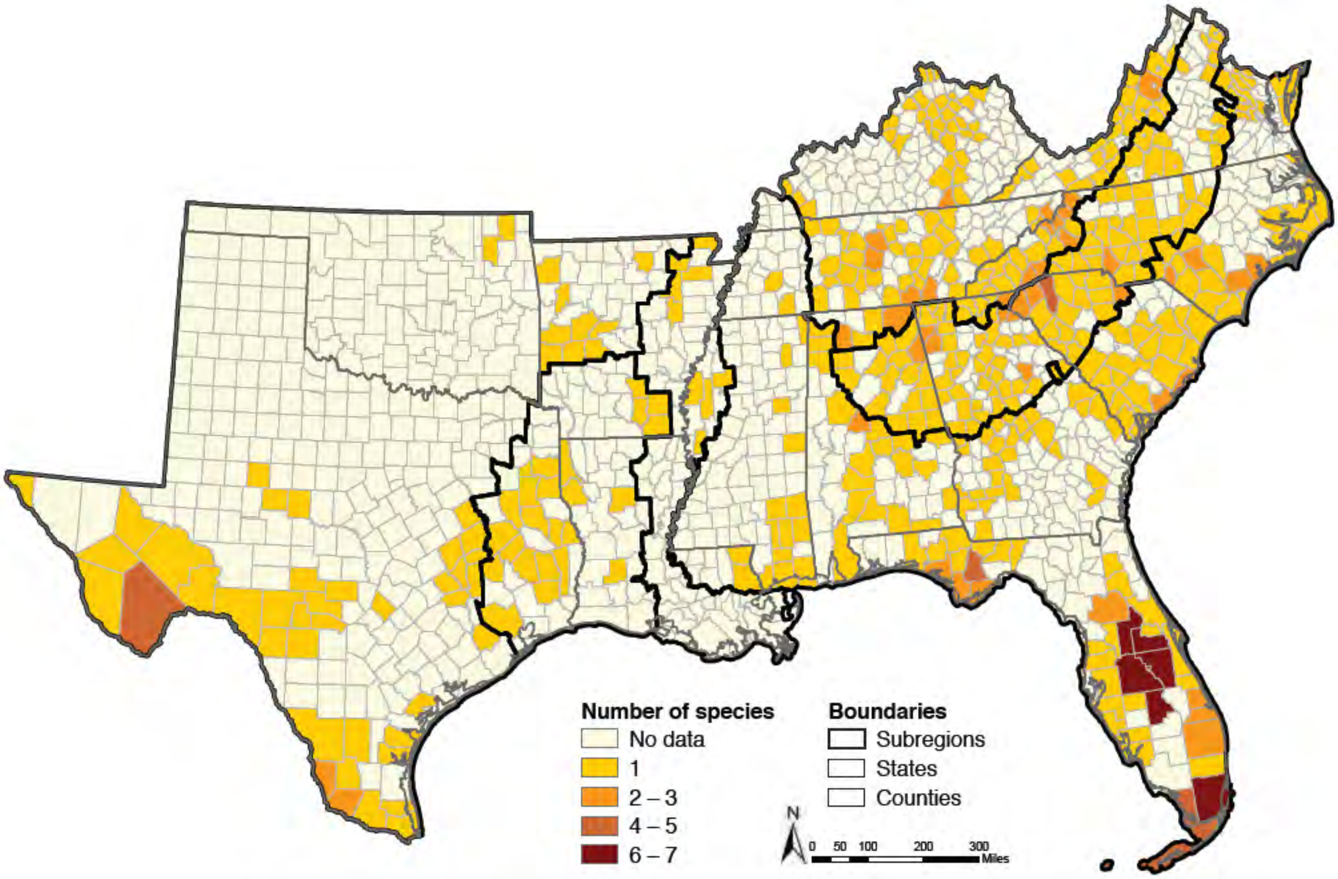


Figure 14.16—County-level counts for amphibian species of conservation concern in the South. (Source: NatureServe 2011)

species) lead in the number of species of concern followed by the Appalachian-Cumberland highlands (31 vertebrate and 207 plant species) and Piedmont (29 vertebrate and 188 plant species). Nine imperiled vertebrate and 20 plant species inhabit the Mississippi Alluvial Valley. Although several of these hot spots are shared by several species, there are interesting differences among the taxa that are described below.

Amphibians—Sixty-six amphibian species are of conservation concern (table 14.5). Salamanders dominate with 62 listings, followed by frogs and toads with 4 listings.

Amphibians at risk occur in heaviest concentrations across the Appalachian-Cumberland highlands, Coastal Plain, and Mid-South (fig. 14.16). Numbers of imperiled amphibians are prominent in the Blue Ridge (15 salamanders) where they are affected by habitat degradation, water pollution, drought, and acid rain. Characteristic species include the Blue Ridge gray-cheeked salamander (*Plethodon amplus*), Tellico salamander (*Plethodon aureolus*), and hellbender (*Cryptobranchus alleganiensis*).

Also important in supporting species at risk are the High Plains (12 species) and Southern Gulf (11 species). These areas provide important habitat for the dusky gopher frog (*Rana sevosa*), Florida bog frog (*Rana okaloosae*), and striped newt (*Notophthalmus perstriatus*). Threats to these species include loss of longleaf pine, agricultural and urban development, fire exclusion, contamination of springs, introduction of nonnative fish into breeding ponds, and stream impoundment.

Birds—Eighteen avian species are of conservation concern (table 14.6). The breakdown along subtaxa is 3 wading and shorebirds, 7 perching birds, and 8 others. Species include the Kirtland's warbler (*Dendroica kirtlandii*), golden-cheeked warbler (*Dendroica chrysoparia*), Fea's petrel (*Pterodroma feae*), and lesser prairie chicken (*Tympanuchus pallidicinctus*).

Bird species at risk occur predominately along the Atlantic Ocean extending from southern Virginia to Florida and continuing along the Gulf of Mexico across Louisiana to the southernmost tip of eastern Texas (fig. 14.17). Highest numbers occur in the Cross Timbers (7 species) and High Plains (6 species) sections of the Mid-South. Species such as the piping plover (*Charadrius melodus*) are vulnerable to disturbance of nesting areas, declining fish populations, oil spills, and extreme weather conditions. The black-capped vireo (*Vireo atricapilla*) is vulnerable to cowbird parasitism and loss of nesting habitat from housing development, road construction, and over-browsing by domestic livestock.

Peninsular Florida supports six birds at risk, including the Florida scrub jay (*Aphelocoma coerulescens)* and wood stork. Conservation concerns center on rapidly growing population centers and habitat conversion to urban and agricultural uses (such as sugarcane and citrus production). Imperiled birds also occur in the Eastern Atlantic, Southern Gulf, and Western Gulf sections; these species include the whooping crane (*Grus americana)* and red-cockaded woodpecker (*Picoides borealis)*. Threats to birds in these areas include conversion of longleaf pine and upland hardwoods to other uses, hydrological alteration, and coastal development.

Mammals—Twenty-two mammal species are imperiled or vulnerable (table 14.7). Rodents dominate with 8 listings, followed by bats (7), carnivores (4), and others (3). Species include the Texas kangaroo rat (*Dipodomys elator*), Strecker's pocket gopher (*Geomys streckeri*), red wolf (*Canis rufus*), and jaguar (*Panthera onca*).

Although the Coastal Plain (10 species) and Mid-South (9 species) support the largest number of imperiled mammals (fig. 14.18), it is the Appalachian-Cumberland highlands where the majority of hot spots occur. Numbers of imperiled mammals are particularly prominent in Oklahoma and Tennessee in the Interior Low Plateau, Cumberland Plateau and Mountain, Southern Ridge and Valley, and in the Blue Ridge of North Carolina. Species occurring in these sections include the eastern small-footed myotis, Carolina and Virginia northern flying squirrels, and Virginia big-eared bat. The Ozark-Ouachita Highlands are also notable, supporting the Ozark big-eared bat, southeastern myotis (*Myotis austroriparius*), and several other bat species. Cave disturbance, vandalism, and destruction of roost sites imperil these species, as does habitat loss stemming from deforestation and stream channelization. Threats to other mammals in these areas include insect pests (such as balsam wooly adelgid, gypsy moth), acid rain which contaminates mycorrhizal food sources, and heavy metals in forest litter. Habitat fragmentation has resulted in population isolation and the loss of dispersal and travel corridors.

Peninsular Florida and the northern portion of the Eastern Atlantic are also important for mammals at risk, supporting the round-tailed muskrat (*Neofiber alleni*), Florida deermouse (*Podomys floridanus*), and West Indian manatee (*Trichechus manatus*). Threats to these species include loss of wetlands, marsh drainage, and salt water intrusion—all of which reduce available habitat and further isolate populations. For the manatee, the potential loss of warm-water refugia from residential and commercial development of coastal land remains a problem.

Table 14.6—Bird species of global conservation concern within the South (NatureServe 2011)[a]

Scientific name	Common name	Subregion name	Section[b]
Wading Birds			
G1			
Grus americana	Whooping crane	Coastal Plain, Mid-South	1_3, 5_2, 5_3
Shorebirds			
G3			
Charadrius melodus	Piping plover	Coastal Plain, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 1_7, 4_2, 5_2, 5_2
Charadrius montanus	Mountain plover	Coastal Plain, Mid-South	1_7, 5_2, 5_3
Perching Birds			
G1			
Dendroica kirtlandii	Kirtland's warbler	Coastal Plain	1_1, 1_3, 1_4
G2			
Aphelocoma coerulescens	Florida scrub-jay	Coastal Plain	1_2, 1_3, 1_4
Dendroica chrysoparia	Golden-cheeked warbler	Mid-South	5_2, 5_3
G3			
Aimophila aestivalis	Bachman's sparrow	Coastal Plain, Piedmont, Appalachian-Cumberland, Mid-South	1_1, 1_2, 1_3, 1_4, 1_5, 1_6, 1_7, 2_1, 2_2, 2_3, 3_3, 3_4, 3_5, 5_1, 5_2
Tachycineta cyaneoviridis	Bahama swallow	Coastal Plain	1_3
Vermivora crissalis	Colima warbler	Mid-South	5_4
Vireo atricapilla	Black-capped vireo	Mid-South	5_2, 5_3, 5_4
Other Birds			
G1			
Campephilus principalis	Ivory-billed woodpecker	Coastal Plain, Mississippi Alluvial Valley	1_3, 1_4, 1_6, 4_1
Pterodroma feae	Fea's petrel	Coastal Plain	1_1
Pterodroma hasitata	Black-capped petrel	Coastal Plain	1_2, 1_3
G3			
Oceanodroma castro	Band-rumped storm-petrel	Coastal Plain	1_2, 1_3
Patagioenas leucocephala	White-crowned pigeon	Coastal Plain	1_3
Picoides borealis	Red-cockaded woodpecker	Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 1_5, 1_6, 1_7, 2_1, 2_2, 2_3, 3_3, 3_4, 3_5, 4_1, 5_1, 5_2
Strix occidentalis	Spotted owl	Mid-South	5_4
Tympanuchus pallidicinctus	Lesser prairie-chicken	Mid-South	5_3

[a]G1 = Critically imperiled; G2 = Imperiled; G3 = Vulnerable.
[b]1_1 (Northern Atlantic); 1_2 (Eastern Atlantic); 1_3 (Florida Peninsular); 1_4 (Southern Gulf); 1_5 (Middle Gulf-Eastern); 1_6 (Middle Gulf-Western); 1_7 (Western Gulf); 2_1 (Central Appalachian Piedmont); 2_2 (Southern Appalachian Piedmont); 2_3 (Piedmont Ridge, Valley and Plateau); 3_1 (Blue Ridge); 3_2 (Northern Ridge and Valley); 3_3 (Southern Ridge and Valley); 3_4 (Cumberland Plateau and Mountain); 3_5 (Interior Low Plateau); 4_1 (Holocene Deposits); 4_2 (Deltaic Plain); 5_1 (Ozark-Ouachita Highlands); 5_2 (Cross Timbers); 5_3 (High Plains); 5_4 (West Texas Basin and Range).

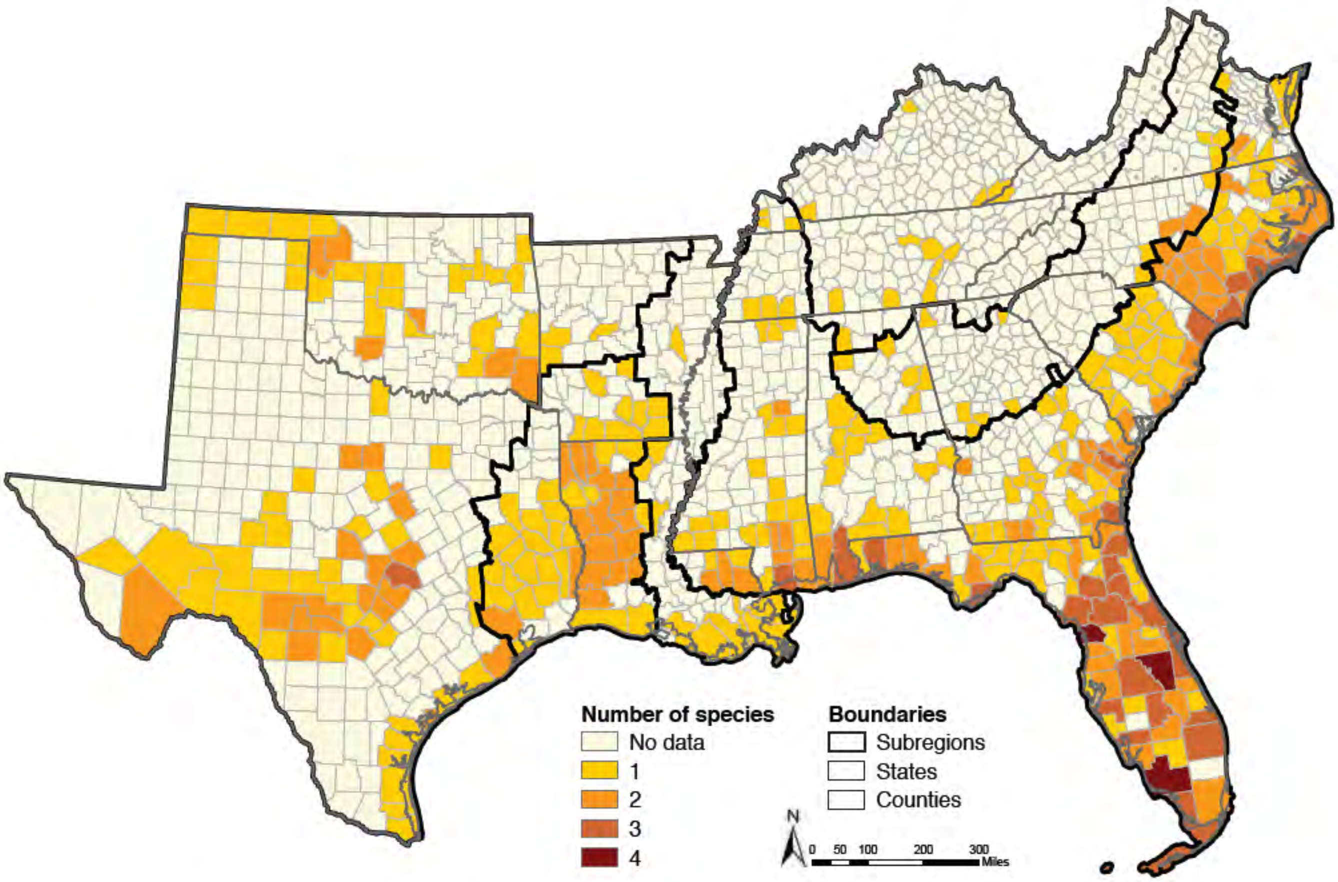


Figure 14.17—County-level counts for bird species of conservation concern in the South. (Source: NatureServe 2011)

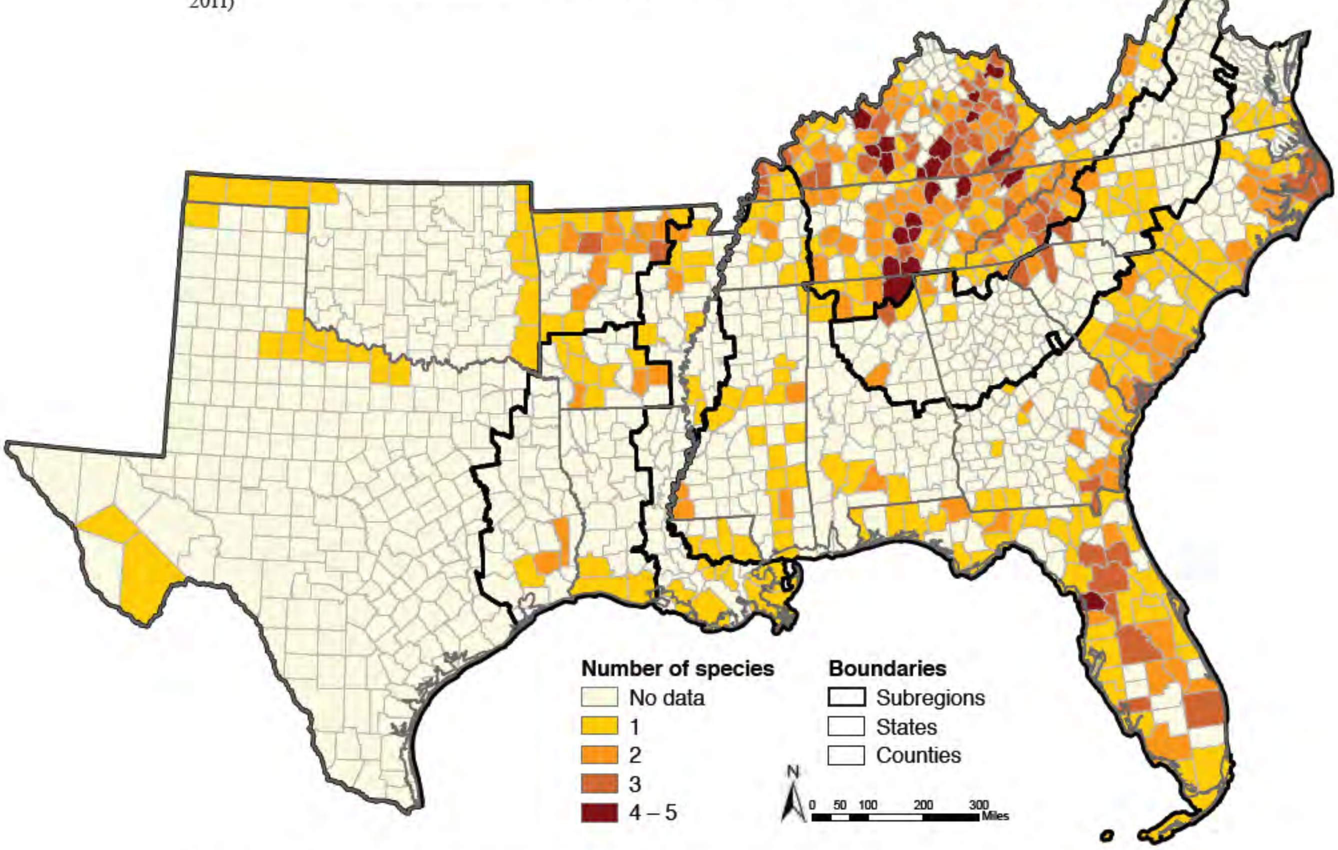


Figure 14.18—County-level counts for mammal species of conservation concern in the South. (Source: NatureServe 2011)

Table 14.7—Mammal species of global conservation concern within the South (NatureServe 2011)[a]

Scientific name	Common name	Subregion name	Section[b]
Bats			
G1			
Eumops floridanus	Florida bonneted bat	Coastal Plain	1_3
G2			
Myotis sodalis	Indiana myotis	Coastal Plain, Piedmont, Appalachian-Cumberland, Mid-South	1_5, 2_1, 2_2, 2_3, 3_1, 3_2, 3_3, 3_4, 3_5, 5_1
G3			
Corynorhinus rafinesquii	Rafinesque's big-eared bat	Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, Mid-South	1_2, 1_3, 1_4, 1_5, 1_6, 1_7, 2_2, 2_3, 3_1, 3_3, 3_4, 3_5, 4_1, 5_1
Leptonycteris nivalis	Mexican long-nosed bat	Mid-South	5_4
Myotis austroriparius	Southeastern myotis	Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 1_5, 1_6, 1_7, 2_1, 2_2, 3_1, 3_4, 3_5, 4_1, 5_1
Myotis grisescens	Gray myotis	Coastal Plain, Piedmont, Appalachian-Cumberland, Mississippi Alluvial Valley, Mid-South	1_2, 1_4, 1_5, 2_1, 2_3, 3_1, 3_2, 3_3, 3_4, 4_1, 5_1
Myotis leibii	Eastern small-footed myotis	Piedmont, Appalachian-Cumberland, Mid-South	2_1, 2_2, 2_3, 3_1, 3_2, 3_3, 3_4, 3_5, 5_1
Rodents			
G1			
Geomys streckeri	Strecker's pocket gopher	Mid-South	5_3
G2			
Dipodomys elator	Texas kangaroo rat	Mid-South	5_2, 5_3
Geomys texensis	Central Texas pocket gopher	Mid-South	5_2, 5_3
G3			
Geomys arenarius	Desert pocket gopher	Mid-South	5_4
Geomys knoxjonesi	Knox Jones pocket gopher	Mid-South	5_4
Neofiber alleni	Round-tailed muskrat	Coastal Plain	1_2, 1_3, 1_4
Neotoma magister	Allegheny woodrat	Piedmont, Appalachian-Cumberland	2_1, 2_3, 3_1, 3_2, 3_3, 3_4
Podomys floridanus	Florida deermouse	Coastal Plain	1_2, 1_3, 1_4
Carnivores			
G1			
Canis rufus	Red wolf	Coastal Plain	1_2, 1_4
Mustela nigripes	Black-footed ferret	Mid-South	5_2, 5_3, 5_4
G3			
Vulpes velox	Swift fox	Mid-South	5_3
Panthera onca	Jaguar	Mid-South	5_2, 5_3
Other Mammals			
G2			
Trichechus manatus	West Indian manatee	Coastal Plain, Mississippi Alluvial Valley	1_1, 1_2, 1_3, 1_4, 4_2
Sorex species 1	A shrew	Coastal Plain	1_1
G3			
Sylvilagus robustus	Robust cottontail	Mid-South	5_4

[a]G1=Critically imperiled; G2=Imperiled; G3=Vulnerable.
[b]1_1 (Northern Atlantic); 1_2 (Eastern Atlantic); 1_3 (Florida Peninsular); 1_4 (Southern Gulf); 1_5 (Middle Gulf-Eastern); 1_6 (Middle Gulf-Western); 1_7 (Western Gulf); 2_1 (Central Appalachian Piedmont); 2_2 (Southern Appalachian Piedmont); 2_3 (Piedmont Ridge, Valley and Plateau); 3_1 (Blue Ridge); 3_2 (Northern Ridge and Valley); 3_3 (Southern Ridge and Valley); 3_4 (Cumberland Plateau and Mountain); 3_5 (Interior Low Plateau); 4_1 (Holocene Deposits); 4_2 (Deltaic Plain); 5_1 (Ozark-Ouachita Highlands); 5_2 (Cross Timbers); 5_3 (High Plains); 5_4 (West Texas Basin and Range).

Table 14.8—Reptile species of global conservation concern within the South (NatureServe 2011)[a]

Scientific name	Common name	Subregion name	Section[b]
Crocodilians			
G2			
Crocodylus acutus	American crocodile	Coastal Plain	1_3
Lizards			
G2			
Plestiodon reynoldsi	Sand skink	Coastal Plain	1_3
Sceloporus arenicolus	Dunes sagebrush lizard	Mid-South	5_3, 5_4
G3			
Coleonyx reticulatus	Reticulated gecko	Mid-South	5_4
Crotaphytus reticulatus	Reticulate collared lizard	Mid-South	5_3
Ophisaurus compressus	Island glass lizard	Coastal Plain	1_2
Ophisaurus mimicus	Mimic glass lizard	Coastal Plain	1_1, 1_2, 1_4
Sceloporus woodi	Florida scrub lizard	Coastal Plain	1_3
Snakes			
G1			
Tantilla oolitica	Rim Rock crowned snake	Coastal Plain	1_3
G2			
Clonophis kirtlandii	Kirtland's snake	Coastal Plain, Appalachian-Cumberland	1_5, 3_5
Heterodon simus	Southern hog-nosed snake	Coastal Plain, Piedmont	1_1, 1_2, 1_3, 1_4, 2_2
Nerodia harteri	Brazos watersnake	Mid-South	5_2, 5_3
Nerodia paucimaculata	Concho watersnake	Mid-South	5_2, 5_3
Pituophis ruthveni	Louisiana pinesnake	Coastal Plain, Mid-South	1_6, 1_7, 5_2
G3			
Drymarchon couperi	Eastern indigo snake	Coastal Plain	1_2, 1_3, 1_4
Lampropeltis extenuata	Short-tailed snake	Coastal Plain	1_2, 1_3, 1_4
Tantilla cucullata	Trans-Pecos black-headed snake	Mid-South	5_4
Turtles			
G1			
Lepidochelys kempii	Kemp's Ridley sea turtle	Coastal Plain, Mid-South	1_1, 1_2, 1_3, 1_4, 5_2, 5_3
Pseudemys alabamensis	Alabama redbelly turtle	Coastal Plain	1_4

(Continued)

Table 14.8—(continued) Reptile species of global conservation concern within the South (NatureServe 2011)[a]

Scientific name	Common name	Subregion name	Section[b]
G2			
Dermochelys coriacea	Leatherback	Coastal Plain	1_1, 1_2, 1_3
Graptemys barbouri	Barbour's map turtle	Coastal Plain, Piedmont	1_2, 1_4, 2_2
Graptemys ernsti	Escambia map turtle	Coastal Plain	1_4
Graptemys flavimaculata	Yellow-blotched map turtle	Coastal Plain	1_4, 1_5
Graptemys gibbonsi	Pascagoula map turtle	Coastal Plain	1_4
Graptemys oculifera	Ringed map turtle	Coastal Plain	1_4, 1_5
Sternotherus depressus	Flattened musk turtle	Coastal Plain, Piedmont	1_5, 2_3
G3			
Caretta caretta	Loggerhead	Coastal Plain, Mississippi Alluvial Valley, Mid-South	1_1, 1_2, 1_3, 1_4, 4_2, 5_2, 5_3
Chelonia mydas	Green turtle	Coastal Plain	1_1, 1_2, 1_3, 1_4
Eretmochelys imbricata	Hawksbill	Coastal Plain	1_1, 1_3
Glyptemys muhlenbergii	Bog turtle	Piedmont, Appalachian-Cumberland	2_1, 2_2, 3_1
Graptemys caglei	Cagle's map turtle	Mid-South	5_3
Gopherus polyphemus	Gopher tortoise	Coastal Plain, Piedmont	1_2, 1_3, 1_4, 1_5, 2_2
Graptemys nigrinoda	Black-knobbed map turtle	Coastal Plain, Piedmont	1_4, 1_5, 2_2
Macrochelys temminckii	Alligator snapping turtle	Coastal Plain, Piedmont, Mississippi Alluvial Valley, Mid-South, Appalachian-Cumberland	1_2, 1_3, 1_4, 1_5, 1_6, 1_7, 2_2, 2_3, 3_5, 4_1, 5_1, 5_2, 5_3
Pseudemys gorzugi	Rio Grande River cooter	Mid-South	5_3
Trachemys gaigeae	Mexican plateau slider	Mid-South	5_4

[a]G1 = Critically imperiled; G2 = Imperiled; G3 = Vulnerable.
[b]1_1 (Northern Atlantic); 1_2 (Eastern Atlantic); 1_3 (Florida Peninsular); 1_4 (Southern Gulf); 1_5 (Middle Gulf-Eastern); 1_6 (Middle Gulf-Western); 1_7 (Western Gulf); 2_1 (Central Appalachian Piedmont); 2_2 (Southern Appalachian Piedmont); 2_3 (Piedmont Ridge, Valley and Plateau); 3_1 (Blue Ridge); 3_2 (Northern Ridge and Valley); 3_3 (Southern Ridge and Valley); 3_4 (Cumberland Plateau and Mountain); 3_5 (Interior Low Plateau); 4_1 (Holocene Deposits); 4_2 (Deltaic Plain); 5_1 (Ozark-Ouachita Highlands); 5_2 (Cross Timbers); 5_3 (High Plains); 5_4 (West Texas Basin and Range).

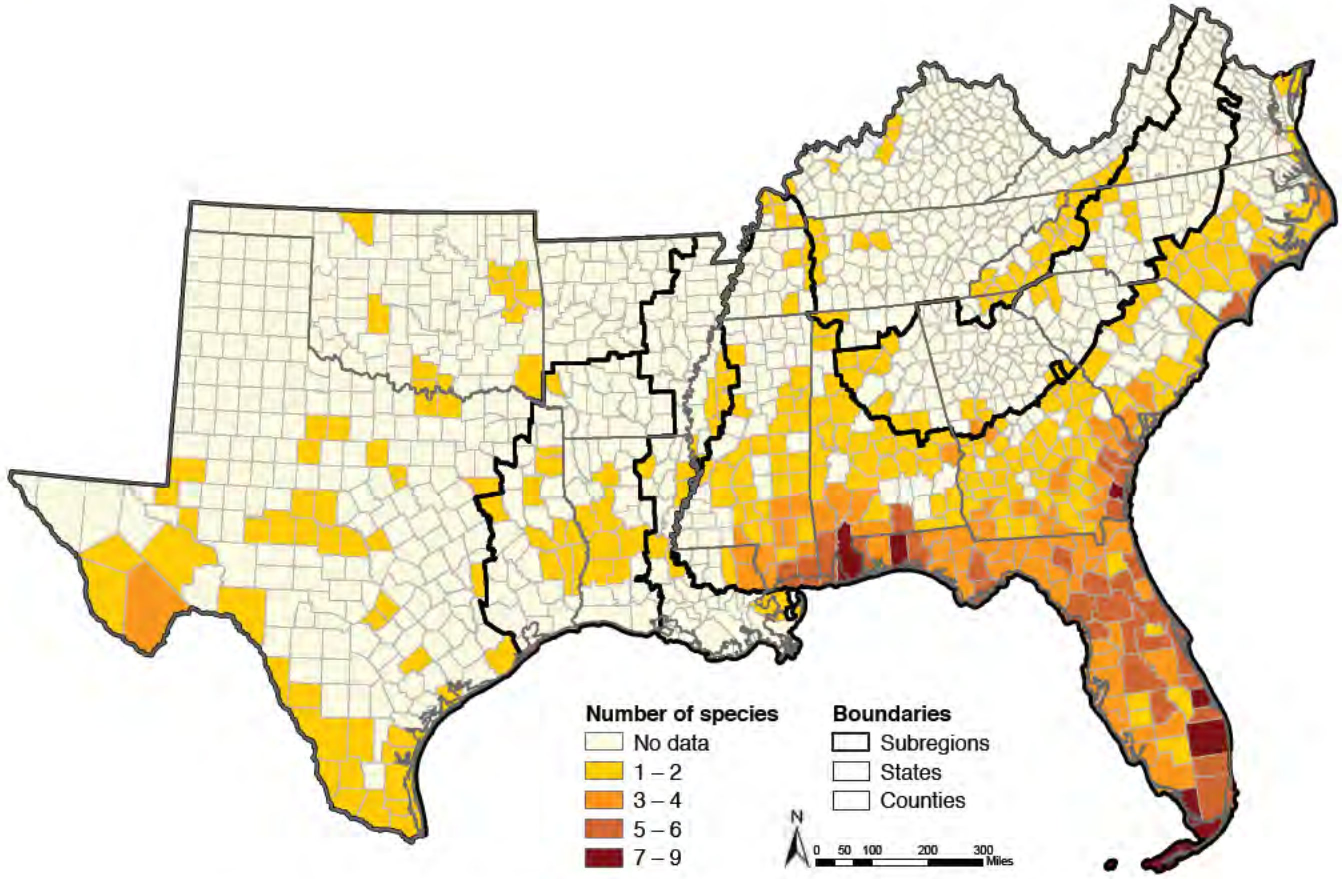


Figure 14.19—County-level counts for reptile species of conservation concern in the South. (Source: NatureServe 2011)

Reptiles—Thirty-six reptile species are of conservation concern (table 14.8). Nineteen are oceanic and map turtles (53 percent), followed by snakes (9), lizards (7), and crocodilians (1). Representative species include the southern hog-nosed snake (*Heterodon simus*), loggerhead (*Caretta caretta*), gopher tortoise, and alligator snapping turtle (*Macrochelys temminckii*).

The Coastal Plain supports more reptiles at risk (27 species) that the other four subregions combined (fig. 14.19). The highest concentration of imperiled turtles occurs in the Southern Gulf (13 species), Eastern Atlantic (7 species), and Florida Peninsula (7 species). The occurrence of imperiled snakes is also highest in these three areas but far fewer numbers are involved (3 to 4 species per section). Turtles occurring in these areas include the hawksbill (*Eretmochelys imbricata*) and Alabama redbelly turtle (*Pseudemys alabamensis*). Snakes are represented by the Concho watersnake (*Nerodia paucimaculata*) and Rim Rock crowned snake (*Tantilla oolitica*). Other reptiles at risk inhabiting these areas include the mimic glass lizard (*Ophisaurus mimicus*) and bluetail mole skink (*Plestiodon egregius lividus*).

Many reptiles are long-lived, late maturing, and have restricted geographic ranges. For map turtles, those limits magnify the risk from degradation of aquatic habitats, disease, or illegal collection. Sea turtles are imperiled by commercial turtle fishing, exploitation of the juveniles, beach development, and incidental take. Lizard species with insular populations and restricted ranges are at risk to habitat loss. Malicious killing of snakes, as well as biocides and the pet trade, contribute to their imperilment.

Plants—Species of conservation concern are concentrated in five areas. One of these is Big Bend National Park in the West Texas Basin and Range, where the Chihuahuan desert ecosystem is home to an endangered perennial herb, Terlingua Creek cat's-eye (*Cryptantha crassipes*), and two cacti, Nellie Cory (*Escobaria minima*) and Davis's hedgehog (*Echinocereus viridiflorus* var. *davisii*). Eastward, the islands, marshes, swamps, and flatwoods of the southern Gulf Coast, especially the Apalachicola area, contain over 150 species of concern, including 12 that are endangered—among them Apalachicola false rosemary (*Conradina glabra*), Florida nutmeg (*Torreya taxifolia*), and purpleflower pinkroot (*Spigelia gentianoides*); and five that are threatened—among them Florida skullcap (*Scutellaria floridana*) and Telephus spurge (*Euphorbia telephioides*). Two other regions in Florida, the central ridges and uplands, including Lake Wales Ridge, and much of the area south of Lake Okeechobee, have a number of sensitive species. Sandhills, scrub, flatwoods, bayheads, and hammocks of the Florida central uplands have 21 species listed as endangered or threatened. These include pygmy fringetree (*Chionanthus pygmaeus*), false rosemary (*C. brevifolia*), and scrub balm (*Dicerandra frutescens*). Upward along the Atlantic Coastal Plain, at-risk plants in North Carolina include wet-site species. Examples include the endangered pondberry (*Lindera melissifolia*) and Canby's dropwort (*Oxypolis canbyi*), as well as American chaffseed (*Schwalbea americana*) and other species of fire-prone ecosystems that occupy pine savannas, bottomland and swamp forests, and scattered pocosin wetlands.

Species Extirpation within Selected States of the South

Terrestrial vertebrates—The Southern Forest Resource Assessment (Trani 2002b) presented 32 terrestrial species that were classified as extinct or extirpated from the South. In the years following that effort, the databases from State Heritage Agencies (NatureServe 2011) indicate this list has expanded to 65 species (table 14.9). The degree of extirpation species varies among taxonomic groups, with birds comprising 61 percent, followed by mammals (28 percent), reptiles (6 percent), and amphibians (5 percent).

Recent extirpation was most prominent in the perching bird and wading bird groups. Nine perching species have been lost from six States. Henslow's sparrow (*Ammodramus henslowii*) has experienced population and range reductions due to habitat alteration (urban growth and industrial development), while the bobolink (*Dolichonyx oryzivorus*) decline has been attributed to incompatible agricultural practices (NatureServe 2011). There appears to be a pattern among extirpated wading birds that reflects the continuing loss and modification of wetland habitat in the South. The American bittern (*Botaurus lentiginosus*) is threatened by the degradation of wetlands due to drainage, siltation, and conversion to agriculture; the wood stork has been negatively impacted by human alteration of natural hydrological conditions that affect both nesting and feeding areas. The white-faced ibis is also vulnerable to fluctuating water levels, habitat alteration, and pesticide contamination.

Also notable is the first appearance of extirpated bat species on the list since the Southern Forest Resource Assessment. Populations of the Northern myotis (*Myotis septentrionalis*) in the South are small and widely dispersed; the philopatry displayed by this bat for winter roosts may lead to local extirpation if a hibernaculum is modified or destroyed (Chapman 2007). The Indiana myotis is quite vulnerable to natural and human-caused disturbance due to concentrated populations in few winter hibernacula. Population declines have also been attributed to destruction of summer foraging and roosting habitat by deforestation and stream channelization (Ford and Chapman 2007).

Carnivore species (10) remain the largest group of extirpated mammals in the South. The extirpation of large carnivores such as the gray wolf (*Canis lupus*) reflects the history of European settlement (Trani 2002b) where they were regarded as threats to livestock and personal safety. The decline of the red wolf has been attributed to indiscriminate predator control, extensive land clearing, and coyote (*Canis latrans)* hybridization (Trani and Chapman 2007). The disappearance of the jaguar reflects habitat destruction, illegal hunting, and exploitation by the fur industry (NatureServe 2011). Other carnivores such as the cougar (*Puma concolor*) were relegated to relatively remote areas.

Recent extirpation of reptile species occurred in four States. The mimic glass lizard has a disjunct distribution in the South; it is vulnerable to habitat loss from development, conversion to pine plantations, and road mortality. Snakes comprise three-fourths of the State-level reptile extirpations. The Southern hog-nosed snake is declining throughout most of its range in the Coastal Plain; potential threats include fire ants, intensive agricultural/silvicultural activities, widespread pesticide application, and road mortality.

Frogs and toads are new to the list of extirpated amphibian species since the Southern Forest Resource Assessment. The dusky gopher frog formerly occurred in the Coastal Plain from Alabama to Louisiana; it is now known from a small area in Mississippi and threatened by habitat degradation (NatureServe 2011).

Vascular plants—The 550 extirpated plant species listed by NatureServe (2011) databases include those within 74 vascular plant families (table 14.10). Habitat loss has reduced the range of species associated with unique plant communities or those found in areas subject to development. Climate change may cause further reduction in species range. For example, seaside heliotrope (*Heliotropium curassavicum* var. *curassavicum*), a plant of salt flats and marshes in the South, has disappeared from North Carolina, likely due to past coastal development, and may be threatened in the future by sea level rise in other Southern States (chapter 13). Other obligate and facultative freshwater wetland plants, including four bladderwort (*Utricularia*) species, have disappeared from selected States. Plants of locally unique areas such as glades, savannas, and prairie-like sites (e.g., yellow flax (*Linum sulcatum*), entire leaf Indian paintbrush (*Castilleja indivisa*), and American columbo (*Frasera caroliniensis*), have been extirpated from some States,

Table 14.9—Sixty-five terrestrial vertebrate species considered to be extirpated from selected States in the South (NatureServe 2011). Species in red are new additions since the Southern Forest Resource Assessment (Trani 2002b)

Scientific name	Common name	No. Species	Former Area of Occurrence
AMPHIBIANS		**3**	
Frogs and Toads		**2**	
Rana heckscheri	River frog		NC
Rana sevosa	Dusky gopher frog		AL, LA
Salamanders		1	
Plethodon ainsworthi	Catahoula salamander		MS
BIRDS		**40**	
Other Birds		**15**	
Anhinga anhinga	Anhinga		KY
Campephilus principalis	Ivory-billed woodpecker		AL, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX
Centrocercus urophasianus	Greater sage-grouse		OK
Chlidonias niger	Black tern		KY
Columbina passerina	Common ground-dove		NC
Conuropsis carolinensis	Carolina parakeet		AL, AR, FL, GA, KY, LA, MA, NC, OK, SC, TN, TX, VA
Cynanthus latirostris	Broad-billed hummingbird		TX
Ectopistes migratorius	Passenger pigeon		AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA
Fulica americana	American coot		SC
Geotrygon chrysia	Key West quail-dove		FL
Picoides borealis	Red-cockaded woodpecker		KY, TN
Sterna dougallii	Roseate tern		VA
Tympanuchus cupido	Greater prairie-chicken		AR, KY, LA, TN
Tympanuchus phasianellus	Sharp-tailed grouse		OK, TX
Zenaida aurita	Zenaida dove		FL
Perching Birds		**11**	
Ammodramus henslowii	Henslow's sparrow		TX
Chondestes grammacus	Lark sparrow		VA
Contopus cooperi	Olive-sided flycatcher		VA
Corvus corax	Common raven		AL
Dendroica cerulea	Cerulean warbler		TX
Dendroica nigrescens	Black-throated gray warbler		TX
Dolichonyx oryzivorus	Bobolink		TN
Riparia riparia	Bank swallow		AL
Thryomanes bewickii	Bewick's wren		AL, GA, NC
Vermivora bachmanii	Backman's warbler		AL, AR, FL, GA, KY, LA, MS, OK, SC, TN, VA
Vireo bellii	Bell's vireo		TN
Raptors		**3**	
Aquila chrysaetos	Golden eagle		KY, NC, VA
Elanoides forficatus	Swallow-tailed kite		OK
Falco peregrinus	Peregrine falcon		AL, SC
Shorebirds		**2**	
Bartramia longicauda	Upland sandpiper		KY
Numenius borealis	Eskimo curfew		SC, TX

(Continued)

Table 14.9—(continued) Sixty-five terrestrial vertebrate species considered to be extirpated from selected States in the South (NatureServe 2011). Species in red are new additions since the Southern Forest Resource Assessment (Trani 2002b)

Scientific name	Common name	No. Species	Former Area of Occurrence
Wading Birds		**6**	
Botaurus lentiginosus	American bittern		KY
Grus americana	Whooping crane		AR, GA, LA, TX
Grus canadensis	Sandhill crane		AL
Mycteria americana	Wood stork		TX
Plegadis chihi	White-faced ibis		AL
Plegadis falcinellus	Glossy ibis		AR, SC
Waterfowl		**3**	
Anas discors	Blue-winged teal		NC
Anas rubripes	American black duck		TX
Cygnus buccinator	Trumpeter swan		LA, OK
MAMMALS		**17**	
Bats		**2**	
Myotis septentrionalis	Northern myotis		FL
Myotis sodalis	Indiana myotis		MS
Carnivores		**9**	
Canis lupus	Gray wolf		AR, FL, GA, KY, NC, OK, TN, TX, VA
Canis rufus	Red wolf		AL, AR, FL, GA, KY, LA, MS, OK, TN, TX, VA
Leopardus pardalis	Ocelot		AR, LA
Leopardus wiedii	Margay		TX
Panthera onca	Jaguar		LA, TX
Puma concolor	Cougar		AL, GA, KY, NC, SC
Martes pennanti	Fisher		NC
Mustela nigripes	Black-footed ferret		OK, TX
Ursus arctos	Brown bear		OK, TX
Other Mammals		**4**	
Bos bison	American bison		AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA
Cervus canadensis	Elk		AL, GA, LA, OK, TN, SC, VA
Lepus americanus	Snowshoe hare		NC
Ovis canadensis	Bighorn sheep		TX
Rodents		**2**	
Erethizon dorsatum	North American porcupine		NC, VA
Microtus ochrogaster	Prairie vole		LA
REPTILES		**4**	
Lizards		**1**	
Ophisaurus mimicus	Mimic glass lizard		MS
Snakes		**3**	
Heterodon simus	Southern hog-nosed snake		AL, MS
Masticophis flagellum	Coachwhip		KY
Sonora semiannulata	Groundsnake		AR
TOTAL VERTEBRATES		**64**	

Table 14.10—Number of vascular plant species by family considered to be extirpated from selected States in the South (NatureServe 2011)

Family	No. Species	Former Area of Occurrence
Acanthus	3	GA(2), SC(2)
Amaranth	3	AR(1), OK(2)
Aster	56	AL(7), AR(7), FL(2), GA(10), KY(8), LA(3), NC(13), OK(1), TN(5), TX(1), VA(4)
Barberry	1	AL(1)
Beech	5	AL(1), AR(1), GA(1), FL(1), TX(1)
Bladderwort	4	AR(1), NC(2), VA(1)
Blazingstar	2	AR(1), OK(1)
Borage	4	FL(1), KY(1), NC(2)
Broom-Rape	2	KY(2), TN(1)
Buckthorn	1	LA(1)
Buckwheat	3	GA(1), NC(2)
Buttercup	13	AL(2), KY(5), NC(3), OK(1), SC(1), TN(2), VA(2)
Cactus	1	TX(1)
Carrot	11	AR(2), GA(2), KY(3), LA(2), OK(1), VA(2)
Currant	1	TN(1)
Dodder	1	GA(12)
Dogbane	1	MS(1)
Elm	1	AL(1)
Evening-Primrose	8	AL(2), AR(2), FL(1), KY(2), TX(1), VA(1)
Ferns and Relatives	29	AL(1), AR(3), FL(4), GA(1), KY(4), LA(6), MS(1), NC(1), OK(3), SC(1), TN(3), VA(3)
Fig-Marigold	1	TX(1)
Figwort	30	AL(1), AR(4), GA(3), KY(5), LA(6), MS(2), NC(5), OK(2), TN(4), TX(1), VA(4)
Flax	3	FL(2), GA(1), NC(2)
Four-O'clock	2	KY(1), TX(1)
Gentian	8	AL(1), KY(1), LA(3), NC(2), OK(1), TX(1)
Geranium	2	AR(1), TN(1)
Goosefoot	1	NC(1)
Grape	1	GA(1)
Grass	37	AL(1), AR(5), FL(2), GA(6), KY(5), LA(2), MS(2), NC(8), OK(3), TN(4), VA(7)
Greenbrier	3	AR(1), KY(1), VA(1)
Heath	5	GA(2), NC(1), SC(1), TN(1)
Holly	1	GA(1)
Honeysuckle	7	AR(1), GA(2), LA(1), OK(1), TN(2)
Iris	2	AR(1), OK(1)
Laurel	2	AR(1), FL(1), LA(1)
Loosestrife	1	VA(1)
Lily	17	AR(2), GA(3), KY(2), LA(2), NC(5), OK(1), SC(2), VA(1)
Madder	1	FL(1)

(Continued)

Table 14.10—(continued) Number of vascular plant species by family considered to be extirpated from selected States in the South (NatureServe 2011)

Family	No. Species	Former Area of Occurrence
Mallow	6	KY(1), LA(2), NC(1), TN(1), TX(1)
Meadowfoam	1	LA(1)
Melastome	2	GA(1), TX(1)
Morning-Glory	1	NC(1), OK(1), VA(1)
Milkweed	7	AR(1), GA(1), LA(1), MS(1), NC(1), OK(1), TX(1)
Milkwort	4	KY(1), NC(1), VA(2)
Mint	16	AR(1), FL(1), GA(2), KY(5), NC(6), TN(1), TX(1), VA(2)
Mustard	13	AL(3), GA(2), KY(3), LA(2), MS(1), NC(2), TN(1), VA(1)
Nettle	1	NC(1), OK(1)
Orchid	30	AR(1), FL(10), GA(4), KY(4), NC(5), OK(2), SC(3), TN(2)
Other Flowering Plants	24	AL(1), AR(1), FL(1), GA(2), KY(3), LA(6), OK(3), SC(2), TX(1), VA(5)
Pea	25	AL(3), AR(2), FL(2), GA(2), KY(2), LA(1), NC(6), SC(1), TN(2), TX(3), VA(3)
Pepper	1	FL(1)
Pink	11	AL(1), FL(1), LA(2), OK(1), SC(2), TN(1), VA(5)
Pipewort	2	SC(1), TN(1)
Pitcherplant	2	LA(1), TN(1)
Plantain	1	FL(1), KY(1), VA(1)
Pondweed	5	KY(1), LA(2), NC(2), VA(1)
Potato	7	GA(2), MS(1), OK(4)
Primrose	4	GA(1), KY(3), VA(2)
Rock-Rose	3	AR(1), FL(1), TN(2)
Rose	11	AR(3), GA(1), MS(1), NC(2), TN(1), TX(1), VA(2)
Rue	1	FL(1)
Rush	4	AL(1), KY(1), NC(1), TN(1)
Saxifrage	4	AL(1), KY(1), LA(1), NC(1), TN(1)
Sedge	63	AL(1), AR(8), FL(2), GA(6), KY(11), LA(4), NC(11), OK(2), SC(3), TN(11), TX(1), VA(12)
Spurge	3	AR(2), FL(1)
St. John's Wort	7	AL(1), KY(3), NC(2), VA(2)
Stonecrop	1	NC(1), TN(1)
Sumac	2	OK(1), SC(1)
Valerian	1	OK(1)
Verbena	3	KY(1), NC(1), OK(1), VA(1)
Violet	1	OK(1)
Water-Lily	1	MS(1), NC(1)
Water-Milfoil	1	KY(1)
Water-Plantain	4	AR(1), LA(1), NC(1), VA(1)
Willow	3	AR(1), KY(2), NC(1)
TOTAL	**550**	

especially where the habitat is sparse or at the edge of the range.

Plant species that were initially known from single sporadic locations, or are inconspicuous may easily be overlooked in field surveys. This includes the southern (*Listera australis)* and heartleaf (*L. cordata)* twayblades orchids, possibly extirpated from Kentucky and North Carolina, respectively. On the other hand, showy or specialized plants such as selected orchids may be lost through habitat reduction and exploitation. These include species in the genus *Platanthera:* Chapman's fringed orchid (*P. chapmanii* - Presumed extinct Georgia); white fringeless orchid (*P. integrilabia* - Presumed extinct North Carolina); eastern prairie white-fringed orchid (*P. leucophaea* - Presumed extinct Oklahoma); snowy orchid (*P. nivea* - Presumed extinct Arkansas), and purple fringeless orchid (*P. peramoena* - Presumed extinct South Carolina). Harvesting from the wild may lead to increasing rates of extirpation of economically important plants if market demands increase faster than the supplies from garden populations.

Forecasts of Urban Growth, Forest Loss, and Climate Change

Potential sources of future threats to wildlife and plant communities include forest and range loss, coastal inundation, forest fragmentation with land development, and growing urban centers. Because the forecasts of urban growth vary across the South, species may be impacted disproportionally. Forecast changes in forest cover reflect, for the most part, the pattern forecast for urbanization (chapter 4). Among the possible futures described in chapter 2, the one that predicts the highest loss of forest and the greatest urban growth, Cornerstone B, will be discussed below. Urbanizing areas overlap with several areas of conservation concern in the following subregions:

Mid-South—In Arkansas, the Ozark-Ouachita Highlands region around Hot Springs and Little Rock is predicted to experience 10 to 20 percent forest loss and an equal percentage of urban growth. This area includes Hot Springs National Park and the Ouachita National Forest. Forest and glade plants that could be threatened on unprotected lands in this westernmost area include the vulnerable southern lady's slipper (*Cypripedium kentuckiense*) reported by Case and others (1998), the clasping twistflower (*Streptanthus maculatus*), and least trillium (*Trillium pusillum)* reported by Timmerman-Erskine and others (2003).

Urban growth in this subregion is forecast for counties that support the Caddo Mountain salamander (*Plethodon caddoensis*), the Ozark big-eared bat (*Corynorhinus townsendii ingens*), and the Oklahoma salamander (*Eurycea tynerensis*). Additional Mid-South development along the southern borders shared by Cross Timbers and Western Gulf could impact a numerous reptiles, especially Cagle's map turtle (*Graptemys caglei)*, loggerhead, and other turtles. This area also lies within a band of especially high avian richness that occurs along the Texas Gulf Coast of the Central Flyway.

Appalachian-Cumberland highlands—Ten to twenty-five percent urban growth and 10 to 20 percent forest loss near Nashville in the Interior Low Plateau and around Knoxville and Asheville in the Blue Ridge section could threaten bats, salamanders, and concentrations of sensitive plant species. The central Tennessee basin, adjacent escarpment, and highland rim around Nashville have plants of limestone glades, prairie-like areas, and forests. These include the endangered Pyne's ground plum (*Astragalus bibullatus*) and Tennessee coneflower (*Echinacea tennesseensis*), which are endemic to central basin limestone glades (Baskin and Baskin 2005, Snyder and others 1994).

In eastern Tennessee and western North Carolina, forest loss, increased recreational use and residential development near Knoxville and Asheville threaten to reduce the high biodiversity of the Southern Appalachian Mountains. Warmer temperatures may allow migration of southern species into lower elevation sites. Even though large public land holdings (Great Smoky Mountain National Park, Blue Ridge Parkway, and Nantahala, Pisgah, and Cherokee National Forests) buffer and protect these habitats, residential development and growing recreational use threaten plant species such as the endangered spreading avens (*Geum radiatum*), which is endemic to high elevation rock outcrops, grassy balds, and cliff faces (Murdock 1993). Warmer temperatures, changes in precipitation or fire regime, or climate-change induced competition from offsite plants may threaten spreading avens (Godt and Hamrick 1995; Murdock 1994), along with other species of high elevation and unique habitats such as the vulnerable false dandelion (*Krigia montana*) on cliffs, outcrops, and grassy balds; the vulnerable Rugel's ragwort (*Rugelia nudicaulis*) of spruce forests; and the endangered Smoky Mountains mannagrass (*Glyceria nubigena*) of high elevation seeps. The Blue Ridge supports a notable 53 species of salamanders, 15 of which are imperiled or vulnerable: dwarf black-bellied salamander (*Desmognathus folkertsi)*, red-legged salamander (*Plethodon shermani),* and South Mountain gray-cheeked salamander (*Plethodon meridianus).* Any loss of habitat connectivity will make migration difficult for the amphibians that occur there.

Piedmont—Forecasts of substantial urban growth (10 to 25 percent), with substantial losses of forest habitat, could impair the relatively high richness of amphibians (59 to 76 species/section) and mammals (49 to 58 species/section) that inhabit this subregion. Several species of concern occur in the Central Appalachian Piedmont (14), Southern Appalachian Piedmont (18), and Piedmont Ridge and

Valley (17), including the black warrior waterdog (*Necturus alabamensis)*, gray myotis*,* Peaks of Otter salamander (*Plethodon hubrichti),* and Shenandoah Mountain salamander. The greater than 25 percent urban growth predicted for Atlanta, particularly expansion along Interstate 85 northward toward Greenville, SC, could threaten plants of upland forests and openings, such as American ginseng (*Panax quinquefolius*). However, more than 75 percent of at-risk plant species in the fast-growing DeKalb and Gwinnett counties around Atlanta are either associated with protected lands or with areas that are otherwise inaccessible for development (e.g., granite outcrops).

Areas with concentrations of sensitive plant species or plant communities—including the Blue Ridge escarpment and foothills (Southern Appalachian Piedmont), and southern extensions of the Cumberland Plateau and adjacent Valley and Ridge (Piedmont Ridge, Valley and Plateau)—are predicted to have 3 to 20 percent increase in urban area and forest loss. The escarpment and foothills area, primarily in northern South Carolina, includes mountain outcrops such as Table Rock State Park, gorges, lakes (such as Jocassee, Keowee, and Hartwell), the Chattooga Wild and Scenic River, and the growing urban area around Greenville. Beyond protected public lands, development threatens plants such as the imperiled Oconee-bells (*Shortia galacifolia*) in ravines and shady streambanks. Plants at risk from habitat loss in the Piedmont Ridge and the Valley and Plateau section of northern Alabama and Georgia include the endangered Alabama leather-flower (*Clematis socialis*) that occurs along roadsides and recently logged forests (Trusty and others 2009).

Coastal Plain—The forecast of a 3 to 25 percent forest loss with subsequent urban development, especially along the Atlantic and Gulf coasts, threatens wildlife and their habitats. Areas close to the coast also are at risk of storm surges and the greater salinity that accompanies sea level rise (chapter 13). For example, seabeach amaranth (*Amaranthus pumilus*) on barrier island dunes is threatened by beach erosion and inundation as well as construction (U.S. Department of the Interior 2011). More extensively, loss of freshwater emergent marsh and pool habitat threatens wildlife such as the marsh rabbit (*Sylvilagus palustris*) and several waterbirds that depend on these habitats (Erwin and others 2006).

Climate change-induced inundation of mangrove forests (e.g., *Rhizophora mangle, Avicennia germinans,* or *Laguncularia racemosa*) along the coast of the Coastal Plain may reduce available habitat and nesting substrate for birds such as the frigatebird (*Fregata magnificens*), mangrove cuckoo (*Coccyzus minor*), reddish egret (*Egretta rufescens*), and roseate spoonbill (*Ajaia ajaia*). Loss of this habitat may also impact the diamondback terrapin (*Malaclemys terrapin*) and salt marsh snake (*Nerodia clarkii*). Live oak (*Quercus virginiana*) maritime forests that occur on Atlantic and Gulf coast barrier islands may also be degraded by predicted sea level rise. These forests serve as important nesting habitat for many birds that feed in aquatic habitats as well as supporting a diversity of winter avifauna. Birds affected by the loss of live oak maritime forests include the boat-tailed grackle (*Quiscalus major*), fish crow (*Corvus ossifragus*), great crested flycatcher (*Myiarchus crinitus*), and northern parula (*Parula americana*). Other characteristic species of this forest are the broadhead skink (*Eumeces laticeps*), green treefrog (*Hyla cinerea*), golden mouse (*Ochrotomys nuttalli),* and southeastern shrew (*Sorex longirostris).*

Coastal areas also have a mixture of vegetation types, such as fire-maintained wet pine savannas and flatwoods, seeps and pocosins, marshes, swamps, and bottomlands—that are home to diversity of species and are at risk from changing fire regimes and other indirect effects of climate change (chapter 3). One area of at-risk plant diversity is the Cape Fear Arch region of North and South Carolina: LeBlond (2001) lists 22 endemic and another 22 near-endemic plant species such as coastal goldenrod (*Solidago villosicarpa*) in coastal edge forests and roughleaf loosetrife (*Lysimachia asperulifolia*) in the ecotone between upland pine forest and pocosin (Sorrie and others 2006) in this region. Along the Eastern Atlantic and Florida coastlines that coincide with portions of the Atlantic Flyway, extensive development will likely eliminate important stopover habitat for spring and fall migrating birds as well as habitat for resident species. This coastline is also an important nesting area for sea turtles such as the leatherback and Kemp's Ridley (*Lepidochelys kempii).* This forecast will impact the habitat for 25 species of conservation concern including the red wolf*,* round-tailed muskrat*,* and short-tailed snake (*Lampropeltis extenuata).*

The Florida Peninsula, especially around Palm Beach and Miami, is threatened by projected 10 to 25 percent urban growth and also by sea level rise (chapter 13). This area is ecologically diverse and unique; Monroe and Miami-Dade counties include part of the Everglades and are a mix of pine forests, hammocks, beach dune and strand, prairies, cypress swamps, mangroves, and freshwater and saltwater marshes. These counties contain seven plant species listed as threatened or endangered (U.S. Department of the Interior 2011); while most of them may be further threatened by urban growth and sea level rise, marine species such as Johnson's seagrass (*Halophila johnsonii*) could expand their range (Virnstein and Hall 2009). The habitat of several aquatic and marsh species in the Everglades may be vulnerable to sea level rise. This includes the common yellowthroat (*Geothlypis trichas*), greater siren (*Siren lacertina*), northern harrier (*Circus cyaneus*), squirrel treefrog (*Hyla squirella*), and American mink (*Mustela vison).* The Florida Peninsula also includes the inland Lake Wales Ridge. Although this area is projected to have a moderate (3 to 10 percent) increase in urban area and forest loss, its diverse fire-maintained ecosystems may be more threatened by changing fire regimes that could accompany climate change.

The Southern Gulf, which includes the Apalachicola region westward to the tip of Louisiana, is projected for 3 to 25 percent urban growth and forest loss. Near-coastal areas and the southern part of Louisiana also are threatened by direct and indirect effects of sea level rise. Off protected lands, upland plant species such as Apalachicola false rosemary are threatened by disturbances caused by urbanization and other land use changes. Some rare species such as Florida nutmeg are also at risk from pathogens (Schwartz and others 2000). The projected urban growth of the Southern Gulf is coincident with the highest turtle diversity in the region and with especially rich areas of habitat for species such as the Mississippi sandhill crane (*Grus canadensis pulla).*

Forecasts of increased urbanization in Peninsular Florida would affect bird habitat on the Gulf and Atlantic Coasts, as well as the 38 amphibians that occur in the northern areas of the State. Numerous species of conservation concern could be imperiled by future habitat losses: 38 species in the Southern Gulf and 30 species in the Florida Peninsula. Included are the Florida grasshopper sparrow (*Ammodramus savannarum floridanus),* Florida panther, Key Oryzomys (*Oryzomys palustris natator),* ringed map turtle (*Graptemys oculifera*), and yellow-blotched map turtle (*Graptemys flavimaculata*).

Mississippi Alluvial Valley—Portions of the Deltaic Plain are forecast for 10-25 percent urban growth, while the Holocene Deposits are predicted to expand to a lesser degree (3-10 percent). This growth could negatively influence the current richness of shorebirds and waterfowl occurring within the Mississippi Flyway that runs through these sections; the wetlands of Louisiana and Mississippi provide critical stopover habitat for migrating birds crossing the Gulf from South America. Twenty-five species of frogs and toads that inhabit the Deltaic Plain could also be impacted. The projected areas of urban development/forest loss are adjacent to conservation priority areas designated for habitat enhancement for the threatened Louisiana black bear*,* which are intended to promote bottomland forest connectivity within the landscape (Lower Mississippi Valley Joint Venture Forest Resource Conservation Working Group 2007). Other forest-dependent vertebrate species of concern in this subregion include the American woodcock (*Scolopax minor*), ivory-billed woodpecker (*Campephilus principalis*), and several forest interior songbirds including the Swainson's warbler (*Limnothlypis swainsonii*).

The sea level rise predicted for the Deltaic Plain would inundate the coastal wetland habitat inhabited by numerous species including the American bittern, king rail (*Rallus elegans*), least bittern (*Ixobrychus exilis*), and southern cricket frog (*Acris gryllus*).

Overall, southern ecosystems will continue to be threatened by forest loss and urban growth, as well as effects of climate, such as altered fire regimes, sea level rise, and spread of pathogens. Changes in forest communities may occur due to warming and precipitation patterns. Coastal regions, high elevation areas, species of fire-maintained systems (especially near growing urban centers) are especially at-risk. The value of public and private forest lands for the preservation and conservation of these species and their communities will continue to increase in the future.

Forecasts for Selected Forest Communities

High elevation forests—These forests are distributed above 4,000 feet elevation on the peaks of the Southern Appalachians and northward in the Appalachian–Cumberland highlands. Species include red spruce (Forest Type 123), red spruce/balsam fir (Forest Type 124), eastern hemlock (Forest Type 105), and northern hardwoods consisting of sugar maple/beech/yellow birch (Forest Type 801; Woudenberg and others 2010). They occur in the Allegheny Mountains of the Central Appalachians in east-central West Virginia and west-central Virginia, the northern Blue Ridge of central and northern Virginia, and the southern Blue Ridge of eastern Tennessee, western North Carolina, and limited areas of northern Georgia.

High elevation communities are characterized by cool temperatures, relatively high moisture levels within forests, short growing seasons, exposed rock and acidic soils, and extreme weather events. Canopy trees are often misshapen by persistent strong winds. Open (sparse-to-no tree canopy) communities such as heath or grassy balds and rock outcrops are scattered throughout. The distinctive flora includes the vulnerable Rugel's ragwort, which is restricted to a few counties in the Great Smoky Mountains (USDA National Resource Conservation Service Plants Database 2010), and the imperiled Fraser fir (*Abies fraseri)*, which is recovering from infestation (Moore and others 2008) by the balsam woolly adelgid (*Adelges piceae*).

High elevation forests support several mammals including the fisher (*Martes pennanti*), snowshoe hare (*Lepus americanus*), northern flying squirrel, and rock vole (*Microtus chrotorrhinus*). The golden-crowned kinglet (*Regulus satrapa*), red crossbill (*Loxia curvirostra*), saw-whet owl (*Aegolius acadicus*), and yellow-bellied flycatcher

(*Empidonax flaviventris*) also inhabit this community. Although few reptiles can tolerate these harsh conditions (Bailey and others 2006), there are locally high populations of several salamanders, some of which are endemic habitat specialists with restricted ranges. Species include the Allegheny Mountain dusky (*Desmognathus ochrophaeus*), imitator salamander (*D. imitator*), pigmy salamander (*D. wrighti*), shovel-nosed salamander (*D. marmoratus*), Southern Appalachian salamander (*Plethodon teyahalee*), and Weller's salamander (*P. welleri*).

High elevation forests are threatened by air pollution, heavy metal deposition, acid precipitation (which influences soil and stream chemistry), natural disturbances such as hurricanes and landslides, and housing development on unprotected lands (Moore and others 2008; Turner and others 2003; Wear and Bolstad 1998; White and others, in preparation). Recent pressures include drier, warmer conditions normally associated with climate change (Ibanez and others 2007) and recreational activity that results in soil compaction and physical damage to young trees (Trani 2002b). These forest types occur infrequently in the Forest Inventory and Analysis data that provided the baseline for Forest Future modeling, precluding any accurate predictions of future changes. Nevertheless, if population centers expand and air temperatures warm by 2060 as predicted by several of the forecasts, the pressures that are currently affecting high elevation forests are likely to continue. For example, the Carolina northern flying squirrels that inhabit high elevation spruce, northern hardwoods, and hemlock forests are ceding territory to expanding populations of southern flying squirrels (*Glaucomys volans*) as well as suffering from human impacts on the size, quality, and connectedness of their habitat (Weigl 2007) and from the infestation of eastern hemlock (*Tsuga canadensis*) by the hemlock woolly adelgid (*A. tsugae*).

Upland hardwood forests—Cornerstone B forecasts the greatest loss in upland hardwood forests caused by moderate population growth, high urbanization due to strong income growth, and falling timber prices. The forecast is a 14 percent decrease South-wide, although the dominant forest type, oak-hickory forest, is forecast to lose only 1 percent of its area (chapter 5).

Upland hardwood forests of the South were established in the 1800s and early 1900s (Lorimer 2001). These forests are aging and, like forests in all subregions except the newly planted Mississippi Alluvial Valley, will see a decrease in acreage of midsuccessional forest and concomitant increase in late successional forest (chapter 5). Forest aging, with increasing tree sizes and canopy development, could benefit interior species that are sensitive to forest fragmentation and habitat patch size; examples include the gray fox, black and white warbler (*Mniotilta varia*), hooded warbler (*Wilsonia citrina*), scarlet tanager (*Piranga olivacea),* and worm-eating warbler (*Helmitheros vermivorus*).

Over longer time intervals, oak-hickory forest species are predicted to increase (Dale and others 2010) or shift northward, decreasing abundance of this forest type in the South (Iverson and others 2008, Prasad and others 2009). In addition, continued forest fragmentation in this heavily-used forest type, microclimate changes associated with climate warming, and greater recreational use of the forest with increasing human population growth, could threaten forest interior species, thereby offsetting the benefits of forest aging.

Longleaf pine forests—These forests historically dominated Coastal Plain sites from southern Virginia to eastern Texas. The fire-maintained longleaf pine–grassland ecosystem currently occupies less than 5 percent of its original 30 million acres (Van Lear and others 2005). Now highly fragmented, this diverse, open-canopied ecosystem occurs primarily in the Coastal Plain over gradients from bogs through flatwoods to sand ridges. Community composition varies with soil moisture and geography. Wiregrass and bluestem dominate the herbaceous layer of longleaf pine savanna. The herb layer of wet longleaf pine forests is diverse and includes grasses, wildflowers, and carnivorous plants. In mature communities, the trees are thinly distributed, flat-topped, and have limbless lower trunks.

Rare plant species (including 27 plants listed as threatened or endangered by the U.S. Fish and Wildlife Service) occur in embedded wetlands, wetland-upland ecotones, pine flatwoods, savannas, and dry ridges (Van Lear and others 2005). The threatened or endangered plants include the Canby's dropwort in wetlands and the vulnerable sandhills milkvetch (*Astragalus michauxii*) in longleaf pine–wiregrass savannas. The longleaf community supports several vertebrates. The red-cockaded woodpecker occurs in the open pinewoods; Bachman's sparrow (*Aimophila aestivalis*) breeds in dense, grassy areas with scattered trees. Other avifauna include Henslow's sparrow, brown-headed nuthatch (*Sitta pusilla*), and pine warbler (*Dendroica pinus*). Characteristic mammals include the southern short-tail shrew (*Blarina carolinensis*), eastern mole (*Scalopus aquaticus*), Seminole bat (*Lasiurus seminolus*), nine-banded armadillo (*Dasypus novemcinctus*), fox squirrel (*Sciurus niger*), marsh rice rat (*Oryzomys palustris*), and long-tailed weasel (*Mustela frenata*; Trani and others 2007). Longleaf pine communities support 74 amphibians and 96 reptiles (Dodd 1995), including the eastern spadefoot (*Scaphiopus holbrookii*), pine snake (*Pituophis melanoleucus*), pine woods treefrog (*Hyla femoralis), s*and skink*,* and *s*outhern hognose snake (*Heterodon simus).*

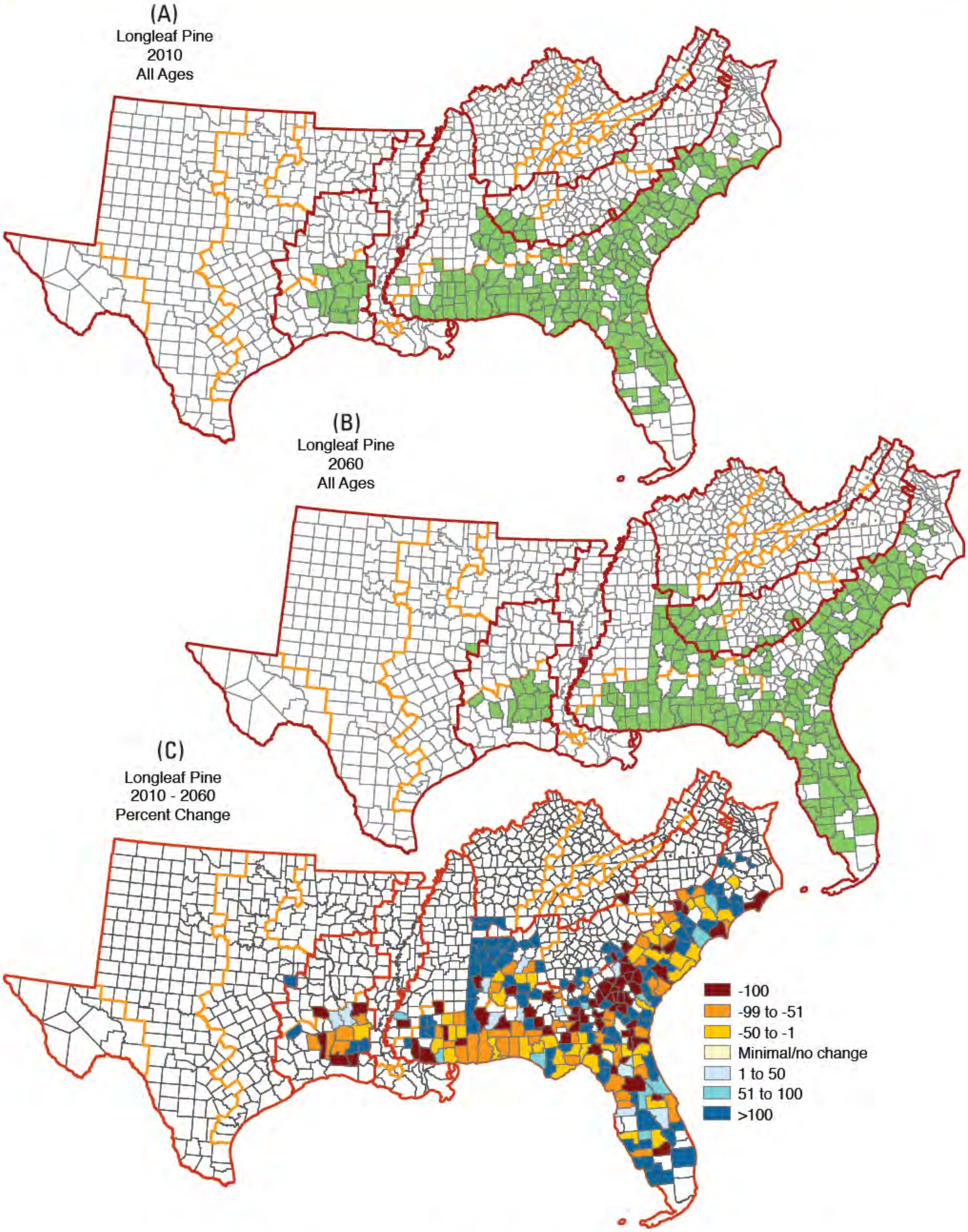


Figure 14.20—Longleaf pine distribution under Cornerstone A's high-urbanization/high-timber-prices forecast in (A) 2010 and (B) 2060; and (C) percent change for the 50-year period.

Longleaf pine forests traditionally have been managed with prescribed fire to promote regeneration and timber yield (Mitchell and others 2006). Today restoration is underway and many of these forests are managed primarily to promote biodiversity and only secondarily for timber yield (Mitchell and others 2006). Cornerstone A (high economic growth and high demand for wood products) predicts the greatest change in longleaf pine forests. Areas of the Coastal Plain, especially from Virginia southward to Georgia, are projected to lose the majority of their longleaf community by 2060 (fig. 14.20). The urban growth forecast under Cornerstone B also threatens the range of longleaf pine communities, particularly in the Southern Gulf, Eastern Atlantic, and northern portion of Peninsular Florida. In contrast, other areas are projected for expansion of longleaf pine beyond the current 2010 distribution, potentially enabling associated species to spread or new associations to form. This is notable in south-central Florida and northwest Alabama.

Early successional forests—Abandoned farmlands, grassland, shrub-scrub, and recently harvested forest are all considered early successional communities (Thompson and DeGraaf 2001). These open habitats are disappearing as abandoned farmland and pastures return to forest, and existing forests mature (Trani and others 2001). Suppression of natural disturbance has also been implicated as has the loss of these habitats to urban growth.

Many southern species are associated with early successional or disturbance-dependent environments, and there is rising concern among natural resource professionals about decline of habitat for these specialists (Thompson and DeGraaf 2001), which include the American woodcock, blue-winged warbler (*Vermivora pinus*), chestnut-sided warbler (*Dendroica pennsylvanica*), golden-winged warbler (*V. chrysoptera*), ruffed grouse (*Bonasa umbellus*), and veery (*Catharus fuscescens*). Mammals such as the bobcat (*Lynx*

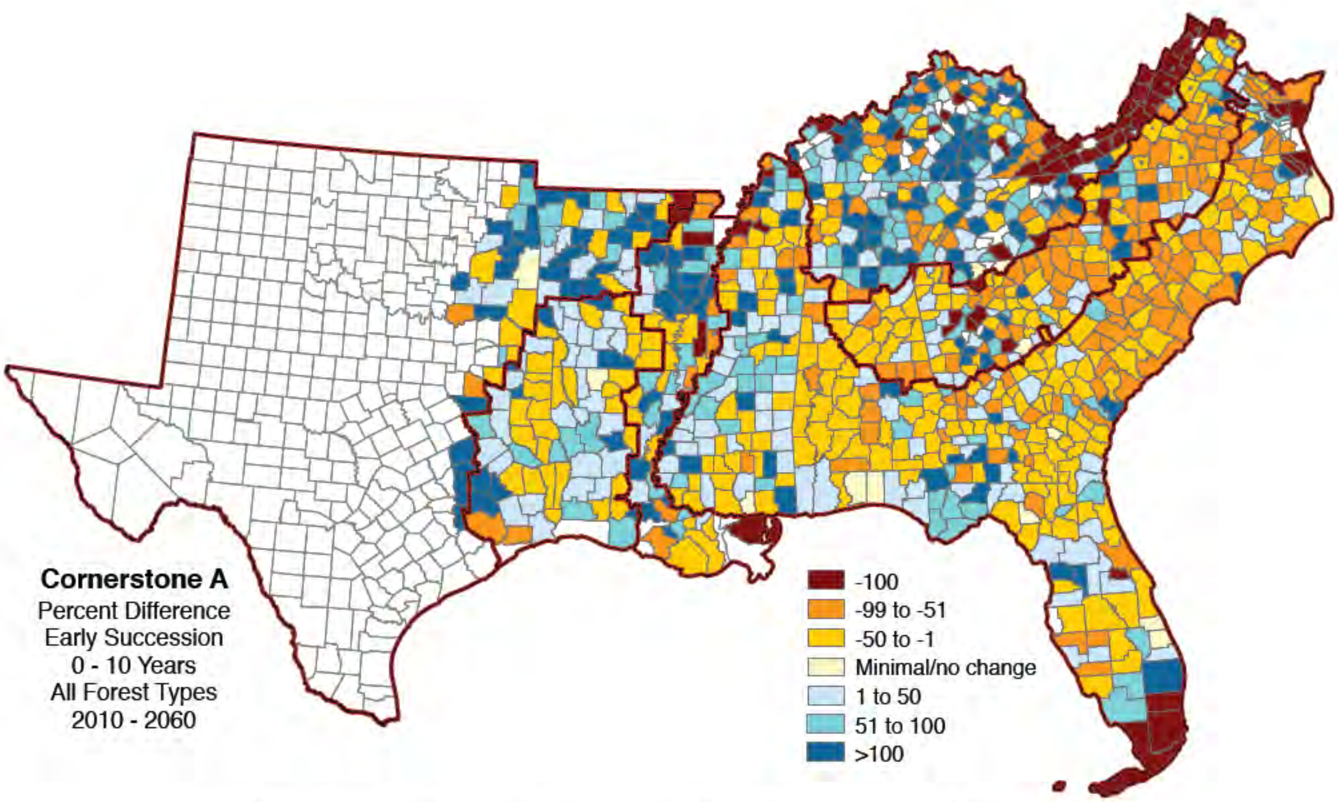


Figure 14.21—Changes in the amount of early successional forest (10 years or younger) of all types from 2010 to 2060 under Cornerstone A's high-urbanization/high-timber-prices forecast.

rufus), common gray fox (*Urocyon cinereoargenteus),* and least weasel (*Mustela nivalis)* rely on prey associated with early successional habitats.

The focus in this section is on young forest habitat (10 years or less). The high-urbanization/high-timber-prices of Cornerstone A forecasts the greatest loss of young forest habitat in the Northern Ridge and Valley section of Virginia, southern Florida and associated Keys, and scattered locations in the Northern Atlantic, Southern Appalachian Piedmont, Blue Ridge, northern Interior Low Plateau, and Mississippi Alluvial Valley (fig. 14.21).

The greatest gain in young forest is predicted in the Cumberland Plateau and Mountains and adjacent Southern Ridge and Valley, Apalachicola region of Florida, Ozark-Ouachita Highlands and adjacent northern area of the Mississippi Alluvial Valley, and scattered areas throughout Mississippi and Louisiana. Disturbances that create open-canopy habitat could benefit some forest plant species, such as the imperiled Lesquereux's mustard (*Lesquerella globosa*) as reported by the Center for Plant Conservation (2010b). Gain of young forest, especially if accompanied by loss of mature forest, could threaten plants and animals of forest interior and specialized habitats. For example, Lucy Braun's white snakeroot (*Ageratina luciae-brauniae*) which lives on wet, shaded cliff ledges and overhangs (Kral 1983), and the endangered Braun's rockcress (*Arabis perstellata*) occurring on moist calcareous forest slopes (Center for Plant Conservation 2010a) could be threatened by localized canopy opening, indirect effects of logging, or land clearing.

DISCUSSION AND CONCLUSIONS

Patterns of Species Richness, Imperilment, and Extirpation

The richness of species in the South is impressive, with 1,076 native terrestrial vertebrates: 179 amphibians, 525 birds, 176 mammals, and 196 reptiles. Species richness is highest in the Mid-South (856 species in 115 ecosystems) and the Coastal Plain (733 species in 153 ecosystems), reflecting both the large area of these subregions and the diversity of habitats within them.

The pattern of species richness varies by taxon. The distribution of amphibians encompasses mountains, highlands, and coastal areas along the Atlantic Ocean and Gulf of Mexico. Bird richness along the coastal areas and wetlands of the Atlantic Ocean and Gulf of Mexico points to the importance of these areas, while mammal richness highlights patterns in the Mid-South and Appalachian-Cumberland. In contrast, the distribution of reptiles is greatest across the southern portion of the region, with notable differences among the various subtaxa.

There are 142 terrestrial vertebrate species considered to be of conservation concern in the South; 77 of these are threatened or endangered. However, they are overshadowed by at-risk plants—more than 900 are species of concern and 141 are threatened or endangered. Threats to biodiversity are occurring throughout the region, particularly in the Coastal Plain, Mid-South, and Appalachian-Cumberland highlands.

The distribution of threatened or endangered species coincides with areas of serious conservation concern along the Atlantic and Gulf coasts, Peninsular Florida, and Southern Gulf. This pattern has remained relatively stable and has been observed by others using different data sources and criteria (Chaplin and others 2000, Dobson and others 1997, Flather and others 2008, Rutledge and others 2001), which suggests that the geographic extent of identified endangerment locations is not an artifact of any particular data set (Flather and others 2008).

There is also a pattern of geographic coincidence between the Federal status and NatureServe ranking schemes for both plants and vertebrates with regard to the Atlantic and Gulf coastal areas and that of Peninsular Florida. However, the NatureServe rankings provide an additional perspective on the geography of risk, pointing to locations that are emerging as new areas of concern: the Appalachian-Cumberland highlands (Blue Ridge, Southern Ridge and Valley, Cumberland Plateau and Mountain, Interior Low Plateau sections) and the Mid-South (Ozark-Ouachita Highlands, West Texas Basin and Range sections, Edwards Plateau in central Texas).

The NatureServe ranking scheme also identified five hotspot areas representing threatened or endangered plant diversity: Big Bend National Park in the West Texas Basin and Range, the Apalachicola area of the Southern Gulf Coast, Lake Wales Ridge and the area south of Lake Okeechobee in Peninsular Florida, and coastal counties of North Carolina in the Atlantic Coastal Plain. The Appalachian-Cumberland highlands also contain plant species of concern at the State level.

Across all taxa groups, habitat loss and degradation remain the primary threats to maintaining the current number of plant and animal species. Degradation can take the form of environmental contamination (such as water pollution, acid rain, and pesticides) and agricultural, urban, and commercial development (such as channel modification, impoundments, and habitat fragmentation and isolation). Species are also impacted by many other factors such as introduction of forest pests and nonnative plants, disruption of fire regimes, collection, indiscriminant killing, driving off-road vehicles through rare plant communities, caving in maternity bat caverns, and building road networks, power lines, and cell towers. Each species varies in its vulnerability to these threats, and the severity of threats often varies by subregion.

Numerous plants and vertebrates are presumed extirpated from selected States in the South; over 50 percent of the terrestrial vertebrates have been added to this list since the time of the Southern Forest Resource Assessment. The causes that factored in species extirpations are, in the majority of cases, the same as those that jeopardize species of conservation concern today. Although the wide-spread land clearing of European settlement is not occurring, dramatic urban growth with accompanying infrastructure development in the South is projected for all subregions. In addition, sea level rise may further reduce the range of plants in coastal estuaries and marshes.

Prioritizing conservation and management efforts on areas with concentrations of species of concern may be needed to avert future species losses. New long term strategies are required that focus upon (and mitigate) multiple environmental stressors by incorporating ways to promote landscape connectivity, facilitate species movement, reduce mortality, and increase species viability.

Forecasts of Urban Growth, Forest Loss, and Climate Change

Forecasts of human population growth and urban expansion (chapter 4) raise the possibility of a substantial impact on species and the communities that support them over the next several decades. As the South continues to grow, so also will the number of threats associated with infrastructure development, water development, land conversion, and other effects of an urbanizing population. The number of species negatively affected by the loss of forest is expected to increase. The geographic pattern of richness and imperilment indicates that many species in the South are clustered into identifiable areas of unique richness. Analyzing the overlap of these areas with hot spots of imperiled species under the Cornerstone B projections of urban growth and associated forest loss suggests that several subregions may experience conflicts between development and species conservation and management:

- In the Mid-South, forest loss and urban growth in the Ozark-Ouachita Highlands threatens forest plant and animal species. Urban development along the southern borders shared by Cross Timbers and Western Gulf could impact a large number of reptiles. In addition, the area lies within a band of especially high avian richness.
- In the Appalachian-Cumberland highlands, urban growth in the Interior Low Plateau of central Kentucky and Tennessee may threaten wildlife and associated plant species. Forest loss may degrade forest connectivity, hindering migration of amphibians that are at-risk for elimination or displacement. In addition, successful management of the wildland-urban interface will be needed to balance species conservation with anticipated increases in residential development and recreation. And finally, a warming climate threatens species endemic to high elevation outcrops and forests.
- Substantial urban growth in the Piedmont could reduce the richness of amphibians and mammals. Management of species on public lands may be hindered by the pressure of expanding human populations in surrounding counties, while the smaller (and shrinking) tracts typical of private ownership provide little opportunity for sustainable forest management. Plants in transitional communities, such as the escarpment and foothills of northern South Carolina or southern extensions of the Plateau in northern Alabama and adjacent Georgia, also are at-risk from habitat loss and climate change.
- Urban growth in the Deltaic Plain Section at the mouth of the Mississippi River could negatively impact the richness of shorebirds and waterfowl occurring within the wetlands of the Mississippi Flyway as well as habitat for the Louisiana black bear. Sea level rise could inundate the coastal habitat of the American alligator and numerous species of frogs and toads. Ongoing reforestation programs such as restoration of bottomland hardwoods will remain of especial importance in the light of this forecast.
- Urban development and the effects of sea level rise threaten wildlife habitat and plant species in the Atlantic and Gulf Coastal Plain and Peninsular Florida. The projected inundation and loss of mangrove and coastal live oak forests would reduce nesting habitat for several birds, snakes, and reptiles. Forecasted development along the coastline portion of the Atlantic Flyway will likely eliminate important stopover habitat, as well as nesting areas for several imperiled sea turtles. Inland, the diversity of flora in fire-maintained Coastal Plain ecosystems is threatened by urban development and changing fire regimes.
- Urban development forecasted for the South will place continued demands on natural ecosystems, species, and their habitats. Biodiversity often declines as development proceeds: habitats for native species are replaced, while other habitats are modified or degraded. The forecasts also raise concern for conservation of imperiled species, bringing unique management challenges in areas becoming increasingly urbanized such as Peninsular Florida, the Blue Ridge, and the Piedmont.

Losses of forests on the southern landscape would affect the persistence of species by changing the distribution and availability of spatial resources. Isolated populations in fragmented habitat are prone to inbreeding depression and genetic drift; this is especially true for those species that cannot disperse long distances. Strategic land acquisition may improve habitat quality by promoting connectivity and enabling movement of habitat-restricted species, especially in the face of climate change (Haddad and Baum 1999, Rosenburg and others 1998). There are a number of policies and programs that promote habitat conservation. These approaches include collaborative conservation plans, landowner incentive programs, and conservation easements.

Biodiversity and Climate Change

Climate change represents an additional source of stress on terrestrial species and ecosystems (Lovejoy and Hannah 2005). Climate scenarios are incorporated into the forest condition and land use futures analyses described previously. Chapter 3 also presents projections for temperature increase and variability in precipitation patterns over the next century; this may change the future distribution of many species.

Species respond to environmental conditions based on habitat needs and physiological tolerances, which in turn influences community composition, structure, and resilience. A rise in temperature could influence seasonal movement, recruitment, and mortality (Inouye and others 2000). Changes in phenology (e.g., timing of resource availability, advances in flowering or nesting dates) may alter predator-prey, competitive interaction, and herbivore-vegetation dynamics.

Characteristics of species at risk from climate change include those with restricted geographic range, fragmented distributions, and those that occur at the margins of their ranges. Other characteristics include limited dispersal ability, low genetic diversity, strong affinity to aquatic habitats, narrow physiological tolerance, and late maturation (Manley and Trani-Griep 2012, Midgley and others 2002). For example, the Southern Appalachian Mountains and Piedmont have an exceptionally high diversity of salamanders whose ecology is strongly influenced by temperature and precipitation; there is significant projected loss of high elevation habitat for these and other species existing at their thermal maxima (Milanovich and others 2010). Forest amphibians associated with cool, moist conditions may be subject to microclimates beyond their tolerance. Ephemeral streams and ponds may be especially vulnerable to drying with variable precipitation patterns; this may affect habitat limitations of several taxa.

Matthews and others (2004) modeled the potential future distribution of eastern bird species under global climate change (table 14.11). Climate change has influenced the geographic range of species along environmental gradients; temperate birds have shifted their ranges to higher latitudes, affecting migration strategies and community composition (LaSorte and Jetz 2010). Successful migration will depend on the rate of climate change relative to essential habitat needs and key community interactions. Species may move into the habitats of others, creating new assemblages. The effect of this migration is unknown at this time.

Climate warming (ranging between 0.14–0.49 °C and 2.0–2.6 °C) is projected across the South by 2050 (chapter 3). Warmer temperatures could decrease the winter cold period, which limits some species, but is tolerated by others, such as high-elevation plants (Larcher 2010) and is required for seed germination in others (Walck and Hidayati 2004). Although moderate change in average annual precipitation is projected, warmer temperatures could increase summer drought and fire potential, or allow less cold-tolerant plant species to establish. It is unlikely, however, that the large-scale shifts in forest communities predicted under longer-term climate warming scenarios (e.g., Dale and others 2010) will occur by 2060; fifty years is a short time for widespread dispersal and growth of long-lived species (such as trees). In addition, more immediate factors such as disturbance (e.g., trampling) and land use can override climate change effects on species distributions (Feeley and Silman 2010).

Plant communities at high elevations may be particularly susceptible (Currie 2001, Malcolm and others 2006), where warming temperatures can lengthen the growing season. Forest communities in the Piedmont and Coastal Plain may be influenced by changes in fire frequency. Although some species of the fire-maintained longleaf pine – grassland ecosystem of the Coastal Plain Subregion might benefit from frequent fire, urban growth around major cities may override climate change effects on much of this ecosystem. Species whose ranges are limited to coastal areas will be vulnerable to projected changes in sea level as well as beach erosion. Sea level rise may inundate barrier islands, coastal wetlands, and marshes of the Coastal Plain, as well as along the eastern Atlantic and Gulf coasts.

Communities that support threatened or endangered species are currently at-risk from a variety of environmental stressors. The small or disjunct populations that often accompany species of conservation concern are likely to be impacted by stochastic climatic events. Sensitive species, influenced by a number of stressors discussed in this chapter, may not have the ability to adapt to a changing

Table 14.11—Predicted influence on selected bird species based on climate change scenarios (Matthews and others 2004)

Scientific name	Common name	Influence on species[a]
Aimophila aestivalis	Bachman's sparrow	Extensive loss in abundance.
Ammodramus savannarum	Grasshopper sparrow	Decrease in abundance and range.
Archilochus colubris	Ruby-throated hummingbird	Population losses in the South.
Buteo jamaicensis	Red-tailed hawk	Substantial increase in abundance.
Buteo platypterus	Broad-winged hawk	Shift in range with losses in northern areas.
Caprimulgus vociferus	Whip-poor-will	Range expands northward; decrease in overall abundance.
Catharus fuscescens	Veery	Substantial decrease in abundance and contraction in range.
Chaetura pelagica	Chimney swift	Little change in abundance.
Coccothraustes vespertinus	Evening grosbeak	Near extirpation.
Coccyzus erythropthalmus	Black-billed cuckoo	Contraction to the north.
Coragyps atratus	Black vulture	Extensive expansion northward and increase in abundance.
Colinus virginianus	Northern bobwhite	Expansion northward.
Dendroica cerulea	Cerulean warbler	Decrease in abundance and shift in range northward.
Dendroica dominica	Yellow-throated warbler	Decrease in abundance in southern range.
Hylocichla mustelina	Wood thrush	Reductions in numbers over its range in eastern forests.
Ictinia mississippiensis	Mississippi kite	Increase in range from Tennessee northward.
Passerculus sandwichensis	Savannah sparrow	Decrease in abundance and range northward.
Picoides pubescens	Downy woodpecker	Loss in abundance in the south; population gains to the north.
Progne subis	Purple martin	Increase in abundance.
Sayornis phoebe	Eastern phoebe	Shift in eastern population to northwest.
Sitta carolinensis	White-breasted nuthatch	Increase in abundance; expansion in range southward.
Spinus tristis	American goldfinch	Extensive loss in abundance.
Tyrannus tyrannus	Eastern kingbird	Decrease in abundance.
Vermivora chrysoptera	Golden-winged warbler	Contraction in range northward.

[a]Canadian Climate Center Model and Hadley Center for Climate Prediction and Research Model.

climate. Thus, climate change projections pose important questions about future challenges for biological diversity in the South.

Forecasts of Special Communities

High elevation forests, which occur above 4,000 feet, are too infrequent to be captured by Forest Inventory and Analysis data for this assessment. This provided the baseline for Forest Future modeling, precluding any accurate predictions of future changes. These forests traditionally have been subject to air pollution, acid deposition, and natural disturbances. Climate warming and housing development may result in the loss of endemic species or changes in species ranges.

Upland hardwood forests are forecast to decline 14 percent over the region under the high urbanization and low timber demand predictions of Cornerstone B. The dominant forest type, oak-hickory, is forecasted to lose only 1 percent. However, distributions of oak-hickory forest species are predicted to shift northward, which could threaten forest interior species of this widespread and heavily used forest type.

Although some areas of the Coastal Plain are forecasted to lose acreage of longleaf pine forest under the high urbanization and high timber demand predictions of Cornerstone A, other areas such as south-central Florida and northwest Alabama, are predicted to gain acreage of this forest type and are potential sites for expansion of the numerous vertebrates that inhabit this community.

Maturation of southern forests raises concern about the loss of early successional habitat. Cornerstone A projects the greatest loss of young forest habitat in the Northern Ridge and Valley section of western Virginia, southern Florida and associated Keys, and scattered locations in the Northern Atlantic. Gains are forecasted for the Cumberland Plateau and Mountains and adjacent Southern Ridge and Valley, Apalachicola region of Florida, Ozark-Ouachita Highlands and adjacent northern area of the Mississippi Alluvial Valley.

Management Challenges

Finally, our analysis of biodiversity and the Southern Forest Futures projections underscores the challenges that resource managers face to conserve the rich species legacy of the South. The potential implications described herein bring uncertainty about how best to implement future conservation and management strategies. Although there is an existing framework of regulations and programs which promote species conservation (e. g., Endangered Species Act, sustainable forestry certification standards, among others), preparing for future growth will require new strategies to prepare for the changes in land use, forest conditions, and urbanization that are expected. For example, extinctions in longer lived species are expected to lag behind climate change; adaptation strategies across land ownerships will require anticipatory measures to ensure the future of the South's biodiversity.

New tools and approaches to managing uncertainty will become essential. Scenario planning, sensitivity analysis, or ecological risk analysis may become incorporated into resource planning for areas of concern. Integrating climate science into land management planning will be important, accompanied by monitoring strategies that identify patterns in disturbance, phenology, and species range changes.

Furthermore, static management can no longer be assumed (Hayward and others 2009); that is, the environment will change in a directional way rather than varying around a mean condition (Milly and others 2008). The planning focus will be on spatial and temporal scales that are broader and longer than typically considered. As future impacts occur across large areas, the appropriate decision-making level may shift to cover landscape or regional scales.

The conservation focus on species of at-risk will continue until we understand the relationship between the loss of biodiversity and ecosystem function, resilience, and stability (Flather and others 2008). It may become commonplace for management to consider:

- Implementation of vulnerability assessments to identify species and communities at risk, including strategies to maximize species persistence and dispersal;
- Examination of landscape connectivity and infrastructure barriers to migration, incorporating mitigation measures into planning efforts; and
- Enhancement of genetic diversity to provide resilience against environmental stressors.

The geographic area managed by the Forest Service in the South makes it one of a few land stewards that can have a significant impact on the conservation and management of biodiversity. The agency will play a substantial role in the development and implementation of adaptation strategies. Nevertheless, there is a need for strong collaboration with State and Federal agencies, private landowners, and nongovernmental organizations to successfully implement management across landscapes at scales necessary to make substantive impacts on species and their habitats (Hayward and others 2009). A collaborative approach increases the scale of restoration and conservation on both public and private lands.

Each species differs in its ability to tolerate climate change and other environmental stressors. An awareness of the relationship between the forecasts and the geographic pattern of species occurrence will foster planning efforts that arise from the Southern Forest Futures effort. The implications for the conservation of southern species are significant: in the midst of a growing region, the provision of biological diversity will become a critical conservation issue.

KNOWLEDGE AND INFORMATION GAPS

The forecasts of biodiversity response were based on county-level patterns of coincidence for GIS maps of forecasted stressors, special forest communities, and species richness and rarity. This scale of analysis may over- or under-predict threats to species that occur at finer scales, such as rare species that occur at only a few locations within a county, or those that occur in scattered locations. Because this was a regional assessment, a selection was made early on by the Futures team as to a suitable, manageable scale. This turned out to be the county scale for the forecast and other analyses.

The absence of species data in a county does not necessarily mean the species does not occur there; the area may not have been intensively inventoried or there may be an uneven level of scientific knowledge on the identification of uncommon species or subspecies, particularly herpetofauna. The following describes known data gaps that State Heritage Programs have provided to NatureServe for species-at-risk (G1 to G3 or federal status):

- **Florida:** Access restrictions in some areas have precluded thorough surveys on corporate timberlands across north Florida and on several large (over 10,000 acres) private ranches in central Florida.

- **Kentucky:** Limited access has precluded survey on the Ft. Campbell military installation (14,000 acres).
- **North Carolina:** Eighteen counties have not been systematically inventoried or are currently being inventoried: Alexander, Alleghany, Anson, Caldwell, Caswell, Cherokee, Clay, Dare, Graham, Macon, Mitchell, Robeson, Stanly, Swain, Tyrrell, Union, Wilkes, and Yancey.
- **South Carolina:** A comprehensive survey has not been done; the majority of gaps are on private lands.
- **Tennessee:** Data are limited for the Great Smoky Mountains National Park in east Tennessee due to data sensitivity; no data are available for Ft. Campbell in north-central Tennessee.
- **Texas:** Extensive areas of privately owned land have not been surveyed.

ACKNOWLEDGMENTS

Appreciation is extended to David Schmid and the Biological and Physical Resources Unit in the Southern Regional Office of the Forest Service for their ongoing support and encouragement. The editing efforts of Carol Whitlock and suggestions from four anonymous reviewers greatly improved the quality of this chapter.

Our appreciation also is extended to Jason McNees at NatureServe for his tireless efforts supplying the biodiversity data and related spatial products. Shawna Reid, Southern Research Station, provided GIS support on the forecasts of special forest communities. Gary Wein, Highlands-Cashiers Landtrust, mapped initial draft maps of species richness and concern areas.

Special thanks to Bobby Huggett, Dave Wear, and John Greis for their invaluable help while providing interpretation of forecast and Forest Inventory and Analysis data. Steve McNulty provided the sea level rise data described in the forecast section. Ed Laurent, American Bird Conservancy, contacted several Joint Venture and Bird Conservation Region coordinators for information on the current status and habitat concerns for priority birds in several subregions.

Finally, our appreciation is offered to Ampaporn Mattox who assisted with the Internet searches, status rank updates, production of tables and figures, and species proofing; and to Haven Cook for selected table creation and miscellaneous checks.

LITERATURE CITED

Aguilar, R.; Quesada, M.; Ashworth, L. 2008. Genetic consequences of habitat fragmentation in plant populations: susceptible signals in plant traits and methodological approaches. Molecular Ecology. 17: 5177-5188.

Bailey, M.A.; Holmes, J.N.; Buhlmann, K.A.; Mitchell, J.C. 2006. Habitat management guidelines for amphibians and reptiles of the Southeastern United States. Partners in Amphibian and Reptile Conservation. Technical Publication HMG-2. Birmingham, AL: High Cotton Press. 88 p.

Baskin, J.M.; Baskin, C.C. 2005. Ecology of two geographically restricted *Astragalus* species (Fabaceae), *A. bibullatus* and *A. tennesseensis*, of the Eastern United States. Brittonia. 57: 345-353.

Boyce, S.G.; Martin, W.H. 1993. Introduction: the southeastern setting. In: Martin, W.H.; Boyce, S.G.; Echternacht, A.C., eds. Biodiversity of the Southeastern United States: upland terrestrial communities. New York: John Wiley: 1-46.

Buckner, E. 1989. Evolution of forest types in the Southeast. In: Waldrop, T.A., ed. Pine-hardwood mixture: a symposium on management and ecology of the type. Gen. Tech. Rep. SE-58. Asheville, NC: U.S. Forest Service, Southeastern Forest Experiment Station: 17-33.

Case, M.A.; Mlodozeniec, H.T.; Wallace, L.E.; Weldy, T.W. 1998. Conservation genetics and taxonomic status of the rare Kentucky lady's slipper: *Cypripedium kentuckiense* (Orchidaceae). American Journal of Botany. 85: 1779-1786.

Center for Plant Conservation. 2010a. National collection plant profile for *Arabis perstellata*. http://www.centerforplantconservation.org/collection/cpc_viewprofile.asp?CPCNum=6035. [Date Accessed: July 9, 2010].

Center for Plant Conservation. 2010b. National collection plant profile for *Lesquerella globosa*. http://www.centerforplantconservation.org/collection/cpc_viewprofile.asp?CPCNum=2499. [Date Accessed: July 9, 2010].

Chaplin, S.J.; Gerrard, R.A.; Watson, H.M. [and others]. 2000. The geography of imperilment. In: Stein, B.A.; Kutner, L.S.; Adams, J.S., eds. Precious heritage: the status of biodiversity in the United States. New York: Oxford University Press: 159-200.

Chapman, R. 2007. Northern long-eared myotis. In: Trani, M.K.; Ford, W.M.; Chapman, B.R., eds. 2007. The land manager's guide to the mammals of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region: 199–204.

Crawford, B.A.; Lucash, C.F.; Henry, V.G. 2001. Red Wolf. In: Dickson, J., ed. Wildlife of the Southern forests: habitat and management. Blaine, WA: Hancock House Publishing: 240-247.

Currie, D.J. 2001. Projected effects of climate change on patterns of vertebrate and tree species richness in the conterminous United States. Ecosystems. 4: 216-225.

Dale, V.H.; Tharp, M.L.; Lannom, K.O.; Hodges, D.G. 2010. Modeling transient response of forests to climate change. Science of the Total Environment. 408(8): 1888-1901.

Delcourt, P.A.; Delcourt, H.R.; Morse, D.F.; Morse, P.A. 1993. History, evolution, and organization of vegetation and human culture. In: Martin, W.H.; Boyce, S.G.; Echternacht, A.C., eds. Biodiversity of the Southeastern United States: lowland terrestrial communities. New York: John Wiley: 47-79.

Dobson, A.P.; Rodriguez, J.P.; Roberts, W.M.; Wilcove, D.S. 1997. Geographic distribution of endangered species in the United States. Science. 275: 550-553.

Dodd, C.K., Jr. 1995. Reptiles and amphibians in the endangered longleaf pine ecosystem. In: LaRoe, E.T.; Farris, G.S.; Puckett, C.E. [and others], eds. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. Washington, DC: U.S. Department of the Interior, National Biological Service: 129-131.

Ernst, C.H.; Barbour, R.W.; Lovich, J.E. 1994. Turtles of the United States and Canada. Washington, DC: Smithsonian Institution Press. 578 p.

Erwin, R.M.; Cahoon, D.R.; Prosser, D.J. [and others]. 2006. Surface elevation dynamics in vegetated Spartina marshes versus unvegetated tidal ponds along the mid-Atlantic coast, USA, with implications to waterbirds. Estuaries and Coasts. 29(1): 96-106.

Feeley, K.J.; Silman, M.R. 2010. Land-use and climate change effects on population size and extinction risk of Andean plants. Global Change Biology. 16(12): 3215-3222.

Flather, C.H.; Knowles, M.S.; McNees, J. 2008. Geographic patterns of at-risk species: a technical document supporting the U.S. Department of Agriculture Forest Service Interim Update of the 2000 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-211. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 21 p.

Ford, W.M.; Chapman, B.R. 2007. *Indiana myotis*. In: Trani, M.K.; Ford, W.M.; Chapman, B.R., eds. 2007. The land manager's guide to the mammal's of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region: 205–211.

Fridley, J.D.; Senft, A.R.; Peet, R.K. 2009. Vegetation structure of field margins and adjacent forests in agricultural landscapes of the North Carolina Piedmont. Castanea. 74(4): 327-339.

Gibbons, J.W.; Buhlmann, K.A. 2001. Reptiles and amphibians. In: Dickson, J., ed. Wildlife of the southern forests: habitat and management. Blaine, WA: Hancock House Publishing: 372-390.

Godt, M.J.W.; Hamrick, J.L. 1995. Allozyme variation in two Great Smoky Mountain endemics: *Glyceria nubigena* and *Rugella nudicaulis*. Journal of Heredity. 86: 194-198.

Godt, M.J.W.; Johnson, B.R.; Hamrick, J.L. 1996. Genetic diversity and population size in four rare southern Appalachian plant species. Conservation Biology. 10(3): 796-805.

Guirado, M.; Pino, J.; Rodà, F. 2006. Understory plant species richness and composition in metropolitan forest archipelagos: effects of forest size, adjacent land use and distance to the edge. Global Ecology and Biogeography. 15(1): 50-62.

Haddad, N.M.; Baum, K.A. 1999. An experimental test of corridor effects on butterfly densities. Ecological Application. 9: 623-633.

Harvey, M.J.; Saugey, D.A. 2001. Bats. In: Dickson, J., ed. Wildlife of the southern forests: habitat and management. Blaine, WA: Hancock House Publishing: 359-371 p.

Hayward, G.D.; Flather, C.H.; Uloth, E. [and others]. 2009. Managing fish and wildlife habitat in the face of climate change: U.S. Department of Agriculture Forest Service perspective. North American Wildlife and Natural Resources Conference. 74: 98-109.

Healy, R.G. 1985. Competition for land in the American south: agriculture, human settlement, and the environment. Washington, DC: The Conservation Foundation. 333 p.

Herrig, J.; Shute, P. 2002. Aquatic animals and their habitats. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S.Forest Service, Southern Research Station: 537-582.

Honu, Y.A.K.; Chandy, S.; Gibson, D.J. 2009. Occurrence of non-native species deep in natural areas of the Shawnee National Forest, Southern Illinois, USA. Natural Areas Journal. 29(2): 177-187.

Ibanez, I.; Clark, J.S.; LaDeau, S.; HilleRisLambers, J. 2007. Exploiting temporal variability to understand tree recruitment response to climate change. Ecological Monographs. 77: 163-177.

Inouye, D.W.; Barr, B.; Armitage, K.B.; Inouye, B.D. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences. 97(4): 1630-1633.

International Union for Conservation of Nature. 2009. International Union for Conservation of Nature Red list of threatened species. Version 2009.1. http://www.iucnredlist.org. [Date accessed: July 9, 2010].

Iverson, L.R.; Prasad, A.M.; Matthews, S.N.; Peters, M. 2008. Estimating potential habitat for 134 eastern U.S. tree species under six climate scenarios. Forest Ecology and Management. 254: 390-406.

Kral, R.D. 1983. Asteraceae: *Eupatorium luciae-brauniae* Fernald [Endangered species, perennial plants of shaded sandstone ledges in Kentucky and Tennessee]. In: Kral, R.D., ed. A report on some rare, threatened, or endangered forest-related vascular plants of the South. Technical publication R8-TP. Atlanta, GA: U.S. Department of Agriculture Forest Service, Southern Region: 1143-1146.

Larcher, W.; Kainmuller, C.; Wagner, J. 2010. Survival types of high mountain plants under extreme temperatures. Flora. 205(1): 3-18.

LaSorte, F.; Jetz, W. 2010. Avian distributions under climate change: towards improved projections. Journal of Experimental Biology. 213: 862-869.

LeBlond, R.J. 2001. Endemic plants of the Cape Fear Arch Region. Castanea. 66: 83-97.

Lorimer, C.G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. Wildlife Society Bulletin. 29(2): 425-439.

Lovejoy, T.E.; Hannah, L.J., eds. 2005. Climate change and biodiversity. New Haven, CO: Yale University Press. 440 p.

Lower Mississippi Valley Joint Venture Forest Resource Conservation Working Group. 2007. Restoration, management, and monitoring of forest resources in the Mississippi Alluvial valley: recommendations for enhancing wildlife habitat. Vicksburg, MS: LSU Printing Services. 88 p.

MacArthur, R.; Wilson, E. 1967. The theory of island biogeography. Princeton, NJ: Princeton University Press. 203 p.

Malcolm, J.R.; Liu, C.; Neilson, R.P. [and others]. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology. 20(2): 538-548.

Manley, P.N.; Trani-Griep, M.K. 2012. Biodiversity and climate change. U.S. Department of Agriculture Forest Service, Climate Change Resource Center. http://www.fs.fed.us/ccrc/topics/biodiversity.shtml. [Date Accessed: July 9, 2010].

Matlack, G.R. 1994. Vegetation dynamics of the forest edge: trends in space and successional time. Journal of Ecology. 82: 113-123.

Matthews, S.; O'Connor, R.; Iverson, L.; Prasad, A. 2004. Atlas of climate change effects in 150 bird species of the Eastern United States. Gen. Tech. Rep. NE-318. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Research Station. 340 p.

McCay, T.S. 2007. Cotton mouse (*Peromyscus gossypinus*). In: Trani, M.K.; Ford, W.M.; Chapman, B.R., eds. 2007. The land manager's guide to the mammal's of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region: 327-331.

McNees, J. 2010. Metadata for the U.S. Forest Service: Southern Forest Futures assessment species dataset. NatureServe central databases (July 21, 2010). Arlington, VA: NatureServe. 56 p. http://www.srs.fs.usda.gov/futures/data/. [Date accessed: July 31, 2010].

Midgley, G.F.; Hannah, L.; Millar, D. [and others]. 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology and Biogeography. 11: 445-451.

Milanovich, J.R.; Peterman, W.E.; Nibbelink, N.P.; Maerz, J.C. 2010. Projected loss of a salamander diversity hotspot as a consequence of projected global climate change. PLoS One. 5(8): 1-10.

Milly, P.C.D.; Betancourt, J.; Falkenmark, M. [and others]. 2008. Stationarity is dead: whither water management? Science. 319: 573-574.

Mitchell, R.J.; Hiers, J.K.; O'Brien, J.J. [and others]. 2006. Silviculture that sustains: the nexus between silviculture, frequent prescribed fire, and conservation of biodiversity in longleaf pine forests of the Southeastern United States. Canadian Journal of Forest Research. 36: 2724-2736.

Moore, P.T.; Van Miegroet, H.; Nicholas, N.S. 2008. Examination of forest recovery scenarios in a Southern Appalachian Picea-Abies forest. Forestry. 81: 183-194.

Murdock, N. 1993. Recovery plan for Spreading Avens (*Geum radiatum*) Rafinesque. Southeast Region. Atlanta, GA: U.S. Fish and Wildlife Service. 32 p.

Murdock, N.A. 1994. Rare and endangered plants and animals of Southern Appalachian wetlands. Water Air and Soil Pollution. 77: 385-405.

NatureServe. 2007. Digital distribution maps of the reptiles of the United States and Canada. [Shapefiles]. Arlington, VA: NatureServe. http://www.natureserve.org/getData/animalData.jsp. [Date accessed: January 28, 2010].

NatureServe. 2010. An online encyclopedia of life. [Database]. 2010. Version 7.1. Association for biodiversity information. Arlington, VA: NatureServe. http://www.natureserve.org/getData/animalData.jsp. [Date accessed: January–June 30, 2010].

NatureServe. 2011. An online encyclopedia of life. [Database]. 2010. Version 7.1. Association for biodiversity information. Arlington, VA: NatureServe. http://www.natureserve.org/getData/animalData.jsp. [Date accessed: February 15-April 4, 2011].

Noss, R.F.; LaRoe, E.T., III; Scott, J.M. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28. Washington, DC: National Biological Service. 58 p.

Patterson, B.D.; Ceballos, G.; Sechrest, W. [and others]. 2007. Digital distribution maps of the mammals of the western hemisphere. Version 3.0. [Shapefiles]. Arlington, VA: NatureServe.http://www.natureserve.org/getData/animalData.jsp. [Date accessed: January 28, 2010].

Pelton, M.R. 2001. American black bear. In: Dickson J., ed. Wildlife of the Southern forests: habitat and management. Blaine, WA: Hancock House Publishing: 224-233.

Possley, J.; Woodmansee, S.W.; Maschinski, J. 2008. Patterns of plant composition in fragments of globally imperiled pine rockland forest: effects of soil type, recent fire frequency, and fragment size. Natural Areas Journal. 28(4): 379-394.

Prasad, A.; Iverson, L.; Matthews, S.; Peters, M. 2009. Atlases of tree and bird species habitats for current and future climates. Ecological Restoration. 27: 260-263.

Ridgely, R.S.; Allnutt, T.F.; Brooks, T. [and others]. 2007. Digital distribution maps of the birds of the western hemisphere. Version 3.0. [Shapefiles]. Arlington, VA: NatureServe. http://www.natureserve.org/getData/animalData.jsp. [Date accessed: January 28, 2010].

Rosenburg, D.K.; Noon, B.R.; Megahan, J.W.; Meslow, E.C. 1998. Compensatory behavior of *Ensatina eschscholtzii* in biological corridors: a field experiment. Canadian Journal of Zoology. 76: 117-133.

Rudolph, D.C.; Burgdorf, S.J. 1997. Timber rattlesnakes and Louisiana pine snakes of the west Gulf Coastal Plain: hypothesis of decline. Texas Journal of Science. 49: 111-121.

Rutledge, D.T.; Lepczyk, C.A.; Xie, J.; Liu, J. 2001. Spatiotemporal dynamics of endangered species hotspots in the United States. Conservation Biology. 15: 475-487.

Schwartz, M.W.; Hermann, S.M.; van Mantgem, P.J. 2000. Estimating the magnitude of decline of the Florida torreya (*Torreya taxifolia* Arn.). Biological Conservation. 95: 77-84.

Semlitsch, R.D.; Bodie, J.R. 1998. Are small, isolated wetlands expendable? Conservation Biology. 12: 1129-1133.

Snyder, K.M.; Baskin, J.M.; Baskin, C.C. 1994. Comparative ecology of the narrow endemic *Echinacea tennesseensis* and 2 geographically widespread congeners: relative competitive ability and growth characteristics. International Journal of Plant Science. 15: 57-65.

Sorrie, B.A.; Gray, J.B.; Crutchfield, P.J. 2006. The vascular flora of the longleaf pine ecosystem of Fort Bragg and Weymouth Woods, North Carolina. Castanea. 71: 129-161.

Stein, B.A.; Kutner, L.S.; Adams, J.S., eds. 2000. Precious heritage: the status of biodiversity in the United States. The Nature Conservancy. New York: Oxford University Press. 399 p.

Thompson, F.R., III; DeGraaf, R.M. 2001. Conservation approaches for woody-early successional communities in the Eastern United States. Wildlife Society Bulletin. 29: 483-494.

Timmerman-Erskine, M.; Ballenger, J.; Dute, R.R.; Boyd, R.S. 2003. Allozyme investigation of the *Trillium pusillum* Michaux complex (Trilliaceae): taxonomic and conservation implications. Journal of the Torrey Botanical Society. 130: 1-10.

Trani, M.K. 2002a. Maintaining species in the South. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Forest Service, Southern Research Station: 113-152.

Trani, M.K. 2002b. Terrestrial ecosystems. In: Wear, D.N.; Greis, J.G., eds. Southern forest resource assessment. Gen. Tech. Rep. SRS-53, Asheville, NC: U.S. Forest Service, Southern Research Station: 3-46.

Trani, M.K.; Brooks, R.T.; Schmidt, T.L. [and others]. 2001. Patterns and trends of early successional forests in the Eastern United States. Wildlife Society Bulletin. 29(2): 413-424.

Trani, M.K.; Chapman, B.R. 2007. Red Wolf. In: Trani, M.K.; Ford, W.M.; Chapman, B.R., eds. 2007. The land manager's guide to the mammals of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region: 441-445.

Trani, M.K.; Ford, W.M.; Chapman, B.R., eds. 2007. The land manager's guide to the mammal's of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region. 546 p .

Trusty, J.L.; Miller, I.; Boyd, R.S. [and others]. 2009. Ex situ conservation of the federally endangered plant species *Clematis socialis* Kral (Ranunculaceae). Natural Areas Journal. 29: 376-384.

Turner, M.G.; Pearson, S.M.; Bolstad, P.; Wear, D.N. 2003. Effects of land-cover change on spatial pattern of forest communities in the Southern Appalachian Mountains (USA). Landscape Ecology. 18: 449-464.

U.S. Department of Interior, Fish and Wildlife Service. 2011. Southeast Region 4. [Database]. http://www.fws.gov/endangered/regions/index.html#tabs-4. [Date accessed: April 2011].

U.S. Department of Agriculture National Resources Conservation Service Plants Database. 2010. [Database]. http://plants.usda.gov. [Date accessed: July 13, 2010].

Van Lear, D.H.; Carroll, W.D.; Kapeluck, P.R.; Johnson, R. 2005. History and restoration of the longleaf pine-grassland ecosystem: implications for species at risk. Forest Ecology and Management. 211: 150-165.

Virnstein, R.W.; Hall, L.M. 2009. Northern range extension of the seagrasses, *Halophila johnsonii* and *Halophila decipienis*, along the east coast of Florida, USA. Aquatic Botany. 90: 89-92.

Walck, J.L.; Hidayati, S.N. 2004. Germination ecophysiology of the western North American species *Osmorhiza depauperata* (Apiaceae): implications of preadaptation and phylogenetic niche conservatism in seed dormancy evolution. Seed Science Research. 14(4): 387-394.

Wear, D.N.; Bolstad, P. 1998. Land-use changes in Southern Appalachian landscapes: spatial analysis and forecast evaluation. Ecosystems. 1: 575-594.

Wear, D.N.; Greis, J.G.; Walters, N. 2009. The Southern Forest Futures Project: using public input to define the issues. Gen. Tech. Rep. SRS-115. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 17 p.

Weigl, P.D. 2007. The northern flying squirrel (*Glaucomys sabrinus*): a conservation challenge. Journal of Mammalogy. 88(4): 897-907.

White, P.S.; Collins, B.; Wein, G.R. 2011. Natural disturbances and early successional habitat. In: Greenberg, C.; Collins, B.; Thompson, F., eds. Sustaining young forest communities: ecology and management of early successional habitat in the U.S. central hardwood region. New York: Springer-Verlag: 27-40.

White, P.S.; Wilds, S.P.; Thunhorst, G.A. 1998. Southeast. In: Mac, M.J.; Opler, P.A.; Puckett Haecker, C.E.; Doran, P.D., eds. Status and trends of the nation's biological resources. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey: 255-314.

Wilcove, D.S.; Rothstein, D.; Dubow, J. [and others]. 1998. Quantifying threats to imperiled species in the United States. BioScience. 48(8): 607-615.

Williams, M. 1989. Americans and their forests: a historical geography. New York: Cambridge University Press. 599 p.

Wilson, L.A. 1995. The land manager's guide to the amphibians and reptiles of the South. Chapel Hill, NC: The Nature Conservancy, Southeastern Region. 360 p.

Woudenberg, S.W.; Conkling, B.L.; O'Connell, B.M. [and others]. 2010. The forest inventory and analysis database: database description and user manual. Version 4.0 for phase 2. Gen. Tech. Rep. RMRS-GTR-245. Ogden, UT and Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 336 p.

CHAPTER 15.

The Invasion of Southern Forests by Nonnative Plants: Current and Future Occupation, with Impacts, Management Strategies, and Mitigation Approaches

James H. Miller, Dawn Lemke, and John Coulston[1]

KEY FINDINGS

- Invasive plants continue to escape into and spread through southern forests to eventually form exclusive infestations, and replace native communities to the detriment of forest productivity, biodiversity, ecosystem services, and human use potential.
- Over a 300-year period, invasive plants have been increasingly imported into the South, despite public policies and warnings by professional ecologists and plant experts of long-term irreversible ecosystem damage.
- The invasion process is accelerated by greater forest disturbance, fragmentation, parcelization, and urbanization needed to accommodate and support an increasing population and is being accelerated by climate warming. Approximately 9 percent of southern forests or about 19 million acres are currently occupied by one or more of the 300 invasive plants in the region.
- The annual spread of invasive plants in southern forests is conservatively estimated at a 145,000 forested acres; accelerated by a warming climate and by increasing numbers of forest disturbances that accommodate and support growing human populations.
- Given the current occupation and spread of invasive plants and the increasingly common infestations by multiple species, eradication appears only probable on specific lands unless awareness and strategic programs are greatly enhanced.
- Over a 20 year period, research has developed effective control treatments and integrated approaches that can eradicate or replace invasive plants, while a more robust, coordinated, and focused effort will be required to stem and turn the tide of invasion.
- Model projections show high-threat invasive plants have not reached their potential range or density limits within the region under current conditions. A predicted warming climate will permit northward range extensions for some, while range extensions can be restricted by a simultaneous drier climate. Losses in forest production, recreation, and wildlife habitat would have quality-of-life implications for future generations that would continue to be exacerbated if not mitigated.
- Increased occupation by invasive plants would diminish the variety and abundance of current wood-based products from the "wood basket" of the United States. Some invasive species may find use in biomass and composite products if harvesting and processing become more efficient.
- Most plants escaping into southern forests have been imported, hybridized, sold, and planted for yard and garden beautification, soil stabilization, wildlife habitat enhancement, and livestock production.
- Stricter controls for importing species are pending, but their effectiveness will be hampered as long as garden centers continue to market invasive plants as ornamentals.
- Limiting the degree of occupation and impact depends on the development of adaptive management programs and actions that are coordinated across political boundaries and engage all ownerships. Piecemeal and splintered actions by agencies and ownerships, if continued, cannot dwarf the destructive impacts of this invasion.
- Public awareness campaigns, cooperative spread abatement networks, collaborative programs of detection and eradication, dedicated research and extension programs, and employment of new land restoration options have been found to slow the spread of invasive plants and prevent them from destroying critical habitats.

INTRODUCTION

Invasive plants pose one of the most immediate threats and socio-ecological challenges we face to present and future forests, especially in the South (Miller and others 2010b, Moser and others 2009). These alien plants increasingly infiltrate landscapes to erode and replace native communities while irreversibly degrading critical human-sustaining ecosystems (Mack and others 2000, Pimentel 2002, U.S. Congress OTA 1993). The replacement of diverse native plant communities by dense infestations with limited

[1]James H. Miller is an Emeritus Research Ecologist, Southern Research Station, U.S. Department of Agriculture Forest Service, Auburn, AL 36849-5418; Dawn Lemke is a Research Associate, Department of Natural Resources and Environmental Sciences, Alabama A&M University, Normal, AL 35762; John Coulston is a Supervisory Research Forester, Southern Research Station, U.S. Department of Agriculture Forest Service, Knoxville, TN 37919.

species is becoming widespread—altering forest ecosystem structure and function, threatening all forest communities and agricultural systems, and imposing human economic and cultural costs (Holmes and others 2009, Mack and others 2000, Pfeiffer and Voeks 2008).

The U.S. Congress Office of Technology Assessment (1993) reported that the need for a more restrictive national policy on introductions of nonnative species was widely acknowledged but impeded by historical divisions among agencies and constituencies. Most plants that have escaped into wildlands have gained entry into the United States through the vast and complex plant production industry or by other deliberate introductions (Bryson and Carter 2004, Drew and others 2010). Invasive species continue to be both accidentally and intentionally introduced through relatively porous entry points (Carrete and Tella 2008, Conn and others 2008, Mack and others 2000). The ever increasing volume of trade, including international Internet sales, will continue this trend unless surveillance improves (Britton and others 2005, Mack and others 2000, Simberloff and others 2005). Of the 20,000 species of nonnative plants now living in the United States, about 4,500 have invasive tendencies (Devine 1989), and thousands more reside in gardens, moving with the expanding urban fringe, with unknown consequences to adjoining lands (Pimentel 2002).

Of the 380-plus recognized invasive plants in southern forests and grasslands (more than 330 terrestrials and 48 aquatics) 53 are ranked as high-to-medium risk to natural communities (Morse and others 2004, USDA Forest Service 2008b). Only recently has the extent of invasive plant occupation in the Southern United States and elsewhere in the world been realized (Colton and Alpert 1998, Miller 2003). Colton and Alpert (1998) report that the extent and spread of nonnative plant species over the past several decades has taken most people by surprise, and is still not comprehended by most citizens and policymakers.

In 1999, President Clinton issued Executive Order 13112 defining an "invasive species" as a species: (1) that is nonnative (or alien) to the ecosystem under consideration (such as the South) and (2) whose introduction causes or is likely to cause economic or environmental harm or harm to humans. Thus, a plant invader is a species that occurs outside its area of origin and has become established, can reproduce, and can spread without cultivation to cause harmful impacts. The Executive Order established the National Invasive Species Council to coordinate a counter offensive and instructed Federal agencies to direct available funding toward prevention, detection, response, monitoring, restoration, research, and public awareness efforts.

The National Invasive Species Council involves Federal agency heads as members. They were mandated to establish the National Technical Advisory Council and to write a national invasive species strategic plan with reviews and revisions every five years (National Invasive Species Council 2001). Since then, most agencies have drafted their own strategic plans (such as those prepared by the USDA Forest Service and its Southern Region). As instructed by the Executive Order, agency implementation of invasive programs has been in collaboration with regional efforts and subject to the availability of appropriated funding. Much networking among Federal and State agencies has occurred owing to the Executive Order along with non-governmental partners. Control activities and treatments have been initiated during this period, while these efforts in every Southern State are only coordinated in Florida, with formal partnerships among governmental and non-governmental collaborators.

Not all nonnative plants are invasive. Some 128 crop species have been intentionally introduced and a few are among our most valued crops, including wheat, barley, rice, oats, and corn, which was a Native American introduction from Mesoamerica (Pimentel 2002). Other nonnative grasses are mainstays for forage; however, many of them are often invasive in regenerated forests or forest openings. For example, pasture grasses are highly competitive when invading loblolly pine (*Pinus taeda*) plantings, reducing early survival and growth (Smith 1989). Plant breeding programs over the past 150 years have yielded numerous crop and forage varieties that have improved productivity, useable yields, and tolerance to a wider range of growing conditions and predators. And over the past 50 years, the rapid increase in turf, ornamental and horticultural species and varieties has improved many aspects of modern life, such as landscape beautification and fast growing shade trees and shrubs. But the accumulation of all these introductions and "improved" varieties have taken its toll on our natural ecosystems (Burton and Samuelson 2008, Mack and others 2000); as well as in parks, green spaces, and rights-of-way, where the cost of controlling invasive species has skyrocketed (Perrings and others 2002, Pimentel 2002, U.S. Congress Office of Technology Assessment 1993).

Invasive plants can in general outcompete native species and reproduce rapidly in the absence of predators from their native lands to form dense infestations that exclude most other plants (Randall and Marinelli 1996). These infestations decrease forest productivity, threaten forest health and sustainability, and limit biodiversity and wildlife habitat on millions of acres including protected habitats (Westbrooks 1998). Alterations to forest structure and natural succession result in changes in functions and processes that threaten vital ecosystem services, like soil formation, water yield, and air rejuvenation (Ehrenfeld and others 2001, Gomez-Aparicio and Canham 2008, Martin and others 2009). Some invasives alter natural fire regimes and increase risk of wildfire

Existing Collaborative Invasive Plant Efforts in the South

Nonnative invasive plant collaboration networks in the South are presently organized for horizontal connectivity, usually State centered. The leading collective efforts involved in managing nonnative invasive plants are voluntary State exotic pest plant councils linked via the Internet through university centers with State land management agencies, individual and corporate land owners, and vegetation management associations. Fledgling cooperative weed management areas are becoming organized within States and among groups of counties. The first council was established in 1984 to bring together numerous agencies combating severe outbreaks in the Everglades and tropical Florida. With significant State and Federal funding, strong leadership, a dedicated and inclusive membership, and a focus on natural areas, the Florida council has developed a mission statement, bylaws, invasive list with threat categories, and identification and control publications (Langeland and others 2008).

The Tennessee council was established in 1994 with assistance from Florida council members and support from the Great Smoky Mountains National Park, which has had an invasive plant control program under way since the 1970s. The Tennessee Council's mission and goals, like Florida's, focuses on raising public awareness, facilitating the exchange of information on identification and control, convening forums and workshops to share information, advising on all aspects of nonnative invasive plants, and launching campaigns to prevent future introductions. Among its accomplishments has been an exotic plant management manual for the State (Tennessee Exotic Pest Plant Council 1996) and leadership in organizing both a South-wide council to fulfill a regional mission to one that now includes a national council in 1997. From 1999 to 2008, exotic plant councils were organized in Georgia (1999), Kentucky (2000), Alabama (2002), Mississippi (2002), South Carolina (2003), North Carolina (2005) and Texas (2008). Most of these broadened the scope of their partnerships to include right-of-way managers, gardeners, native plant enthusiasts, and stakeholders from all components of the intricate modern landscape. State and regional annual meetings share current developments in research, policy, new nonnative invasive plant arrivals, and council activities that have helped to propel invasive management efforts in the region. Although their 501(c)(3) Federal tax status allows some collaborative lobbying, this avenue has not yet been pursued.

The South-wide and State Web sites are hosted at the Center for Invasive Species and Ecosystem Health (an offshoot of the Bugwood Network organized in 1994), which was given official status by the University of Georgia in 2007. In cooperation with Federal agencies, the Center provides critical information and services such as the invasive plants listed by each State, identification and control guides for these invasive plants, details and Web hosting for cogongrass (www.cogongrass.org) and other severe invasive plants, and annual meeting proceedings. The Center maintains an image database system containing over 145,000 high-resolution images of native and nonnative species (Bargeron and others 2006) and with The Invasive Plant Atlas of the United States provides identification, distribution, and management methods for most recognized invasive plants of the United States (Bargeron and others 2007). Regional connectivity for council members on nonnative invasive plant matters is also being provided by the Center's managing a listserv, blog, Facebook page, and Twitter site. The Center also hosts a national reporting and mapping Web site entitled EDDMapS, Early Detection and Distribution Mapping System (Bargeron and Moorhead 2007). It is publically accessible, provides for voluntary inputs by State councils, and assigns a verifier to review data submitted on invasive species infestations and distribution. This mapping site has in 2010 been expanded to cover the entire United States. In 2008, the Woodrow Wilson School at Princeton University created another voluntary mapping database—the Invasive Species Mapping Program—that focuses on the southern distribution of Chinese privet, kudzu, and cogongrass (Marvin and others 2008). Additionally, a parallel mapping project, the Invasive Plant Atlas of the MidSouth, is under construction at the Mississippi State University GeoSpatial Institute. It will combine information from the U.S. Geological Survey and other agencies with the Invasive Plant Atlas of New England; and it will incorporate mechanisms and procedures to transmit data both upward (nationally) and downward to the local level for rapid assessment and response. These databases are being linked and projected to map most nonnative invasive plants in the region and eventually provide an effective and efficient early detection and rapid response network for identifying and locating new high-risk introductions (Westbrooks 2004).

State vegetation management associations and societies focused on right-of-way management and their regional and national organizations represent potentially invaluable collaborative partners for pest plant councils. These associations recently added nonnative invasive plant management to their certified training curriculum. Because rights-of-way are major conduits for some invasive plant spread, this increased awareness and added management approaches should greatly aid further containment. Most pest plant councils have a transportation department employee on their boards and many professional right-of-way managers are members of pest plant councils. These interactions have contributed to new regulations ensuring that right-of-way projects use fill-dirt and rock uncontaminated by invasive plant seeds and plants.

occurrence and damage (Brooks and others 2004, Lippincott 2000). Exotic plant bio-pollution is one of the greatest threats to biodiversity, second only to habitat destruction, and continues to attack our highly valued nature preserves and wetlands (Wilcove and others 1998).

To date, successful efforts to combat and contain invasive nonnative plants have taken an integrated approach to vegetation management (Miller 2003, Miller and others 2010b). This approach incorporates all effective control methods, which may include preventive measures (such as quarantines, border inspections, and embargoes), biocontrol using natural predators, herbicide technology, prescribed fire, and mechanical and manual removal. Most preventive measures and biocontrol programs are only effective when organized on a regional basis because cooperation among States is necessary for their success (Moran and others 2005, Pimentel and others 2000, Westbrooks 2004).

This chapter summarizes pertinent information for the most damaging trees, shrubs, vines, grasses, and forbs that have invaded forests and natural areas as well as pastures, rights-of-way, orchards, grasslands, wetlands, and yards in the South (Langeland and others 2008, Miller and others 2010a). Our objective is to provide useful information on species descriptions, traits that make them invasive, and current management procedures and strategies for 56 threatening invasive plants in 31 groups. The chapter also covers principles of invasion and the value of organization, planning, prevention, and management programs in slowing their spread (with the caveat that eradication of widespread invasions appears only possible on specific lands). Finally, the current occupation and impacts of the invasive plants are presented, with projections of potential spread for the next 50 years.

METHODS AND DATA SOURCE

Biological and ecological traits are summarized from the literature for the major invasive plants in the South to guide specific and general management actions. Recognized concepts, impacts, strategies, policies, and program elements regarding invasive plants and their management are synthesized from the literature. The influences and impacts relative to the other meta-issue areas are discussed using current literature and inputs derived from their chapters. Linear regression was used to calculate the mean annual spread rate in forests using the approximate date of introduction, major planting campaigns or escape documented in the literature, and current occupation estimates from Forest Service survey results. The linear regression models provided conservative estimates of future occupation under past and current climate conditions and no expected major control programs. Other modeling approaches used the climate change cornerstones and landscape data bases to forecast current and future potential habitat for five high-threat species.

In 2001, the Southern Research Station of the Forest Service, U.S. Department of Agriculture began surveying 53 invasive plant groups on all forest ownerships in partnership with State forestry agencies (USDA Forest Service 2008a). This survey of 33 regional species (Miller 2003) and 20 species particular to Florida (Langeland and Burks 1998) has become part of the traditional timber data collections that have been conducted by the Station's Forest Inventory and Analysis unit (FIA) since the 1930s. Maps of occupation for the most occupying species and tabular coverage estimates were derived from these data.

The species selected for survey are regionally recognized nonnative plants known to invade interior forest stands, some forest edges, gaps, roadsides, and stream-sides less than 120 feet wide. The 13 State inventories commenced in different years; although they have varying rates of progress and cycle completions, the expectation is that at least a fifth of the plots within a State will be inventoried every year (Oklahoma's data has yet to be verified for posting). Percent cover by species is recorded on existing FIA clusters of four permanent 1/24-acre subplot that are located across forested landscapes on an approximately 3-mile grid. Each subplot represents about 1,500 acres. Invasive plant cover is recorded in five categories: 1 = trace to <1 percent; 2 = 1 to 10 percent; 3 = 11 to 50 percent; 4 = 51 to 90 percent; and 5 = 91 to 100 percent. For each category, midpoint values are used to calculate an estimate of cover by species for the region and for each county within a State. Our methods combine analyses of FIA data to display current occupation by county, State, and subregion, and then follow up with analyses to understand the nature of occupations.

We focused our predictive modeling on five species of high concern in the South using the Cornerstone Futures. These species were selected because they had sufficient datasets, represented a range of plant growth forms and invasion patterns, and varied by subregional occurrence. The modeled species were Japanese climbing fern (*Lygodium japonicum*), Nepalese browntop (*Microstegium vimineum*), nonnative roses (*Rosa* spp.), silktree (*Albizia julbrissin*), and tallowtree (*Triadica sebifera*). Human and environmental landscape variables were extracted from available digital information for each FIA datapoint, including national resource inventory land-use categories, distance to roads and rivers, human population census with projections, elevation, and climate information (Gesch and others 2002, PRISM Group 2008, U.S. Census Bureau 2000). All variables were converted into 295 feet by 295 feet (90 m by 90 m) cells across the South.

Two modeling techniques, logistic regression (Hosmer and Lemeshow 2000) and maximum entropy (Phillips and others 2006), were used to develop a potential distribution for each species. Logistic regression is a generalized linear model that is used to investigate the relationship between a set of explanatory variables for prediction of the probability of occurrence of an event by fitting data to a logistic curve. It makes use of several predictor variables that may be either numerical or categorical. Logistic regression makes no assumptions about the distribution of the independent variables. MaxEnt (Phillips and others 2006) is based on maximum entropy probability distribution. It is a probability distribution whose entropy is at least as great as that of all other members of a specified class of distributions. The MaxEnt approach is to estimate the probability distribution, such as the spatial distribution of a species that is the greatest extent subject to constraints such as the known locations of the species. It is a machine learning technique that predicts species distributions using detailed geospatial data sets together with species occurrence information, conducted using a specialized program package of MaxEnt (Phillips and others 2006). It generally performs as well or better than other algorithms in tests of model performance (Elith and others 2006, Phillips and others 2006). The important difference between the two techniques is that logistic regression uses information on both presence and absence to estimate a predictive linear model, whereas maximum entropy (MaxEnt) uses information from presence-only and is a nonparametric approach. In developing models for species, variables were eliminated using a manual backward selection method to delete those having little or no impact. Impact on the model was measured as percent contribution and with a jackknife test on gain and influence on area under the curve (AUC). This allowed identification of key variables in determining the occurrence of each species.

To identify the key variables in determining each species occurrence, we calculated the contribution of each variable to the model. The omission rate and area under the Receiver Operator Characteristic (AUC) were used to assess the reliability and validity of models. To assess models, FIA data were split spatially with 50 percent used as a test dataset and 50 percent used as a training dataset. The omission rate is the false negative or the proportion of sites where the species was present but the model predicted absence. To calculate this, a cut-off criterion is required to convert continuous model predictions to binary classifications. We used a threshold value that maximized the sum of sensitivity and specificity. The *sensitivity* is the proportion of actual presence correctly identified and the *specificity* is the proportion of absences correctly identified. Sensitivity and specificity for each potential cut-off were added together and the cut-off with the greatest combined number was selected for further work. This has the advantage of giving equal weights to the probability of success of both presences and absences (Manel and others 2002). This is one of the most appropriate methods to correctly derive a binary variable from continuous probabilities when species presence-absence distribution data are unbalanced (Jiménez-Valverde and Lobo 2006, Liu and others 2005). AUC provides a single measure of model performance, independent of any particular choice of threshold but is sensitive to the method in which absences in the evaluation data are selected (Lobo and others 2008). It is most applicable to data with true absences (Jiménez-Valverde 2011), thus it needs to be used with caution with datasets that do not have absence data. The models run with FIA data were measured absences, but as invasions are not at their full potential, these were not necessarily true absences. We used the following classes of AUC to assess model performance: 0.50 to 0.75 = fair, 0.75 to 0.92 = good, 0.92 to 0.97 = very good, and 0.97 to 1.00 = excellent (Hosmer and Lemeshow 2000). AUC is useful when used in conjunction with other validation statistics because invasive species are often not at equilibrium with their environment and their current realized distribution is much smaller than their potential distribution, thus even field absence data can be temporary with a time dimension.

Although logistic and MaxEnt models may be compared individually to select the best overall model for a particular dataset, combining the two (Araújo and New 2007) can reduce the uncertainty associated with dependence on one or the other. We identified areas where both models predict high potential of invasion, areas where just one model predicts moderate potential of invasion, and areas where both models predict low potential of invasion. Variable contribution to the models was calculated as an average of the two models and direction was assessed in combination. The directions were either a linear positive or negative, or a binomial (two peaks) or polynomial (one valley) relationship. The percentage of forest invaded was calculated by overlaying the final occurrence map with a binary layer of forest for each Cornerstone (chapter 2), producing percentages at high and moderate potential levels. For comparison, each was converted to a current and future percentage of forested FIA plots invaded for each species and for each Cornerstone, based on projected forest acreage (chapter 5). Using these same models, a likewise probability for nonforested lands was calculated for display on the same maps. Because the datasets of landscape variables used for modeling were extracted for the entire South and FIA from forested area, predictions for nonforest lands using forest plot occurrence may be less accurate. However, because all invasive species have large populations on nonforested lands, their projected occupation on nondeveloped lands provides a depiction of interconnectivity that has been lacking. This interconnectivity of the forest and nonforest land invasions under way and projected should not be ignored, however limited the strength of the models on the nonforested portion may be.

RESULTS

The South's Most Pervasive Invasive Plants

The 31 groups (taxa) discussed here qualify as the first targets for proactive management because they account for much of the lands occupied by invasive plants. Although they cumulatively pose the greatest threat for the region, priorities vary for specific subregions, depending on current and potential occupations. Most are able to spread from one subregion to another if not contained, because most are limited by spread vectors and not environmental factors (Pattison and Mack 2009). In this section we summarize invasive plant descriptions, current and future occupation with country of origin (table 15.1), and the community layers they mostly impact (table 15.2) in five categories: trees, shrubs, vines, grasses and bamboos, and forbs. Descriptions are mostly derived from Miller and others (2010a) and Langeland and others (2008), while specific traits that lead to their success as invasives are derived from the wider literature.

Invasive Trees

In addition to dramatically altering habitats, nonnative trees hinder reforestation and management of rights-of-way and natural areas. Some species occur initially as scattered individuals and then eventually form dense stands if not controlled. Almost all invasive trees are hardwoods. Most spread by prolific seed production and abundant root sprouts, and all are still sold as ornamentals unless prohibited by State laws. Because they tolerate an exceptionally wide range of soil and site conditions, they are popular as low maintenance ornamentals. Depending on conditions, invasive trees can be eliminated with herbicides by stem injection, cut-treat, soil spots, basal sprays, and foliar sprays (Miller and others 2010b). Although bulldozers with root rake blades, mulchers, chainsaws, and prescribed burning will eliminate or reduce standing trees, only herbicides are effective in controlling roots. Total elimination requires surveillance and treatment of resprouts and plant germinants that originate from the soil seed bank.

Tallowtree—Tallowtree or popcorntree (*Triadica sebifera*) forms nearly pure stands in former wet prairies and is more likely on low and flat lands, areas adjacent to water and roadways, sites recently harvested or disturbed, young stands, and private forestlands (Bruce and others 1995, Gan and others 2009). Tallowtree was originally introduced from China presumably through France into coastal South Carolina near Charleston and Georgia as early as the 1770s (Hunt 1947). It is a deciduous tree growing to 60 feet tall with leaves that are broadly ovate to diamond-shaped and turn bright yellow and scarlet in the autumn, which makes it an attractive and widely planted yard tree (Jubinsky and Anderson 1996). Also, the plant has a high tolerance to insect defoliation (Rogers and Siemann 2003) and all parts of the plant are considered toxic to humans, especially the inner seeds (Everest and others 1996). Although not pollinated by bees (but wind), the tree is prized and planted by honey producers because of its abundant nectar glands (Lieux 1975). Bundles of white waxy popcorn-like seeds appear on branchlets in the autumn and remain into winter. Seeds are high in fat and protein, and birds and possibly mammals consume the waxy seed coat and then pass and spread the seeds (Conway and Smith 2002; Renne and others 2000, 2002). Because they float, seeds are also spread by water around lake and bog margins as well as along drainage ditches, streams, and rivers. Tallowtree is shade intolerant, which limits seedling establishment in intact forests (Pattison and Mack 2009). Trees as young as 3 years can produce viable seed and remain reproductive for 100 years, capable of producing 100,000 seeds per year (Bruce and others 1997, Gray 1950). Seed viability in the soil is 2 to 7 years, and germination rate varies by State from 6 to 52 percent reported (Cameron and others 2000). Infestations intensify seeding and surface root sprouts, and foliage and roots release chemicals that inhibit other vegetation, causing an eventual collapse of biodiversity following invasion (Conway and others 2002).

Occupation occurs mostly in the Coastal Plain along the Gulf of Mexico and Atlantic Ocean, with the greatest concentration on invaded coastal prairies surrounding Houston (fig. 15.1). Reports of China's fourteen centuries of uses prompted the U.S. Department of Agriculture to establish trials and promote Gulf Coastal Plain plantings in Texas during the early 1900s, resulting in the current Texas epicenter (Howes 1949). Tallowtree has the highest regional occupation of any nonnative tree invader, with more than a half million acres covered and a 45 percent increase projected during the next 50 years (table 15.1) under current climate conditions. Floodwaters from multiple hurricanes in the past two decades have facilitated spread into damaged forests, wetlands, and wet prairies (Chapman and others 2008). Oswalt (2010) reported that the numbers of Chinese tallowtree in Louisiana, Mississippi, and eastern Texas increased by about 370 percent from the 1990s to 2005. Because its sole limitation is dispersal vectors, this invasive has yet to occupy the full extent of its range in North America (Pattison and Mack 2008, 2009). Increases in both range and severity have been predicted with a warming climate (Gan and others 2009), and we investigated this further and provide results in a later section.

Tree-of-heaven—Tree-of-heaven (*Ailanthus altissima*) or ailanthus occurs mostly along forest roads where it spreads into recently harvested or disturbed sites and displays exceptional competitive capabilities as a new player in stand development (Landerberger and others 2007, Miller 1990). Tree-of-heaven was imported into the Eastern U.S. as an

Table 15.1—High-priority invasive plants of southern forests: their origin, date of introduction or extensive planting, current cover, annual rate of spread, and projected cover in 2060 (absent control programs)

Species	Origin	Date of introduction or extensive planting	Current cover	Average annual rate of spread	Projected cover 2060
			- - - - - - - - - - -	*acres* - - - - - - - - - - -	
Invasive Trees					
Tallowtree	Asia	About 1900	596,239	5,420	867,257
Tree-of-heaven	China	1784	243,111	1,076	296,897
Chinaberrytree	China/India	1830	101,426	563	129,600
Silktree, mimosa	Asia	1785	90,055	400	110,067
Brazilian peppertree	South America	1898	83,434	745	120,681
Melaleuca	Australia	1934	61,631	811	102,178
Princesstree	China	1844	27,009	163	35,144
Total			**1,202,905**	**9,178**	**1,661,824**
Invasive Shrubs					
Invasive privets	China/Europe/Japan/Korea	Ave 1875	3,180,488	23,559	4,358,447
Invasive roses	Japan/Korea/China	Ave 1877	693,618	5,215	954,377
Invasive lespedezas	Japan	Ave 1863	532,235	3,621	713,267
Bush honeysuckles	Asia	About 1950	345,622	5,760	633,640
Invasive elaeagnus	China/Japan/Europe/Asia	Ave 1930	96,421	1,205	156,684
Sacred bamboo	Asia/India	1960	24,595	492	49,190
Tropical soda apple	Brazil/Argentina	1988	9,570	435	31,320
Winged burning bush	Asia	1980	8,710	290	23,227
Total			**4,891,259**	**40,578**	**6,920,152**
Invasive Vines					
Japanese honeysuckle	Eastern Asia/Japan	About 1850	10,342,030	64,638	13,573,914
Japanese climbing fern	Asia/Australia	About 1918	314,758	3,421	485,822
Kudzu	Japan/China	About 1920	226,889	2,521	352,938
Invasive wisterias	Japan/China	Ave 1873	57,129	417	77,979
Invasive ivies	England/Europe/Asia	Ave 1762	29,328	118	35,241
Vincas, periwinkles	Europe	Ave 1780	25,255	110	30,745
Invasive climbing yams	Asia/Africa	Ave 1900	20,691	188	30,096
Wintercreeper	Asia	1907	11,860	115	17,617
Old World climbing fern	Africa/Asia/Australia	1960	9,369	187	18,738
Oriental bittersweet	Asia	1860	8,654	58	11,539
Total			**11,045,963**	**71,773**	**14,634,630**
Invasive Grasses and Canes					
Nepalese browntop	Tropical Asia	1919	935,529	10,281	1,449,556
Tall fescue	Europe	1940	767,208	10,960	1,315,214
Cogongrass	Japan/Phillipines	About 1935	60,107	801	100,178
Invasive bamboos	China	1882	56,581	442	78,683
Chinese silvergrass	Asia	1957	10,130	191	19,687
Total			**1,829,555**	**22,675**	**2,963,318**
Invasive Forbs					
Garlic mustard	Europe	About 1900	5,991	54	8,714
GRAND TOTAL			**18,975,673**	**146,947**	**26,658,728**

Table 15.2—Forest community layers and edges prone to be replaced by these species of invasive plants

Overstory replacers	Midstory replacers	Understory and ground-layer replacers	Edge and gap eroders	Persistent infestations in openings (disturbed areas)
Tallowtree	Silktree	Japanese honeysuckle	Silktree	All invasive plants readily establish in openings and disturbed areas
Princesstree	Privets	Bush lespedeza	Chinaberrytree	
Tree-of-heaven	Bush honeysuckles	Scared bamboo	Privets	
Melaleuca	Invasive elaeagnus	Winged burning bush	Invasive roses	
Brazilian peppertree	Oriental bittersweet	Japanese climbing fern	Tropical soda apple	
Chinaberrytree	Japanese climbing fern	Winter creeper	Invasive lespedezas	
Kudzu	Wisterias	Vincas, Periwinkles	Kudzu	
Wisterias		Invasive ivies	Japanese climbing fern	
Cogongrass		Nepalese browntop	Wisterias	
Bamboos		Cogongrass	Invasive climbing yams	
Old World climbing fern		Garlic mustard	Oriental Bittersweet	
			Nonnative ivies	
			Invasive Bamboos	
			Cogongrass	
			Nepalese Browntop	
			Chinese Silvergrass	

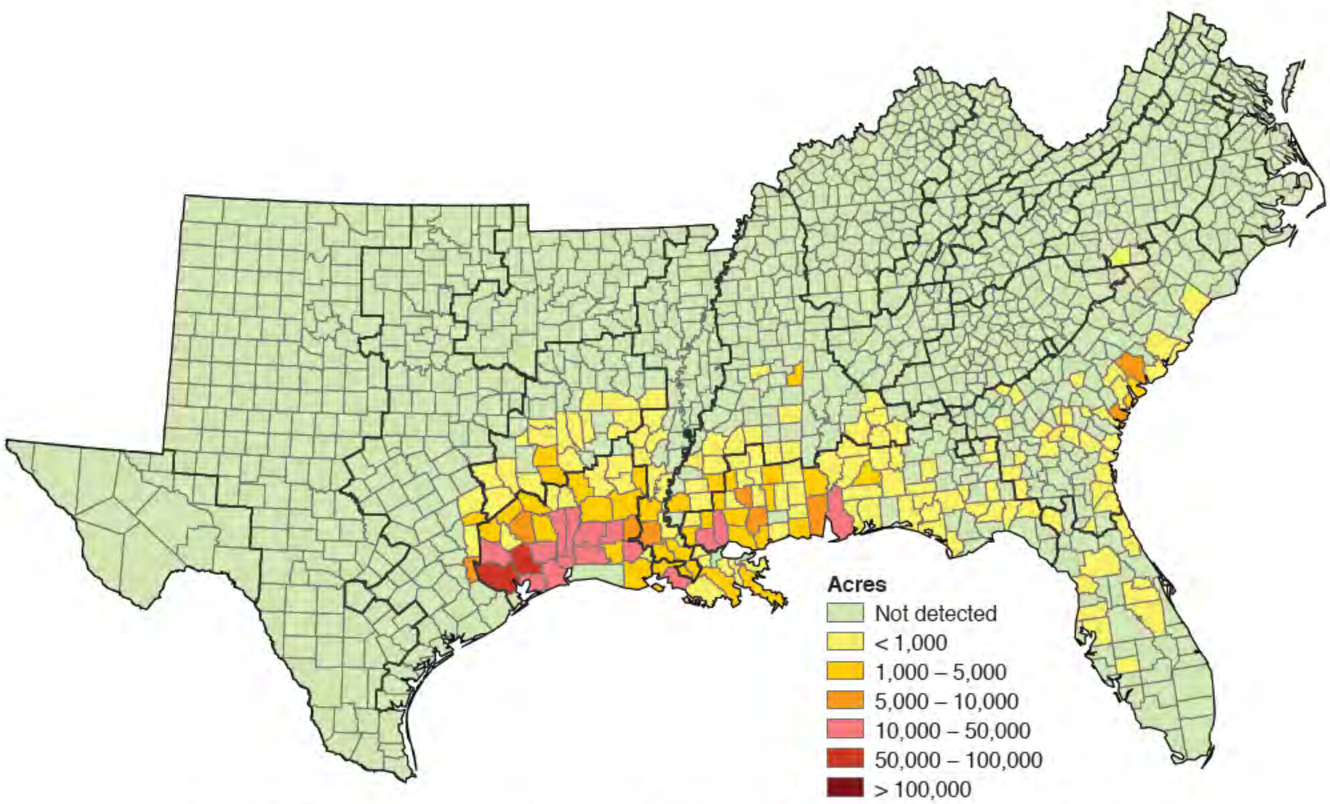


Figure 15.1—Tallowtree: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

ornamental in 1785 and was a common nursery species by the mid-1800s (Davies 1942, Hu 1979). Favorable early tests paved the way for widespread plantings on surface mined lands in Appalachia (Plass 1975). Tree-of-heaven is a shallow-rooted deciduous tree that can grow to 80 feet tall. It has long compound leaves that have rows of non- opposing leaflets on both sides of the stalk with two circular glands under small lobes at leaflet bases (Miller and others 2010a). Large terminal clusters of tiny greenish flowers in early summer yield persistent clusters of wing-shaped fruit with twisted tips on female trees. Viable seeds are produced at 2 to 3 years, and mature trees can produce more than 100,000 seeds per year (Renne and others 2002). Even light-green seeds in midsummer are capable of germination. Renne and others (2002) reported that 40 percent of a seed crop was dispersed by 16 bird species in coastal South Carolina. Seeds can be also blown up to 330 feet from a parent tree (Landenberger and others 2007) and can also float causing long-distance dispersal and infestations along streams and rivers (Kowarik and Saumel 2008). If the main stem is deadened, root sprouts will appear afterward, and root segments left in soil after pulling treatments will sprout (Miller and others 2010b). Sprouts can grow 10 to 14 feet tall the first year (Swingle 1916). This vigorous growth can continue for 4 or more years. Leaves and roots release allelopathic chemicals that inhibit other plants, decreasing biodiversity (Gomez-Aparicio and Canham 2008, Lawrence and others 1991).

The area of highest occupation is around Nashville in the Cumberland Plateau of Tennessee, followed by another one along the Shenandoah Valley where the Piedmont meets the Northern Ridge and Valley Province in Virginia (fig. 15.2). Southward spread is expected since scattered infestations occur even as far south as Florida, with a predicted increase of 24 percent more cover in 50 years (table 15.1).

Chinaberrytree—Chinaberrytree (*Melia azedarach*), a traditional widely escaped ornamental introduced into South Carolina and Georgia from Asia in 1830 (Gordon and Thomas 1997), is increasingly becoming established within forests. It is deciduous, growing to about 50 feet tall with multiple trunks that tend to arch outward. It has lacy, many divided leaves that are dark green, sometimes turning bright yellow in autumn (Miller and others 2010a). Showy panicles of tiny blue flowers in spring yield abundant round yellow pulpy fruits that persist during winter. Some seeds will germinate even when the fruit coats are green. If the main stem is deadened, stump sprouts, root sprouts, and seedlings will eventually emerge. Viable seed can be produced at 4 to 5 years, while the longevity of seed viability in the soil has not been reported. This species spreads by abundant bird- and animal-dispersed seeds (Vines 1960), which are toxic to humans and some mammals (Everest and others 1996). Occupation is highest across the Coastal Plains with scattered outliers elsewhere in the South (fig. 15.3). Occurrences in the cooler climates of northern Virginia indicate that range is not limited by temperature and that further spread can be expected. Chinaberrytree is the third most abundant invasive tree in the region (table 15.1). Region-wide spread has already occurred (USDA Natural Resource Conservation Service 2010), and an additional 28 percent of occupation is forecasted by 2060.

Silktree—Silktree or mimosa (*Albizia julbrissin*) is a small legume tree 10 to 50 feet tall imported into the South from central Asia (Cothran 2004) and traditionally planted as an ornamental owing to abundant showy pink and white flowers in spring and throughout summer. It reproduces by abundant seeds and root sprouts. It has feathery deciduous leaves and smooth light-brown bark. Profuse dangling flat pods containing 5 to 10 seeds are released during winter and can float to spread along waterways and ditches, where seeds remain viable for many years. All subregions have scattered silktree stands, mostly along highways, with the heaviest infestations in north central Alabama surrounding Birmingham (fig. 15.4). Silktree is currently the fourth most abundant invasive tree (table 15.1). Forest occupation is expected to increase by 22 percent over the next 50 years under current climate, resulting in extra roadside maintenance costs to prune jutting limbs. Various diseases attack silktree and may restrict future range and density (Dirr 1998). Estimates of spread rates with climate change scenarios are reported in a later section.

Brazilian peppertree—Brazilian peppertree (*Schinus terebinthifolius*) was initially imported in the mid- and late 1800s (Barley 1944), while it was made popular as an ornamental near Miami in the 1930s where it initially escaped (Morton 1978). Brazilian peppertree completely replaces native vegetation with its tangled infestations that reach heights of 40 feet (Langeland and others 2008). It is an evergreen shrub or small tree and has many short trunks or arching stems of contorted branches. Drooping, odd pinnately-compound leaves smell of turpentine when crushed. It produces many multi-branched clusters of small whitish flowers in summer and autumn that yield abundant clusters of spherical red pepper-smelling fruit in winter (only on female plants). Plants can produce seeds as early as 3 years. Germination mainly occurs from November to April, with seed viability ranging from 30 to 60 percent. Drought appears to be the main cause of seedling mortality. Allelopathic chemicals are released by fallen leaves that inhibit other plants, decreasing biodiversity (Morgan and Overholt 2005). Chemicals are produced in leaves, flowers, fruits, and sap that can irritate human skin and respiratory passages (Morton 1978).

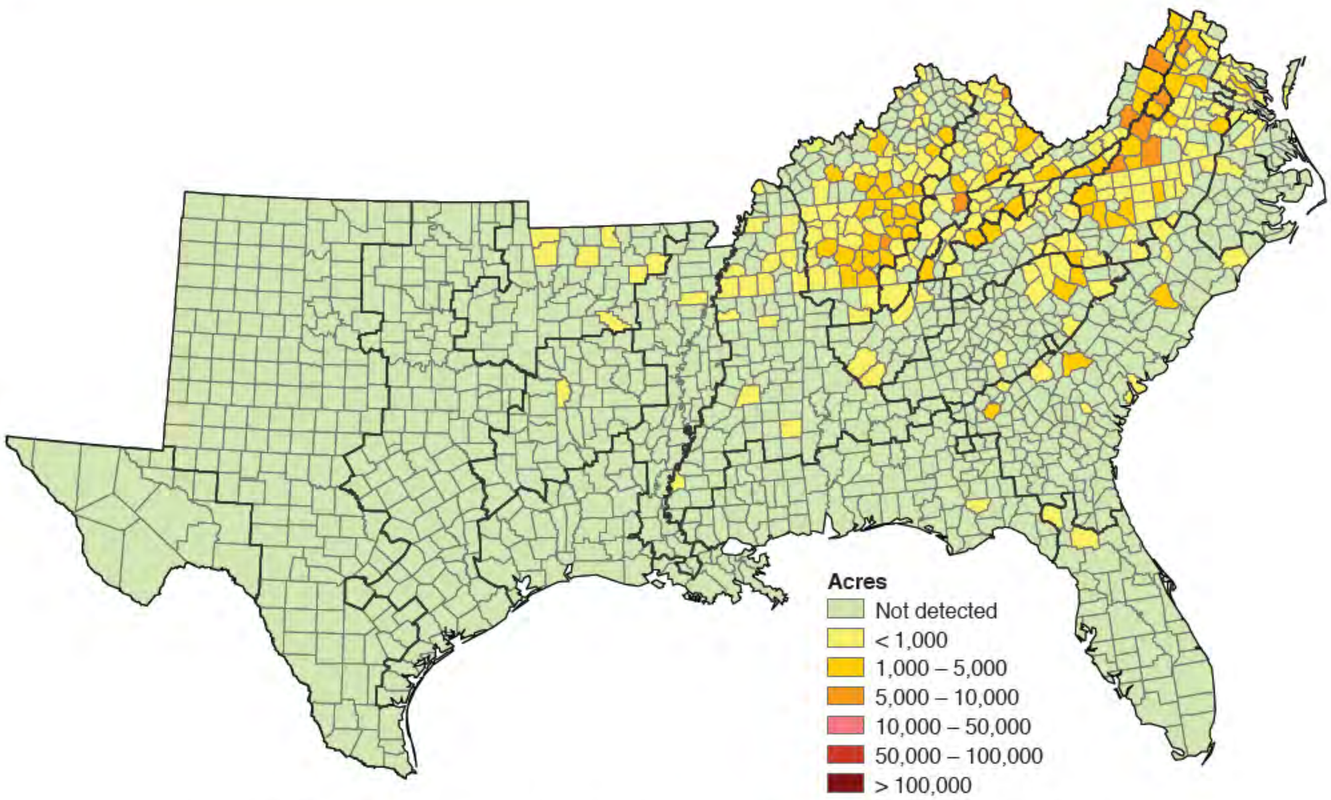


Figure 15.2—Tree-of-heaven: current regional cover, 2010.(Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

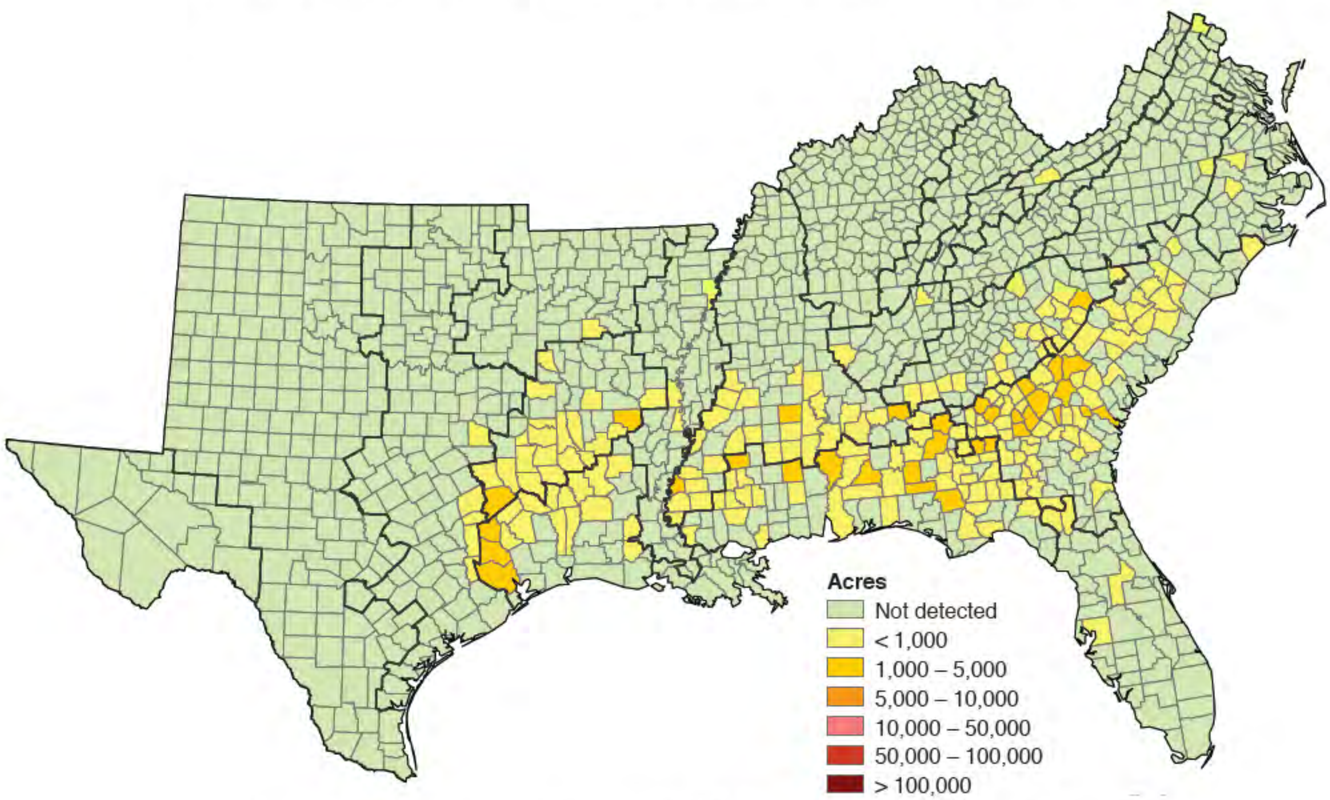


Figure 15.3—Chinaberrytree: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

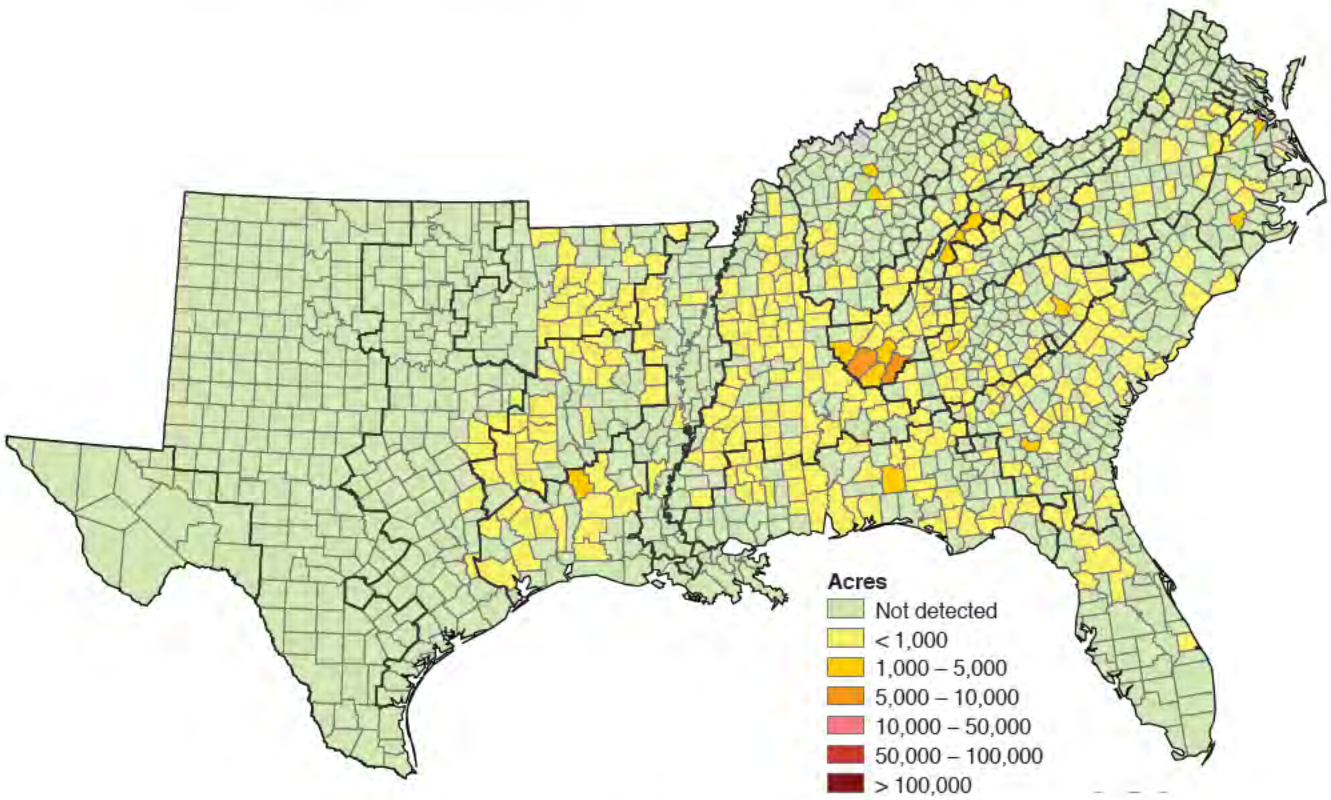


Figure 15.4—Silktree: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Brazilian peppertree is confined to Florida and the southern tip of Texas. Because of the extensive dense infestations in Florida, it is fifth in forest occupation by invasive trees. It has recently extended its range northward to the Panhandle of Florida with an expansion rate projected at 30 percent in 50 years (table 15.1). It can be expected to spread northward even with the current climate.

Melaleuca—Melaleuca (*Melaleuca quinquenervia*) is a widely recognized invasive tree that continues to threaten the biological integrity of the unique ecosystems in Florida's Everglades (Dray and others 2006, University of Florida Institute of Food and Agricultural Sciences 2007). It was introduced to Florida from Australia in about 1887 and promoted by the nursery industry as an ornamental (Dray and others 2006, Langeland and others 2008). In the 1930s it was aerially scattered over the Everglades to create forests and is currently invasive only in the southern and central areas of the State. It is an evergreen tree to 100 feet tall that occurs in vertically dense stands with slender crowns of alternate, grayish-green, lance-shaped leaves to 4 inches long that smell of camphor when crushed (Langeland and others 2008). The bark consists of soft whitish layers that peel and drop, thus the common name, paper-bark. Flowers are whitish, bottlebrush-like spikes to 6 inches long. Tightly clustered around young stems, the fruit are round, woody capsules that release 200 to 300 tiny seeds for windborne distribution. The trees grow exceedingly fast in dense stands that diminish wildlife food and habitat. Aggressive application of herbicides has greatly reduced infestations in the Everglades, but melaleuca continues to spread into pine flatwoods, marshes, and cypress swamps (Nelson 1994). A cooperative management program has coordinated prevention and eradication programs since 1990 (University of Florida Institute of Food and Agricultural Sciences 2007). In addition, three insect biological control agents have been released, two of which are available by mail order, and research is under way on a fourth (University of Florida Institute of Food and Agricultural Sciences 2007).

Surveys indicate dense infestations in southern Florida forests with known outliers in central Florida (Ferriter 2007), where the actual coverage on all lands of this invasive exceeded half a million acres by 1993 (University of Florida Institute of Food and Agricultural Sciences 2007). Also it has been recorded as an escape along the south shores of Lake Pontchartrain near New Orleans (USDA Natural Resource Conservation Service 2010). This species could spread northward with warming climate at an estimated rate of 65 percent more coverage in 50 years, being the highest percentage increase for an invasive tree (table 15.1).

Princesstree—Princesstree or paulownia (*Paulownia tomentosa*) was introduced from Europe to America for ornamental purposes in about 1844, although originally from China (Hu 1961). It was considered naturalized in Georgia by 1896 (Harper 1900). Princesstree is a deciduous tree to 60 feet tall with large heart-shaped leaves that are fuzzy on both surfaces. Before leaves appear in spring, trees are covered with showy pale-violet flowers that produce persistent pecan-like capsules in clusters in autumn and winter. Each capsule splits to release thousands of tiny winged seeds that are spread by wind and water. Abundant flower buds are present on erect stalks over winter. Plants can produce viable seed at 5 to 7 years. In the mountains, seeds can be dispersed as far as 2 miles by wind (Langdon and Johnson 1994). Because germination requires bare soil, princesstree invades widely after wildfire, timber harvesting, and other disturbances, forming colonies from prolific root sprouts (Langdon and Johnson 1994). This ornamental is still widely marketed as royal paulownia or royal empress and planted as an “instant” shade tree. Princesstree occurs as scattered forest infestations in all States except Texas. Heaviest infestations are associated with surface mine plantings (Tang and others 1980) and those cities with numerous ornamental plantings, such as Lexington-Lynchburg (TN), Forest City (NC), Florence and Tuscaloosa (AL), and Vicksburg (MS) (fig. 15.5). Some occurrences are probable escapes from commercial princesstree plantations owing to the promotion by the American Paulownia Association, Inc. The relatively few straight trees produced by these plantations have a high value in Japan but nowhere else (Tang and others 1980). Because of continued sales and plantings along with a naturalized range that covers all Southern States (USDA Natural Resource Conservation Service 2010), spread and intensification is expected to increase by at least 31 percent over the next 50 years (table 15.1).

Invasive Shrubs

Nonnative shrubs often occur as dense understory layers that prevent natural regeneration of the native overstory trees (table 15.2). Herbicide control options resemble those for trees, with a few exceptions: foliar sprays are more often the control of choice for shrubs; cutting shrub stems close to the soil surface and treating the stump with an herbicide is easier with shrubs; and because shrub stems are smaller, basal sprays are usually more effective (Miller and others 2010b). All invasive shrubs are shade tolerant and are spread by bird-dispersed seeds, initially resulting in scattered plants under existing forest canopies that require interior surveillance strategies. All species described below are still produced, sold, and planted as ornamentals and wildlife food plants, except tropical soda apple.

Invasive privets—There are at least eight species of invasive privets (*Ligustrum* spp.) that have been introduced from Asia and Europe into the South as ornamentals from 1794 to 1899 (Dirr 1998, Maddox and others 2010, USDA Natural Resource Conservation Service 2010). They are the second most abundant invasive plants in the South and they form dense stands in the understory of bottomland hardwood forests and exclude most native plants and replacement regeneration (Merriam and Feil 2002). These privets are also increasing in upland forests, fencerows, rights-of-way, and special habitats throughout the region. They drastically change habitat and critical wetland processes. Abundance of common birds is sustained in privet thickets, but abundance of specialist birds and diversity of native plants and bees is decreased (Hanula and others 2009, Wilcox and Beck 2007). Chinese privet (*L. sinense*) is the most common invasive privet across the South, while European privet (*L. vulgare*), Amur privet (*L. amurense*), California privet (*L. ovalifolium*), waxyleaf privet (*L. quihoui*), and border privet (*L. obtusifolium,* only in VA, KY, TN, and NC) are confined to subregions (USDA Natural Resource Conservation Service 2010). These privet species are most often semi-evergreen to evergreen being multi-stemmed shrubs to 30 feet tall and just as wide due to arching tops. They are difficult to distinguish to species since all have leafy stems with opposite leaves less than 3 inches long. The evergreen privets include Japanese privet (*L. japonicum*) that grows to 12 feet tall and just as wide and glossy privet (*L. lucidum*) that grows up to 50 feet in height, with an upward spreading canopy. They have thick leathery opposite leaves 4 to 6 inches long that are glossy, and stems that are hairless. Terminal sprays of small showy white flowers bloom on all privets in spring, except waxyleaf in autumn; abundant clusters of small, green-turning-purple fruit appear in autumn and often persist through winter. Birds spread seeds (Greenberg and Walter 2010), which produce abundant seedlings and are thought to be viable for only a year (Shelton and Cain 2002). Privets also increase in density by stem and root sprouts. If the parent shrub is deadened, many shallow surface roots will produce sprouts (Harrington and Miller 2005). In Georgia, privet has been reported as an important autumn and winter browse for white-tailed deer (*Odocoileus virginianus*) (Stromayer and others 1998).

Occupation is widespread throughout the South, with the most occurrences in an epicenter around Birmingham, AL (fig. 15.6) and the least in Kentucky, Florida, and western Texas (USDA Natural Resource Conservation Service 2010). Thirty-seven percent more privet cover is predicted by 2060, which would amount to 1.2 million more acres, second only to Japanese honeysuckle for potential spread (table 15.1).

Invasive roses—There are over 21 nonnative roses (*Rosa* spp.) invading ecosystems in the South, while multiflora rose (*R. multiflora*) is the most pervasive in the Eastern United States (Miller and others 2010a, USDA Natural Resource Conservation Service 2010). With their dense infestations

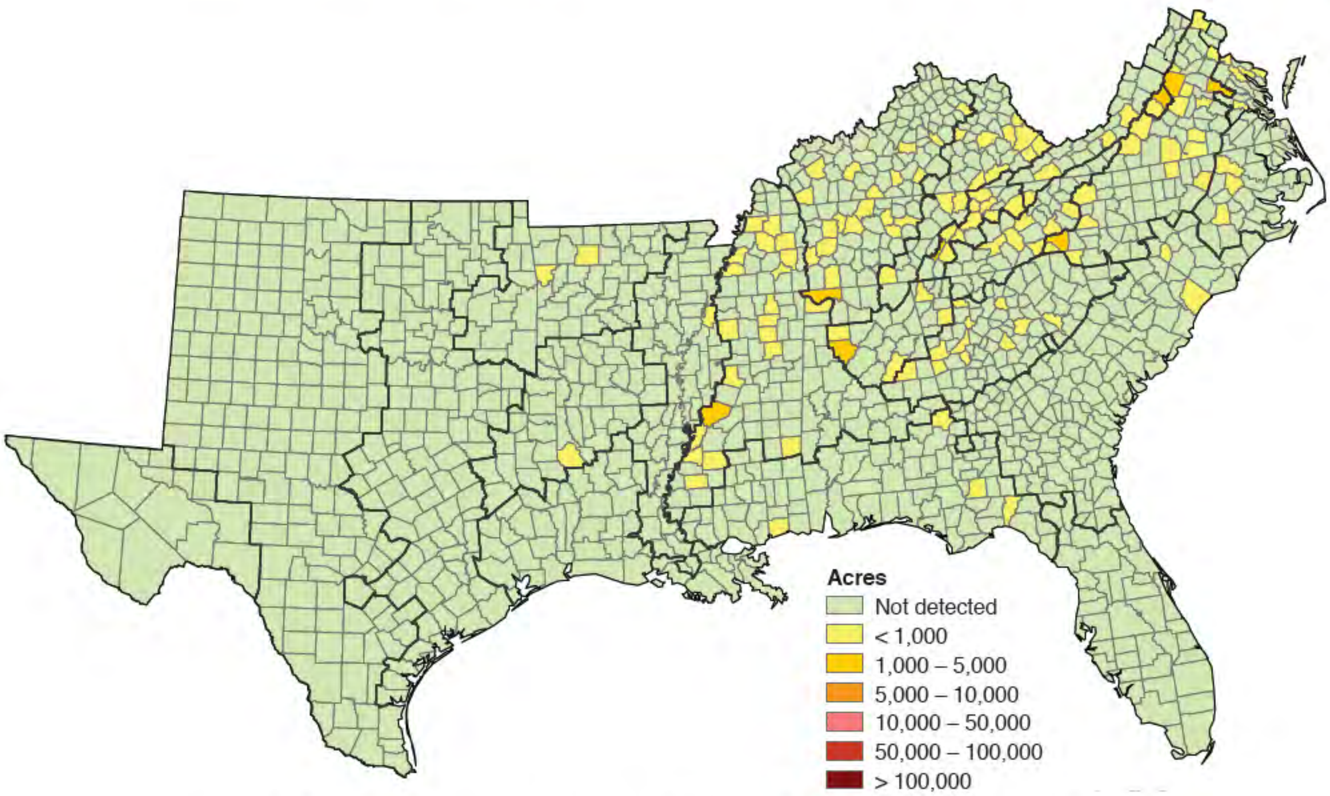


Figure 15.5—Princesstree: current regional cover map, 2010.(Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

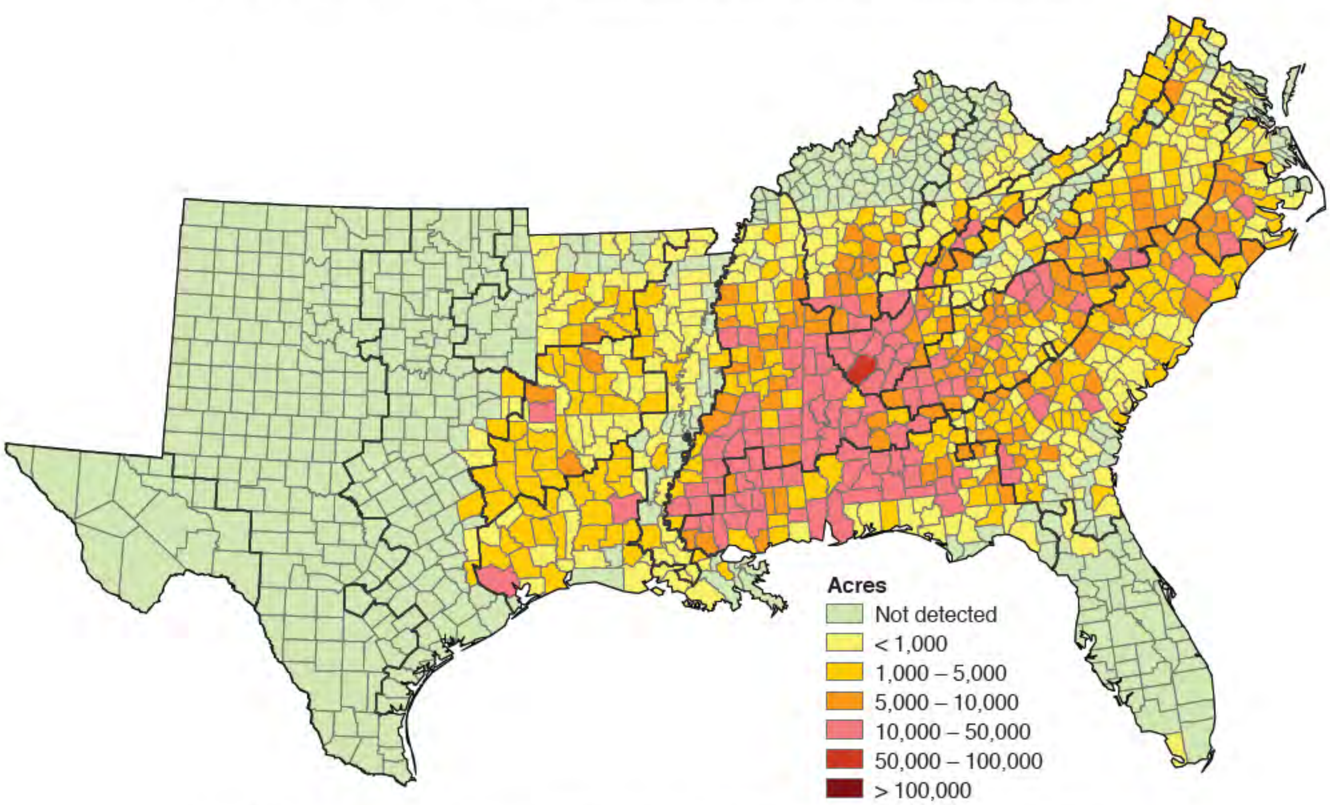


Figure 15.6—Invasive privets: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

of thorny shrubby entanglements, invasive roses occur increasingly along forest margins, within interior forests, and along stream banks where they disrupt forest regeneration, wildlife movement, and land access (Honu and Gibson 2008, Merriam 2003). With the exception of multiflora, all invasive roses are evergreen. Multiflora was imported from Japan and Korea in 1886 (Dirr 1998). Roses can be erect, arching, or trailing shrubs to 30 feet in height or long and clump forming. They have compound leaves with three to nine leaflets and frequent recurved or straight thorns along the stems. Clustered or single white-to-pink flowers appear in early summer to yield red rose hips in autumn to winter. The fruit are consumed by birds resulting in wide seed dispersal (Greenberg and Walter 2010). Roses colonize by prolific sprouting and rooted trailing stems. It has been estimated that an average multiflora rose plant may produce a million seeds per year, which may remain viable in the soil for up to 20 years (Bergmann and Swearingen 2009). Nonnative roses invade along stream banks and forest road edges to extend into open forests. Nonnative roses resemble native Carolina rose (*R. carolina*), swamp rose (*R. palustris*), and climbing rose (*R. setigera*), all of which have pink flowers in spring and nonbristled leafstalk bases, but none form extensive infestations except swamp rose.

Occupation varies by species (fig. 15.7). Supported by government programs that promoted and funded plantings until the 1950s, multiflora rose has been planted for "living fences" to confine livestock, wildlife habitat, and in highway medians as a crash barrier (Bergmann and Swearingen 2009). Its range is the entire Eastern United States and Canada, although declines have been reported in central New Jersey as a forest stand developed over a 40-year period (Banasiak and Meiners 2009). Multiflora occurs in most Southern States with heaviest infestations in Kentucky and Virginia throughout the Cumberland Plateau and Mountains and the Appalachian Mountains. Other infestations are common in the Ozark-Ouachita Highland, while Cherokee rose (*R. laevigata*) principally occurs across the Coastal Plain most notably in the Black Belt Prairie area of southern Alabama. Together, invasive roses occupy almost 700,000 acres of forests—making them the second most common invasive shrub—and they are predicted to increase their coverage by 37 percent over the next 50 years (table 15.1) because of continued spread along highway-forest margins, which go largely untreated. Estimates of spread rates with climate change scenarios are reported in a later section.

Invasive lespedezas—Invasive lespedezas (*Lespedeza* spp.) were introduced in the United States from 1837 to 1896, originally from China, Japan, or Korea (Dirr 1998, Donnelly 1954). All three species have been widely planted for wildlife food plots and forage for more than a century and continue to be used for soil stabilization projects along highways and on surface mines. All were reported to have escaped from plantings in the 1940s (Allard and Leonard 1943, Davison 1945, Gunn 1959). If allowed to escape from planted stands, they form dense exclusive infestations that remain standing during winter dormancy to prevent forest regeneration, wildlife movement, prescribed burning, and land access. All have nitrogen-fixing bacteria on root nodules. Shrubby lespedeza (*L. bicolor*) and its look-alike, Thunberg's lespedeza (*L. thunbergii*), are perennial much-branched semi-woody shrubs 3 to 10 feet in height. Chinese lespedeza (*L. cuneata*) occupies the most lands of the invasive lespedezas and has already spread westward into the Great Plains. A subshrub that grows to 6 feet in height with allelopathic chemicals in the foliage that inhibit other plants (Kalburtji and Mosjidis 1992), it has many tiny cream-colored flowers during summer compared to the pinkish-to-white flowers of shrubby and Thunberg's lespedeza. All three species yield abundant single flat seeds in autumn and winter that are spread by birds, ants, and rodents. Seeds have low germination, but because they are long-lived in the soil seed bank control treatments must be followed by long-term monitoring (Logan and others 1969). These invasives resemble two native species, the slender lespedeza (*L. virginica*) that grows in tufted clumps instead of infestations and the native roundhead lespedeza (*L. capitata* Michx.) that has similar leaves but whitish flowers in round-topped clusters. Superior strains of invasive lespedezas that were developed at Federal plant materials centers (Pieters 1950) have the potential to take over diminishing native grasslands and prairie communities to the detriment of biodiversity (Brandon and others 2004). Chinese lespedeza varieties were developed with lower lignin and tannin concentrations to overcome forage limitations (Donnelly 1954, Hawkins 1955).

All subregions have invasive lespedeza infestations, with an epicenter around Greenville and Spartanburg, SC, while the least are along the Mississippi River Delta and in Florida (figs. 15.8). Occurrence appears to be matched to areas of past planting programs for soil stabilization and wildlife food plots. Region-wide spread mainly along highways and roads is occurring at an estimated annual rate of 7,600 acres, and 71 percent more cover is predicted over the next 50 years (table 15.1).

Bush honeysuckles—There are at least six species of invasive bush honeysuckles (*Lonicera* spp.) that have been repeatedly imported from eastern Asia into the United States over a 100-year period from 1752 to 1860 followed by plant breeding programs. Widespread distribution has occurred through continued nursery sales and Federal programs from 1960s to 1984 (Dirr 1998, Luken and Thieret 1996). They are still planted as ornamentals and for wildlife habitat and soil stabilization, while botanists proclaim their biological threat. Bush honeysuckles now occur as frequent shrubs along forest margins and in openings in many Southern States, and as solid understory

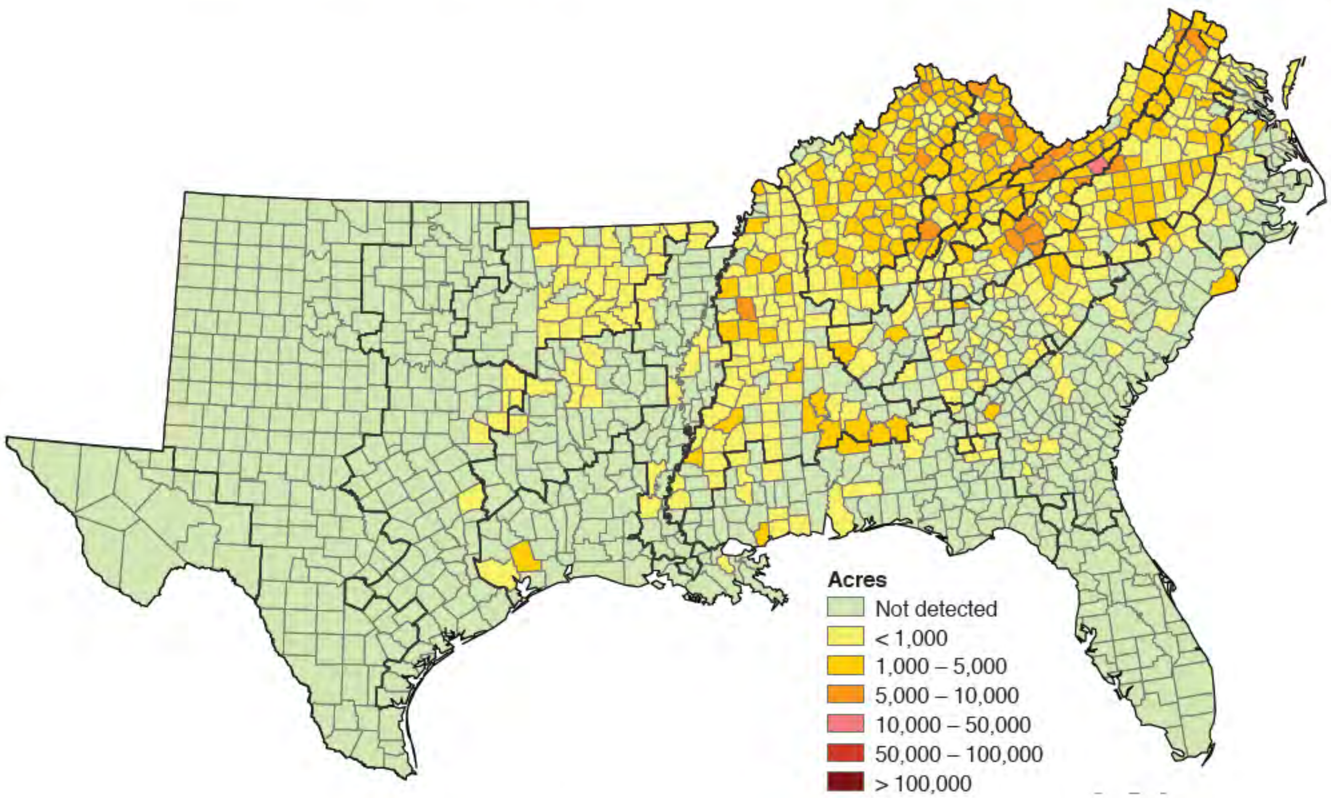


Figure 15.7— Invasive roses: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

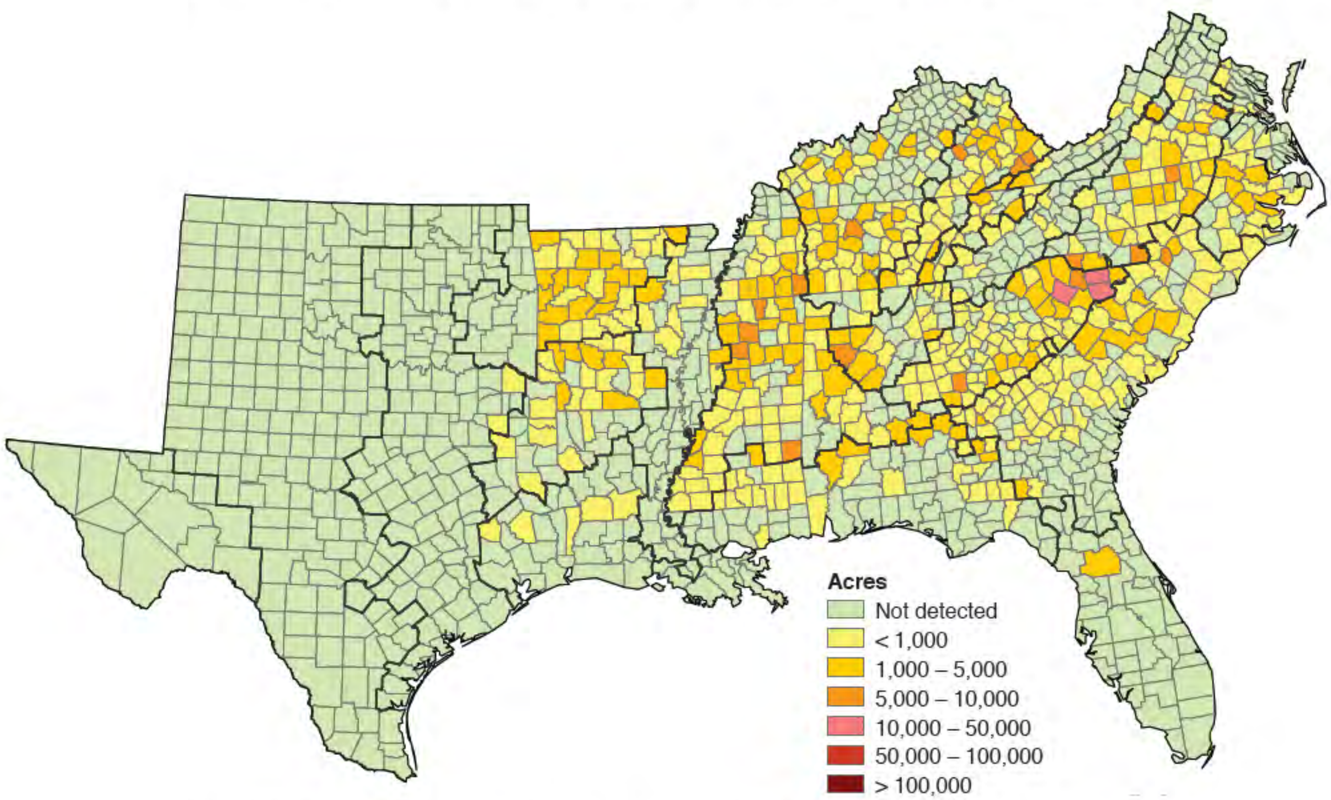


Figure 15.8— Invasive lespedezas: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

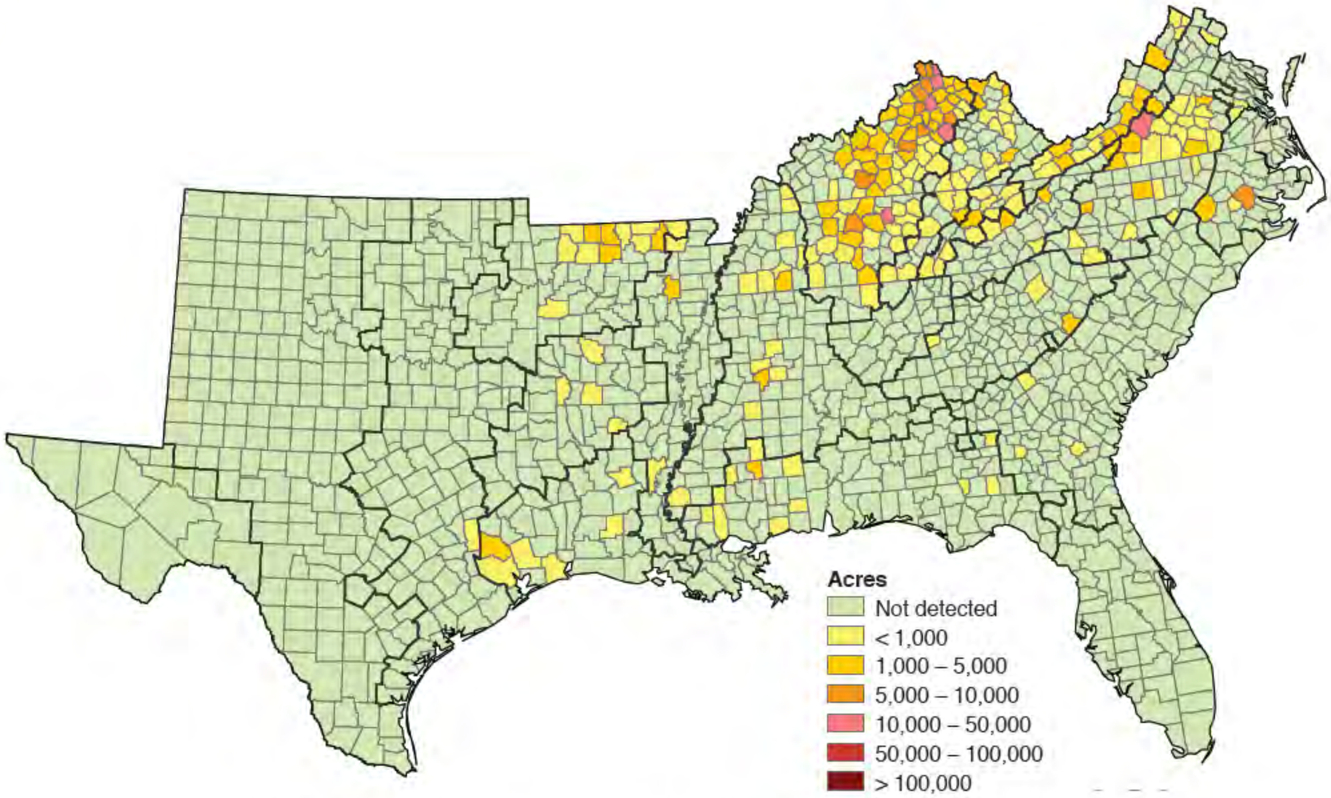


Figure 15.9—Bush honeysuckles: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

infestations in central Kentucky, Tennessee, and Virginia (fig. 15.9) as well as across the Midwest and Northeast. Amur honeysuckle (*L. maackii*), Morrow's honeysuckle (*L. morrowii*), Tatarian honeysuckle (*L. tatarica*), sweet breath of spring (*L. fragrantissima*), Standish honeysuckle (*L. standishii*), and Bell's honeysuckle [*Lonicera ×bella* (morrowii × tatarica)] are upright-to-arching, branched shrubs with a multitude of basal sprouts (Miller and others 2010a). The most widespread is Amur. All have dark green oval-to-oblong distinctly opposite leaves that appear early and remain into winter. Fragrant, showy, tubular and five-lipped, white-to-pink or yellow-paired flowers similar to Japanese honeysuckle appear from mid-March to June. Abundant paired berries that appear at 5 to 8 years in leaf axils (Deering and Vankat 1999, Dirr 1998) are red-to-orange during winter, are spread by birds and mammals (Vellend 2002, Williams and others 1992), and contain seeds that are long lived in the soil. Infestations intensify by prolific root sprouts. Nonnative bush honeysuckles resemble the American fly honeysuckle (*L. canadensis*), which is rare and occurs only around shrubby bogs at high elevations.

Although invasive bush honeysuckle infestations have been reported in southern Georgia and as far west as Houston, the highest levels are in the Cumberland Plateau and Mountains, the Interior Low Plateau, and Central Appalachian Piedmont sections (fig. 15.9). The least occupied are the Coastal Plains, with none reported in Florida. Subregional occupation varies by invasive bush honeysuckle species (USDA Natural Resource Conservation Service 2010). Current occupation of 345,622 acres is projected to more than double by 2060 (table 15.1).

Invasive elaeagnus—Autumn olive (*Elaeagnus umbellata*), silverthorn or thorny olive (*E. pungens*), and the infrequent (in the South but widely invasive in the West and Northeast) Russian olive (*E. angustifolia*) were initially planted as ornamentals (Dirr 1998, USDA Natural Resource Conservation Service 2010). Government and industry programs promoted and planted these species to form dense cover for soil stabilization, surface mine reclamation, and wildlife food plots (Allan and Steiner 1965). Elaeagnus infestations outcompete other species and reduce biodiversity, while the nitrogen-fixing bacteria on their roots alter nitrogen cycles to disrupt processes and alter the mix of soil organisms. Their spreading thorny branches will increasingly obstruct stand access and wildlife movement (Munger 2003).

The most widely invasive and high-threat species, autumn olive is a tardily deciduous bushy, leafy shrub to 20 feet in height (Miller and others 2010a). It has alternate leaves that are green above and silvery scaly beneath, and it produces many silvery-scaled red berries in autumn. Silverthorn is evergreen, shade tolerant, and densely bushy to 25 feet in height, with long limber projecting shoots that can eventually climb into tree crowns. Its leaves are simple, both silver and tawny, scaly, and its tiny cream-colored flower clusters appear in late autumn, producing oblong, red olive-like brown-scaled fruit in spring. Russian olive is deciduous with a single bole that grows to 35 feet tall, silvery-scaled leaves, and fruit that is produced in autumn. All have scattered thorn like short branches along their stems. The fruit are consumed by wildlife followed by widely dispersed seeds. Plants initially occur as scattered individuals, both in the open and under forest shade, and intensify by abundant arching basal sprouts (Munger 2003).

Occurrence is greatest in the Piedmont of Georgia and South Carolina, where government nurseries once supplied elaeagnus for wildlife plantings (fig. 15.10). Surface mine reclamation using autumn olive plantings has resulted in another epicenter in the northern Appalachian and Cumberland highlands. The more recent popularity of silverthorn as an ornamental is likely to result in region-wide escapes into urban forests and then into the broader landscapes. Invasive elaeagnus species are in their early "lag" phase of forest invasion when occurrences are scattered and populations are low, which means the spread of the current 96,421 acres will be at least 60 percent more acres in 50 years (table 15.1).

Sacred bamboo—Sacred bamboo or nandina (*Nandina domestica*) was an early imported ornamental from 1804 due to its evergreen foliage, spring flower clusters, and bunches of red berries that persist during winter. It was only in the 1960s (150 years after introduction) that escapes into forests of North Carolina were recognized (Radford and others 1964). It is still widely sold and cultured to yield new hybrids, some of which are seedless. It is now replacing the shrub layer in deciduous forests due its continuous evergreen growth habit (Langeland and others 2008).

Nandina is an erect shrub that can grow up to 8 feet in height, with multiple bushy jointed stems, somewhat resembling bamboo (Kaufman and Kaufman 2007). Glossy multiple divided leaves are green turning to red or pink in winter. Abundant berries in autumn and winter are a favorite food for birds, spreading seeds from back yards to forests. Nandina is widely escaped to varying degrees in all States (fig. 15.11). Continued production and sale in the plant trade have resulted in occupation on 24,000 acres of forest land, with as much as an 11-fold increase expected by 2060 (table 15.1).

Tropical soda apple—Tropical soda apple (*Solanum viarum*) was listed as a Federal Noxious Weed soon after its accidental introduction from South America into Florida in the late 1980s (Mullahey 1996). Spread was exceedingly rapid, predominantly through intra-State and interstate transportation of cattle with tropical soda apple fruit in their rumens. It infests pastures in at least eight other States. Wildlife now feed on the fruit in pastures and spread its seeds to many land-use areas, including forest margins and gaps and open forests (Akanda and others 1996). Once established, it forms exclusive thorny infestations.

Tropical soda apple is an upright, perennial subshrub or shrub, 3 to 6 feet in height, which remains green year-round in most southern locations. It has thorny oak-shaped and sized leaves, clusters of tiny white flowers, and golf-ball sized fruit that are mottled green-white turning to yellow in late summer to autumn. Even immature fruits can contain viable seeds, which adhere to machinery, wildlife, clothing, and boots. Fruits have a sweet smell that is attractive to livestock and wildlife, and each can contain 400 seeds. Shoots increase in numbers and size annually from the rootcrowns. Most infestations are in the Coastal Plains with migration occurring into the southern Piedmont (fig. 15.12). Research has shown that tropical soda apple will grow and reproduce as far north as Illinois (Patterson and others 1997), indicating that further spread in the South is probable. Forested acres occupied in the region are predicted to triple by 2060, from 9,570 to 31,320 (table 15.1). One biocontrol insect for tropical soda apple has been released with several others undergoing tests (Medal and others 2010).

Winged burning bush—Winged burning bush (*Euonymus alatus*) is an ornamental imported from China around 1860 due to its brilliant pink to red autumn foliage, thus its common name (Dirr 1998). Only recently has it been observed as infestations under forest canopies and along rights-of-way (Ebinger 1983). Winged burning bush is a deciduous, wing-stemmed, bushy shrub to 12 feet in height (Miller and others 2010a). Leaves are opposite, oval with elongated bases and tips, and thin, less than 2 inches long with both surfaces smooth and hairless. Plants are densely branched with a broad leafy canopy. Abundant tiny orange fruit appear in late summer as stemmed pairs in leaf axils and turn purple in autumn.

Winged burning bush has been used extensively as an ornamental in the Northeastern United States and upper reaches of Southern States, and has many cultivars (Dirr 1998). It escapes and spreads by bird-carried seeds and colonizes by root suckers. Along with occupying forest openings and rights-of-way, it forms dense infestations that replace understory shrub layers in deciduous forests because of its tolerance to shade (table 15.2). It resembles the threatened and endangered native burning bush (*E. atropurpureus*), which has erect hairs covering the lower leaf surfaces. Although infestations of winged burning bush are

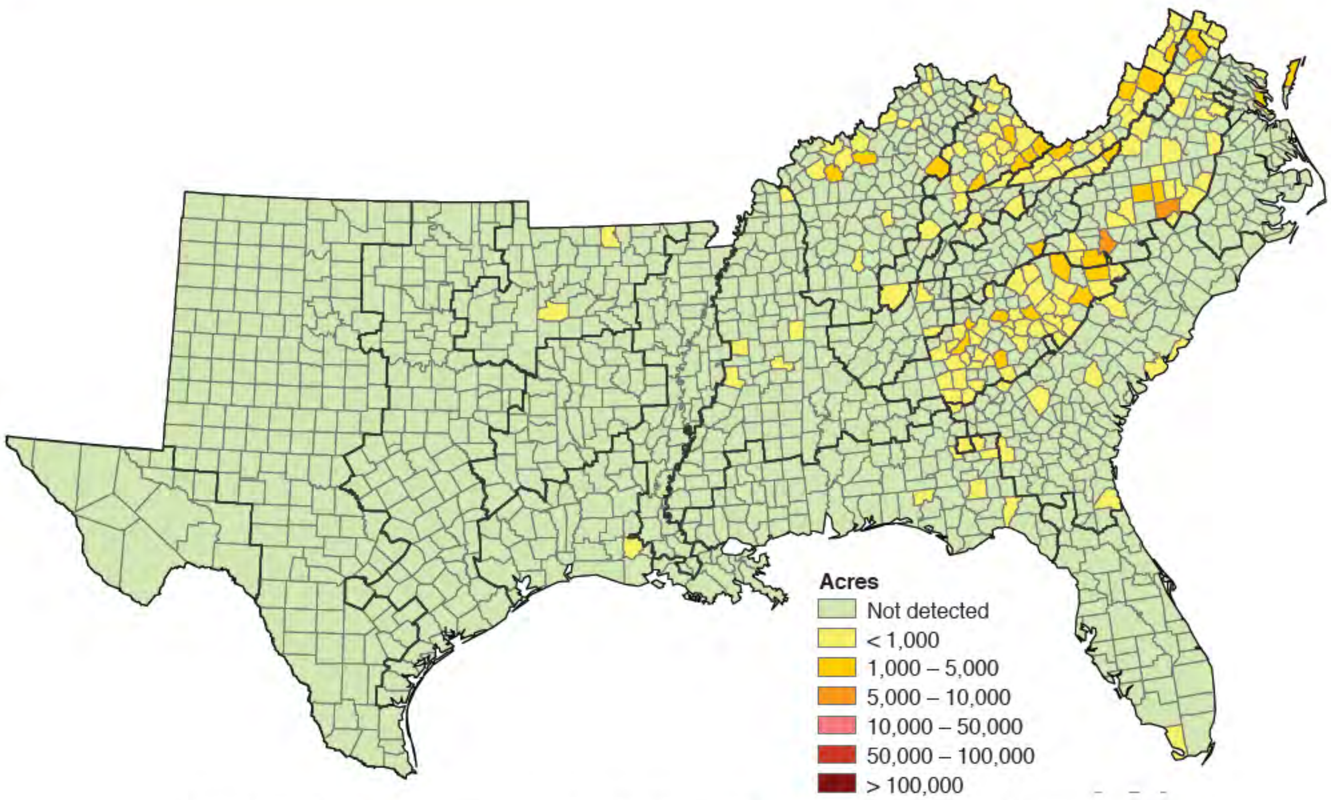


Figure 15.10—Invasive elaeagnus (autumn olive, silverthorn, and Russian olive): current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

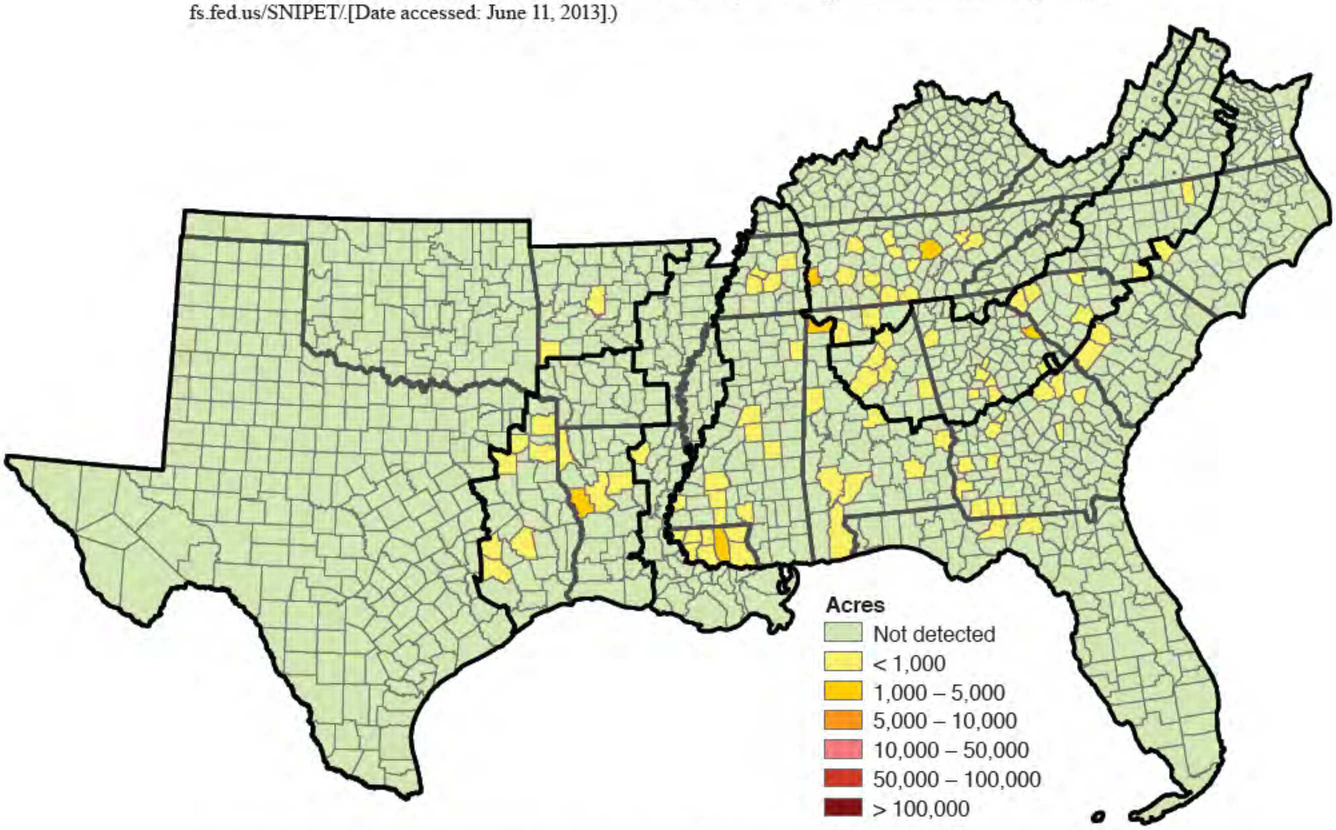


Figure 15.11—Sacred bamboo: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

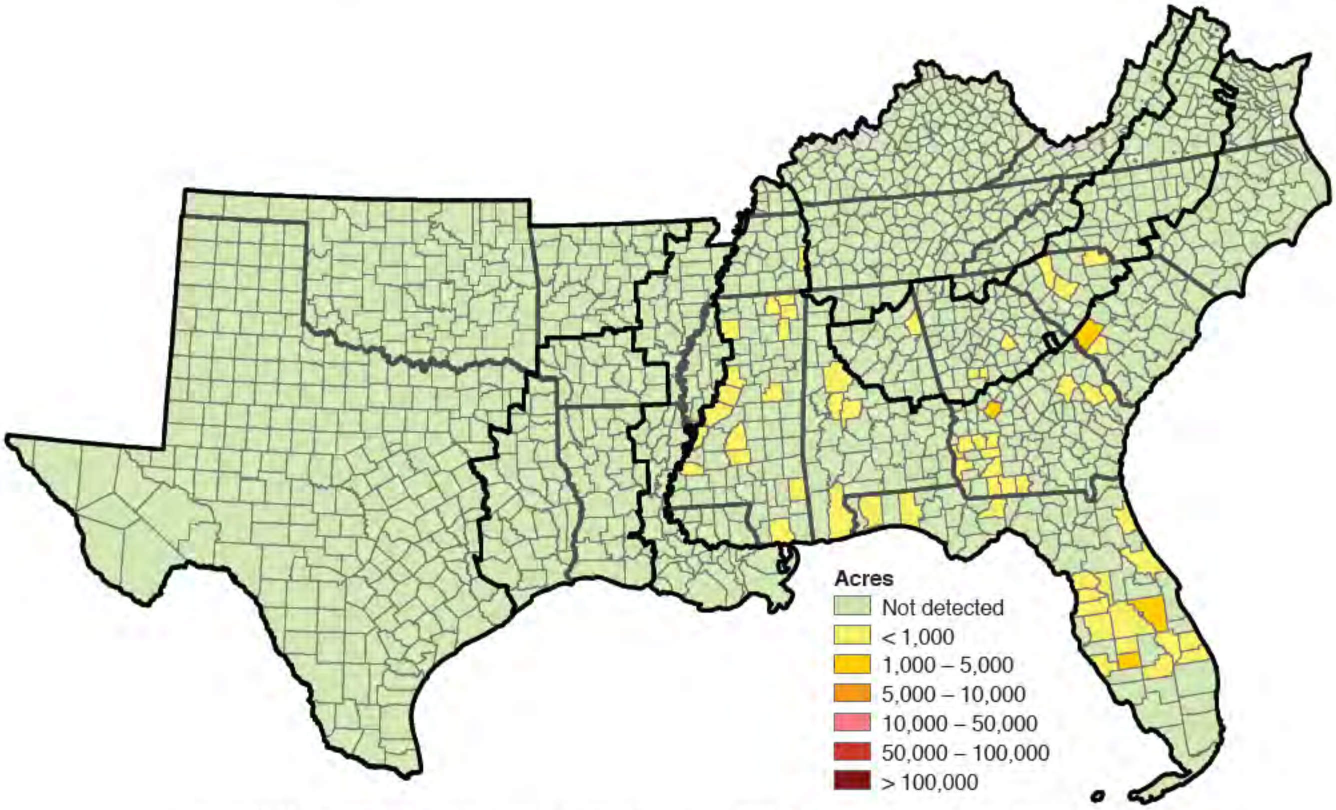


Figure 15.12—Tropical soda apple: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

concentrated in central Kentucky and along the Shenandoah Valley in Virginia, others are expected if ornamental planting continues to expand (fig. 15.13). Although forested acres currently occupied by winged burning bush are small (8,710 acres), they are likely to grow with expanding ornamental markets (table 15.1), up to 5.5-fold.

Nonnative Vines

Nonnative vines form dense infestations that can overtop even the tallest trees or can completely occupy a forest opening. Some invasive vines are shade tolerant and invade the ground layer and edges of forests, eventually climbing shrubs and trees (table 15.2). Herbicide applications and other treatments are complicated by the tendency of many vines to form mixed-species infestations with invasive trees and shrubs. Specific herbicides applied to vines can release the invasive trees and shrubs. Herbicide sprays should be applied as high as possible to foliage of climbing stems. If foliage reappears, cut stems as close to the ground as possible and treat the cut stems with appropriate herbicides (Miller and others 2010b). The upper vines must be cut high enough to prevent the vine from acting like a trellis for the new growth.

Japanese honeysuckle—The most occupying forest invasive in the region, Japanese honeysuckle (*L. japonica*) persists to block establishment of native plants in many forest types over a wide range of sites, often coexisting with both native and invasive plants (Honu and Gibson 2008, Loewenstein and Loewenstein 2005, Yurkonis and Meiners 2004). It was initially introduced into the United States from Asia in 1806 while the first collection in the South was in Kentucky in 1842 (Schierenbeck 2004). It quickly became a very popular plant for homestead beautification, soil stabilization, and wildlife food plots. Dense infestations occur along forest margins and rights-of-way, as well as under closed canopies, and as arbors high in treetops (Merriam 2003, table 15.2). It persists by woody rootstocks and spreads mainly by vines under forest litter rooting at nodes, and less often by animal-dispersed seeds (Evans 1984). It has infrequent seeding in forest stands due to lack of pollinators in some areas (Larson and others 2002). It has very low initial seed viability and low seed survival (less than 2 years) in the soil (Fowler and Larson 2004, Shelton and Cain 2002).

Japanese honeysuckle is a semi-evergreen to evergreen woody vine that climbs by twining and trails to 80 feet. It has opposite leaves less than 2.5 inches along hairy brown vines. Besides the frequently rooting vines, older plants have long underground woody rhizomes that frequently sprout, which often stymies eradication efforts. It is shade tolerant, a vigorous competitor to pine seedlings and has allelopathic

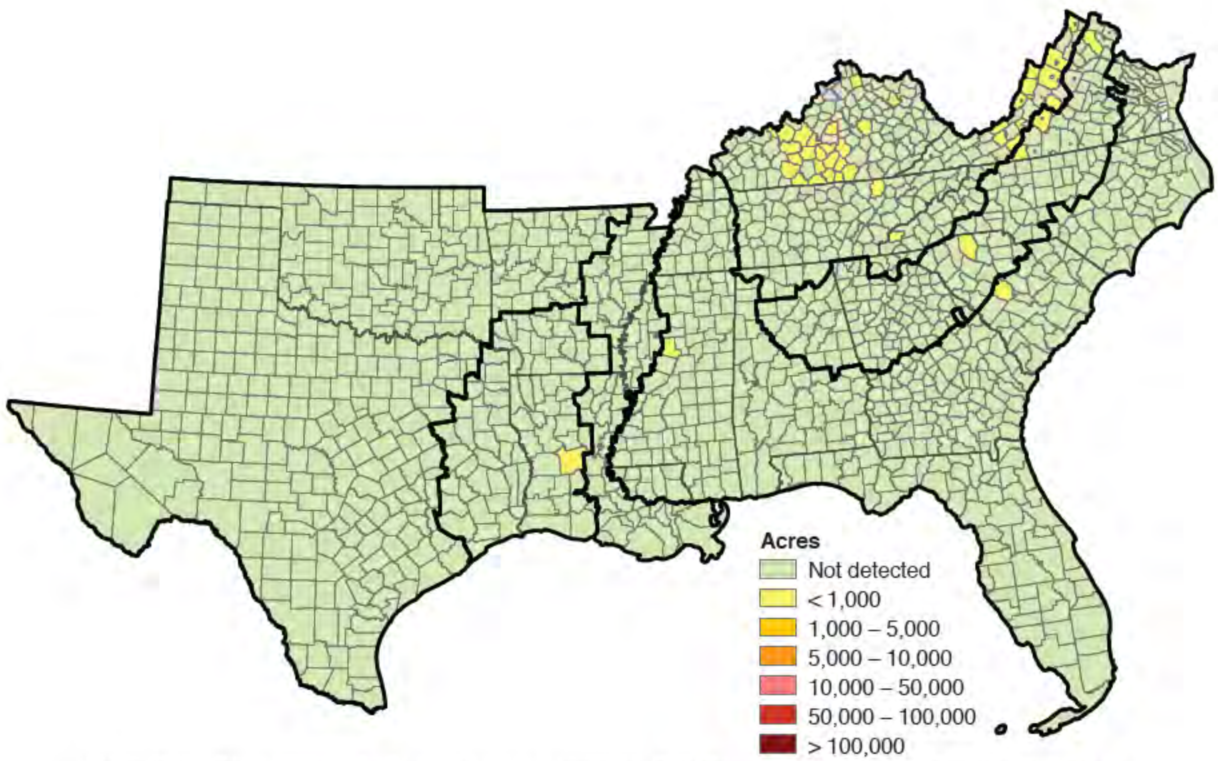


Figure 15.13—Winged burning bush: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

chemicals that inhibit other plants (Skulman and others 2004). It resembles viney native honeysuckles, which usually have reddish hairless stems and hairless leaves and do not have the ability to form extensive infestations.

Japanese honeysuckle is the region's most rampant invasive species, threatening forests in all States and terrains, and is still planted in wildlife openings and still invading surrounding lands. The highest levels of occupation are in east central Alabama and the lowest levels are in Florida (fig. 15.14). The projected spread of 65,000 acres per year would mean a 31 percent increase over the next 50 years and would sustain its ranking as the most occupying forest invasive plant in the South (table 15.1).

Japanese climbing fern—Japanese climbing fern (*Lygodium japonicum*) is rapidly becoming one of the most common invasive plants in Coastal Plain States along the Gulf of Mexico (fig. 15.15). It is a climbing and twining, perennial viney fern to 90 feet long and high, often forming mats of shrub- and tree-covering infestations (table 15.2). Its scattered and dense infestations erode plant diversity and this plant has no known wildlife value. It has lacy finely divided leaves along green-to-orange-to-black wiry vines. Vines arise as branches (long compound leaves) from below ground, widely creeping rhizomes that are slender, dark brown to black, and must be killed for eradication. Fronds that have been frost killed in winter turn tan-brown and persist, but they remain green in Florida and in sheltered places farther north. Dead vines from previous years serve as trellises for reestablishment. Both green and dead plants act as fire ladders to tree crowns during wildfires and prescribed burns. In addition to colonizing by rhizomes, Japanese climbing fern also spreads rapidly by wind-dispersed spores. Since its introduction as an ornamental around 1900 (Ferriter 2001) and eventual escape from plantings first reported in about 1918 in South Carolina (Anderson 1921), it has spread to 314,758 forested acres (table 15.1). It is predicted to increase by almost 54 percent over the next 50 years. Northward spread from the Gulf Coastal Plain is likely with warming trends. Estimates of spread rates with climate change scenarios are reported in a later section.

Kudzu—Kudzu (*Pueraria montana*), one of the most notorious of southern invasive plants, forms dense infestations that are principally limited to forest edges and young forests because it is shade intolerant (table 15.2). It commonly occurs with Chinese privet and often twines and climbs to 100 feet relying on existing Japanese honeysuckle and other vines to form infestations in forest canopies (Miller 2003). It cannot twine around trees or poles greater than 4 inches in diameter. Kudzu is a deciduous, woody leguminous vine that increases nitrogen in occupied soils (Forseth and Innis 2004).

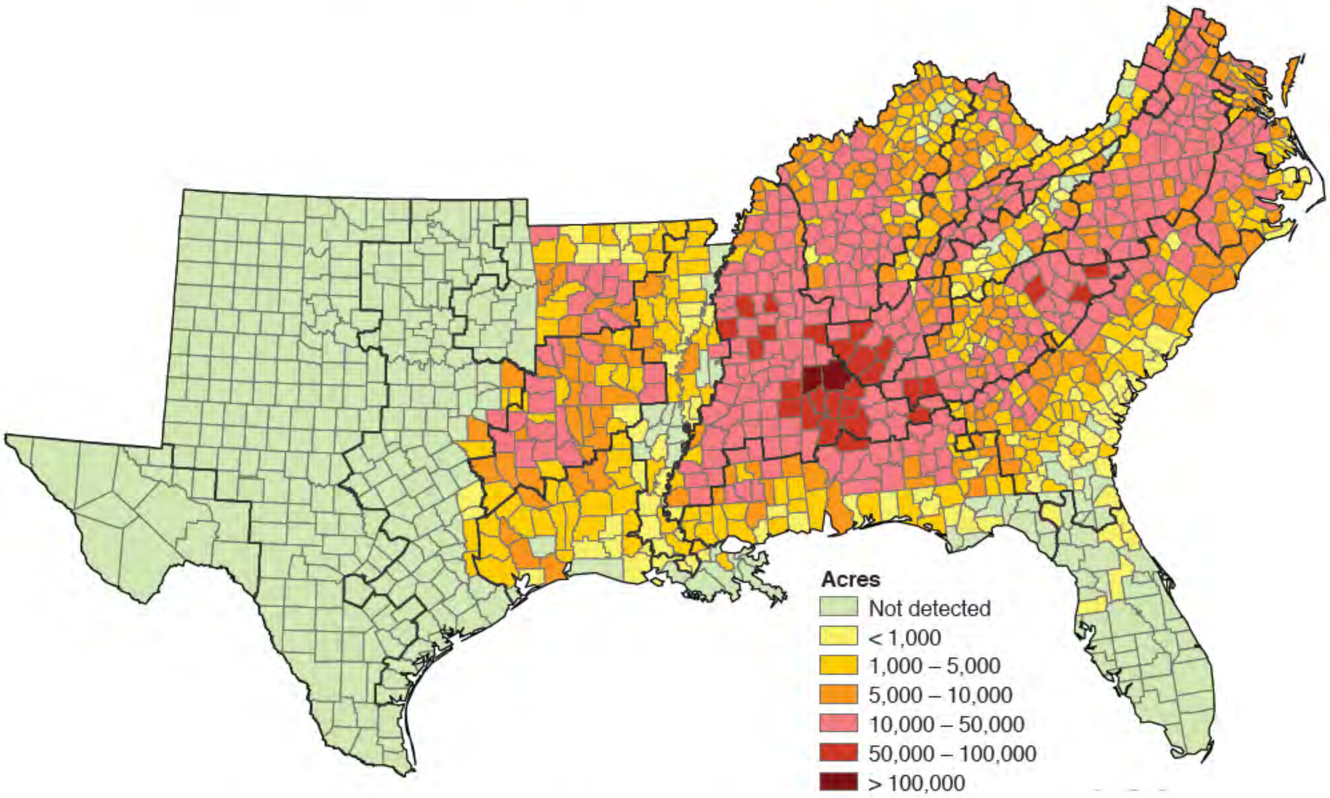


Figure 15.14—Japanese honeysuckle: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

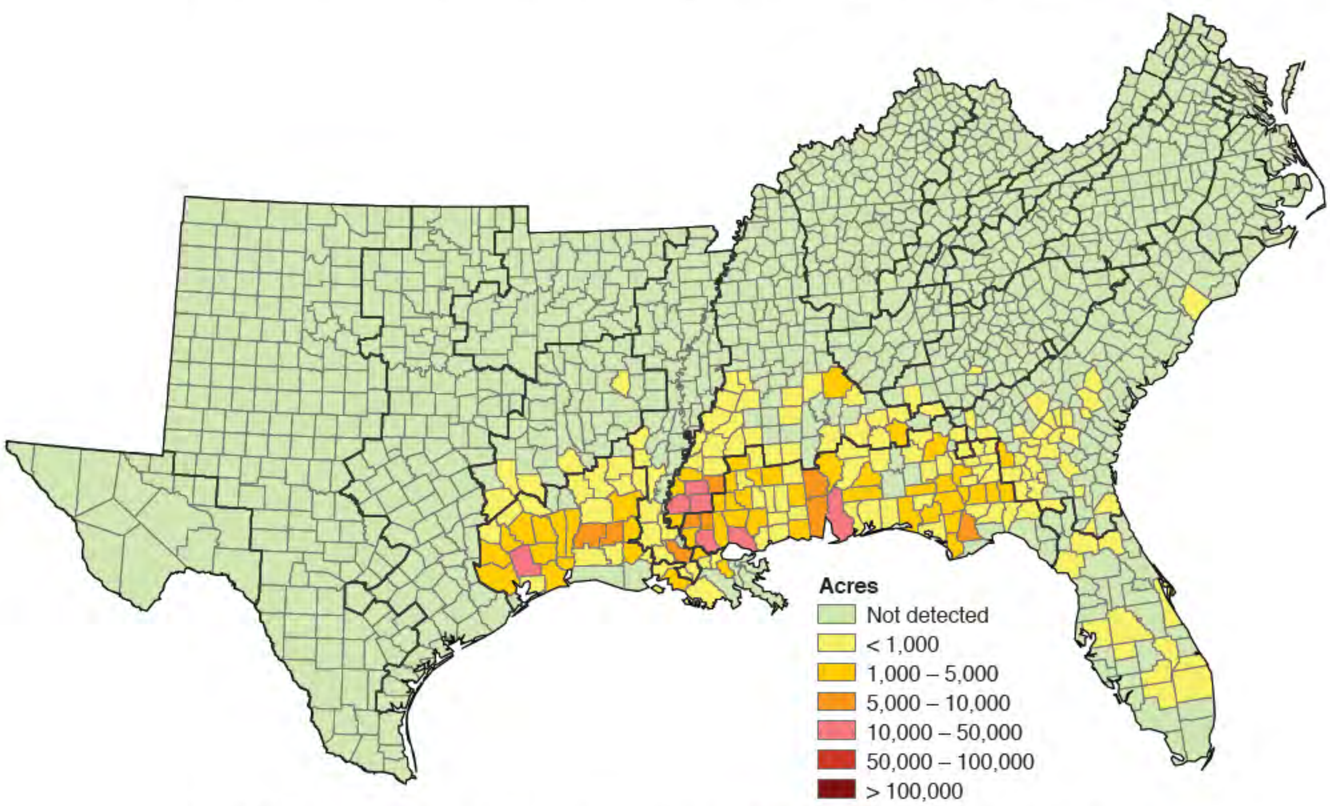


Figure 15.15—Japanese climbing fern: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Leaves have three leaflets with variable lobes, and leaflets have a unique capability to rapidly re-orient to maximize photosynthesis during the day or to droop showing their white hairy underside to decrease plant water use during droughts (Forseth and Termura 1987). Slender tight clusters of white and violet pea-like flowers appear in midsummer and yield clusters of dangling flat, hairy pods in autumn containing 1 to 20 seeds. Pods fall unopened and the viability of seeds across the region is highly variable due to the degree of insect predation. Kudzu colonizes by vines rooting at nodes (stolons) and spreads by wind-, animal-, and water-dispersed seeds, which are also known to hitch-hike on equipment. Large semiwoody tuberous roots with no vine buds reach depths of 3 to 16 feet on older plants. The target of eradication efforts is to deaden or remove a knot- or ball-like root crown on top of the soil surface where vines and roots originate.

Kudzu was promoted by Federal programs in the early 20th century to be planted on an estimated 3 million acres in the South (Forseth and Innis 2004, Miller and Edwards 1983). Seeds were imported from Japan until 1940, and then from other countries for the next 40 years (Tabor 1941), which explains the high degree of genetic variability across the region (Jewett and others 2003, Pappert and others 2000). Kudzu infestations are most numerous in Mississippi and Alabama, States that championed research, promoted landowners to plant this species in 1920 to early 1950s and provided seedlings and incentive funds for planting (O'Brien and Skelton 1946, Sturkie and Grimes 1939, Winberry and Jones 1973, fig. 15.16). The current distribution appears to reveal those counties that were most "successful" with these programs. Kudzu infestations occur in all States in the region (Forseth and Innis 2004), while occupation of this shade intolerant plant is less frequent within forests (table 15.1). Total kudzu cover in the southern region was estimated in 1997 to be about 2 million acres (Corley and others 1997), while we find only 226,889 acres currently on forested plots (table 15.1). Kudzu has been shown to be very responsive to future heightened carbon dioxide levels relative to other woody plants (Sasek and Strain 1988), which means projected spread rates could increase.

Invasive wisterias—Invasive wisterias (*Wisteria* spp.) form some of the most dense and impenetrable invasive plant infestations in the region, often originating from farmstead plantings (Miller 2003) to threaten most layers in a forest community (table 15.2). Chinese wisteria (*W. sinensis*) introduced into United States in 1916 and Japanese wisteria (*W. floribunda*) in 1830 (Dirr 1998) are deciduous high climbing, twining, or trailing leguminous woody vines with

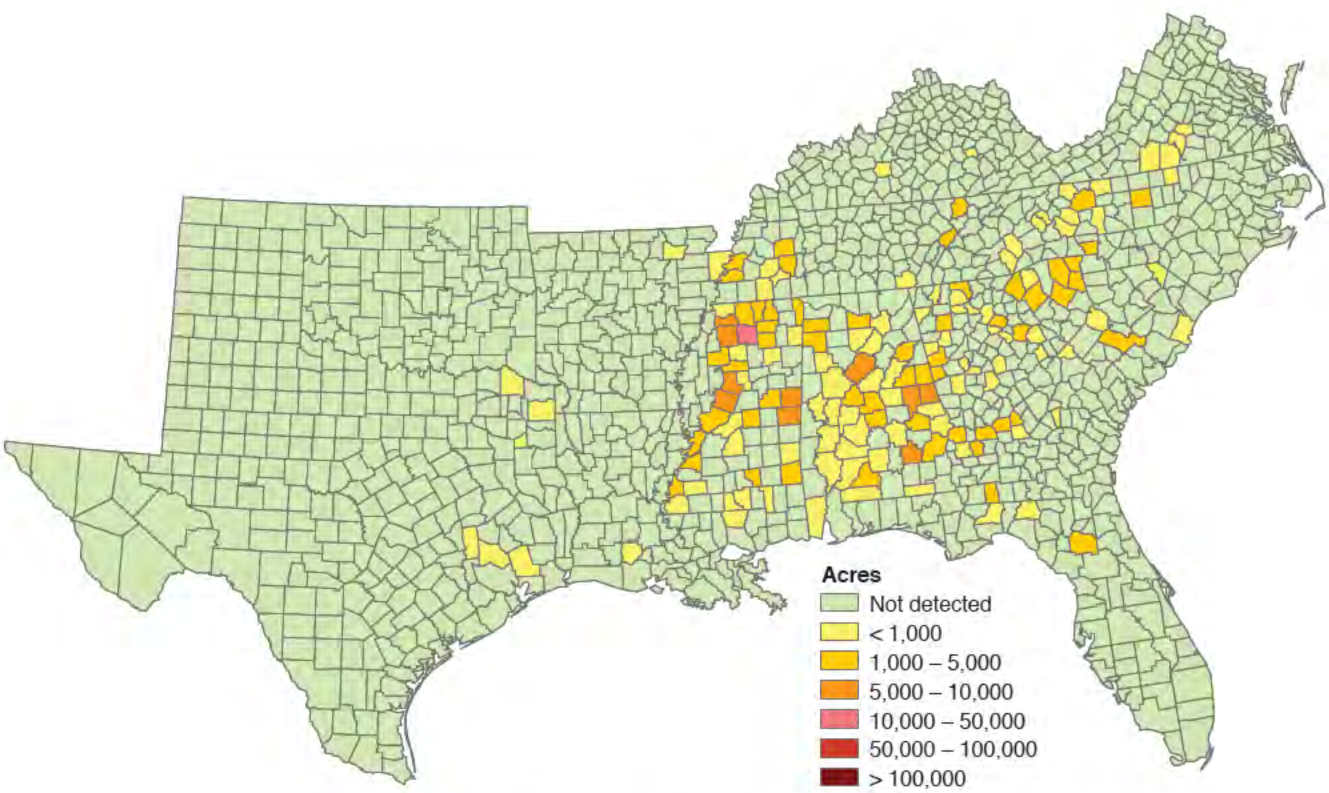


Figure 15.16—Kudzu: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

long pinnately compound leaves. Showy dangling clusters of lavender flowers appear in early spring before leaves that yield flattened hairy pods up to 6 inches long in autumn (Miller 2003). Both colonize by vines twining and covering shrubs and trees and by runners that root at nodes if they have been covered by leaf litter. They are only partially shade tolerant, with vines able to persist into deep shade only if parent plants are growing in open areas. Seeds are primarily water dispersed along riparian areas. Their large sized seeds resemble a dark brown lima bean and are highly poisonous, deterring animal dispersal (Turner and von Aderkas 2009). Genetic analysis shows that most specimens studied in the field are hybrids of the Chinese and Japanese species (Trusty and others 2007). Invasive wisterias are continually being hybridized by the plant industry with many varieties still sold and planted. They resemble the native or naturalized American wisteria (*W. frutescens*), which flowers in June to August after leaves develop and occurs throughout the region in wet forests and edges, sometimes forming large entanglements. Scattered dense infestations of invasive wisterias also occur throughout the region, but most are in the Coastal Plains and Piedmont (fig. 15.17). The current forest occupation of 57,129 acres is expected to increase to at least 77,795 acres in 50 years without concerted control measures (table 15.1).

Invasive ivies—English ivy (*Hedera helix*), Atlantic ivy or Irish ivy (*H. hibernica*), and colchis or Persian ivy (*H. colchica*) are evergreen vines that are difficult to constrain after establishment. They were introduced early in colonial times, while the escape of English ivy was not noted until the 1930s (Clarke and others 2006). They form dense ground cover and can climb to 90 feet by clinging aerial roots to encase trees (table 15.2). They have thick dark green leaves that are heart shaped with three to five pointed lobes when juvenile and that later become lanceolate and lobeless. Leaves are generally less than 3.3 inches wide for English ivy, up to 4 inches wide for Atlantic ivy, and 4 inches or more for colchis ivy. Mature plants at about age 10 have terminal flower clusters in summer that produce dark purple berries in winter that can be retained until spring. Their spread is by bird-dispersed seeds (Greenberg and Walter 2010), and they colonize through vines that root at nodes. All parts of the plant are toxic (even to humans), which discourages over consumption by birds. Contact with plant sap triggers dermatitis and sometimes severe blistering in sensitive individuals, which hinders hand removal (Turner and von Aderkas 2009).

Scattered infestations occur in the Coastal Plains and some in the Piedmont (fig. 15.17). Invasive ivies cover less than 30,000 acres but the infestations can be extremely

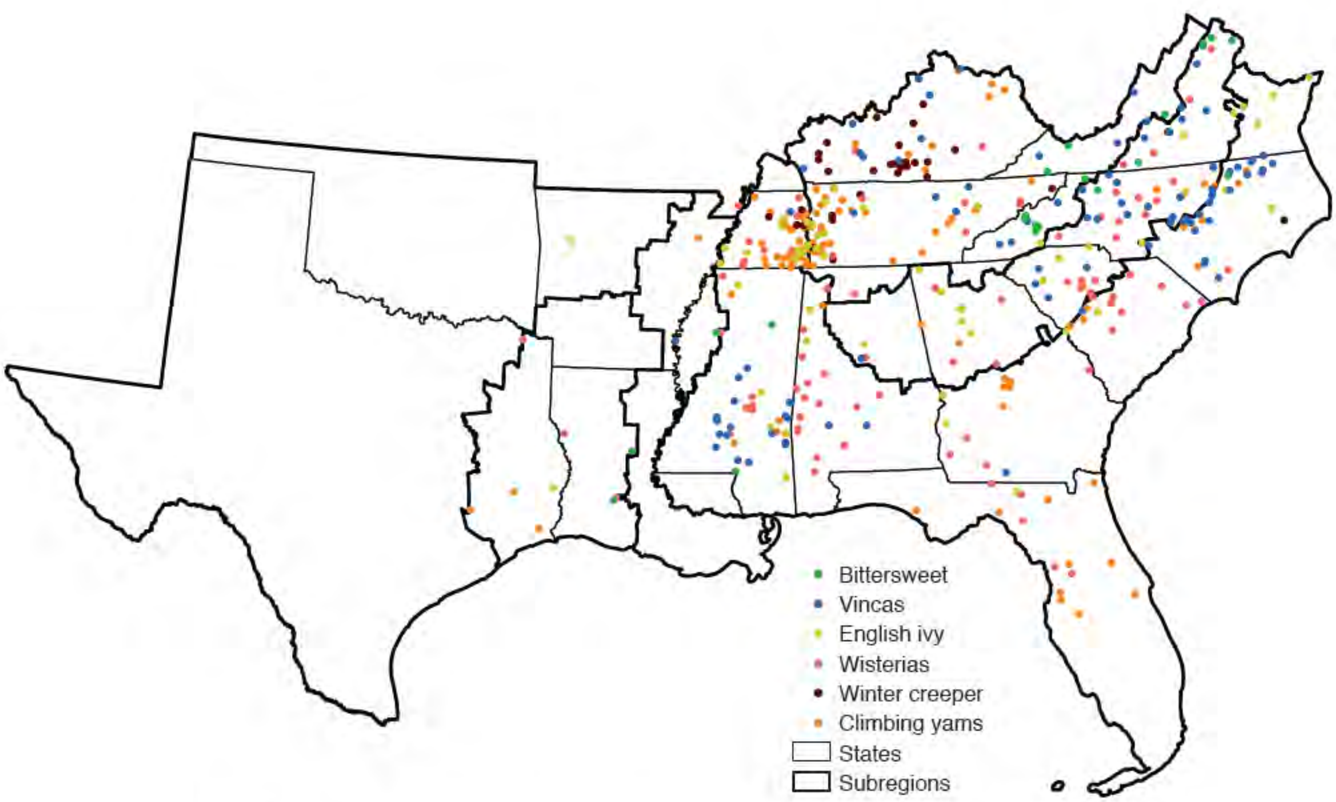


Figure 15.17—Oriental bittersweet, invasive wisterias, periwinkles, winter creeper, invasive ivies, and invasive climbing yams: current regional occurrence map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

dense, blocking introduction of native species (table 15.1 and 15.2). All are still widely produced, sold, and planted as ornamentals. Continued planting by landscapers and developers would accelerate spread at the same time that older plantings reach fruiting age.

Vincas, periwinkles—Periwinkles (*Vinca* spp.) were brought by European colonialists for their many medicinal purposes, but can also be poisonous if used inappropriately (Schittler 1973). Common periwinkle (*V. minor*), introduced in about 1711, and bigleaf periwinkle (*V. major*) in 1789 (Wells and Brown 2000) are evergreen, somewhat woody, trailing or scrambling vines to 3 feet long and upright to 1 foot, which form dense ground cover to exclude all native plants. They have thick opposite lance-to-heart-shaped leaves and five-petaled pinwheel-shaped violet single flowers. They can form mats and extensive infestations by vines rooting at nodes even under forest canopies, especially under deciduous hardwoods, usually near the site of original planting around farm houses. Viable seeds appear to be produced only rarely. Infestations originate from prior plantings and these species are still widely sold and planted as evergreen ground cover. Invasive vincas occur as scattered infestations that vary across States, probably because of historical sources and gardening practices. The highest concentrations are in Virginia, Kentucky, North Carolina, and Mississippi (fig. 15.17). Spread is expected to be slow, unless fertile hybrids appear (table 15.1).

Invasive climbing yams—One species of nonnative climbing yams—Chinese yam or cinnamon vine (*Dioscorea oppositifolia)*—is invading southern forests from the north and two others—air yam (*D. bulbifera*) and water yam (*D. alata*)—are moving northward from the Coastal Plain and Florida. All threaten forested parks and preserves by covering native plants (table 15.2). Water yam was introduced in the 17th century and may have arrived on slave ships from Africa while it became widely cultivated. It was noted as an escape in 1897 (Austin 1999). Air yam is believed to have been introduced before 1777 and was observed by the famous explorer botanist William Bartram in Mobile (Harper 1958). It escaped about 1905 (Morton 1976). Chinese yam was introduced in the 1800s (Flora of North America Association 2009) and believed escaped in the Carolinas after cultivation around 1900 (Rodgers and Shake 1965). Invasive climbing yams are herbaceous vines to 65 feet that cover shrubs and small trees in infestations (Langeland and others 2008, Mueller and others 2003). They have twining and sprawling stems with long-petioled smooth heart-shaped or shield-shaped leaves and dangling potato-like tubers (bulbils) that appear at leaf axils and drop to form new plants. Their aerial tubers spread down slope and by water, sprouting to form new plants, and they also have large underground tubers that hinder eradication. All three species are thought to rarely produce seeds. All vines die back during winter but can completely cover small trees the following year, with old vines providing trellises for regrowth.

Chinese yams are found scattered throughout the region with most common infestations occurring in western Tennessee and less common ones in Virginia; air and water yams occur along the Gulf of Mexico and throughout Florida (USDA Forest Service Natural Resources Conservation Service 2010) (fig. 15.17). All are difficult to control and contain because aerial tubers can persist in the soil. All were traditionally sold as unique ornamentals and readily escaped when fruits were discarded. Air yam and Chinese yams are still sold and their tubers and bulbils are prized as herbal diet supplements. Invasive vines with less than 21,000 acres of current forest cover, climbing yams are projected to increase by 45 percent in 50 years (table 15.1).

Winter creeper—Winter creeper or climbing euonymus (*E. fortunei*) has been planted as an ornamental since the 1907 introduction into the United States from China (Dirr 1998). It is an evergreen shrub to 3 feet in height or woody trailing vine to 40 to 70 feet that forms a dense ground cover, using aerial roots at nodes along stems to colonize and to cling to trees and rocks. Sensitive forest habitats, forested parks and preserves, and unmanaged forests are threatened by loss of diversity after invasion by winter creeper (table 15.2). It has thick leaves less than 2.5 inches long that are opposite, dark-green or green-white-variegated on green stems that become woody and brown with age. Clusters of small, inconspicuous flowers in summer yield pinkish-to-red fruit capsules that open in autumn to expose orange fleshy-covered seeds that are spread by birds, other animals, and water. Many cultivars are still widely produced, sold, and planted as ornamentals in a range of foliar colors, increasing the likely spread rate (table 15.1). Markets have traditionally been confined to the Northern States, although expansion into a more southern range should not be hindered under current climate conditions (Dirr 1998). The Cumberland Plateau in Kentucky and Tennessee has the most recorded occurrences of this species, and escapes from rural population centers continue to promote its spread across the region (fig. 15.17).

Old World climbing fern—Old World or small-leaf climbing fern (*L. microphyllum*), like Japanese climbing fern, is a climbing and twining, perennial viney fern to 90 feet in length, which only occurs in central Florida, escaping about 1960 (Langeland and Burks 1998). It covers shrubs and trees of all sizes and forms mats that are several feet deep (Volin and others 2004). Like Japanese climbing fern, it has lacy but not finely divided leaflets along green-to-orange-to-black wiry vines. Vines arise as long branches from underground wiry and black rhizomes that must be killed for eradication. Dead vines from previous years serve as trellises for reestablishment. This species persists and colonizes by rhizomes and spreads rapidly by wind-dispersed spores and spores carried on contaminated clothing or wildlife fur. Old World climbing fern has blanketed entire tree islands in the Everglades. Currently confined to central and south Florida, it is likely to steadily spread northward (Violin and others 2004), with coverage projected to almost double over the next 50 years (table 15.1). Several biological control insects are in various stages of testing.

Oriental bittersweet—Oriental bittersweet (*Celastrus orbiculatus*) is a popular ornamental vine in the Northeast and upper South, introduced in 1860 (Rehder 1940). The first noted escape in North Carolina was 1895 (Merriam 2003). It is a deciduous, twining, and climbing woody vine to 60 feet high with drooping branches in tree crowns. It forms thicket and arbor infestations (table 15.2) on disturbed sites mainly in the southern Appalachians (McNab and Loftis 2002). It has alternate elliptic-to-rounded leaves 1.2 to 5 inches long. Female plants have axillary dangling clusters of inconspicuous yellowish flowers that yield spherical fruit capsules that are green maturing to yellow. The capsules split in autumn to reveal abundant scarlet fleshy fruits, each with five seeds (Miller and others 2010a), that remain through winter at most leaf axils. It colonizes by prolific vines that root at nodes and seedlings from prolific seeds that have been spread throughout the winter, mainly by birds and possibly by other animals (Greenberg and Walter 2010). Wreaths made of vines covered in the showy fruit have been a traditional Appalachian folk craft item but, when discarded, they are often a source of new infestations.

Seeds are highly viable, germinating immediately even under dense shade and growing rapidly when exposed to light (Greenberg and others 2002) but only remaining viable in the soil for a single year (Ellsworth and others 2004). Oriental bittersweet resembles American bittersweet (*C. scandens*), which has terminal white flower clusters that produce orange fruit capsules and leaves that are usually twice as large but not among the flowers and fruit. Hybridization is occurring between the two species (Pooler and others 2002, White and Bowden 1947). At present, escape of oriental bittersweet can only be found around small towns and cities in North Carolina and Virginia with outliers in Mississippi (fig. 15.17). The widest occupation by this species is in Northern States. Spread projections for the South are based upon the current occupation and an estimate of date of escape. This estimate could be deceptively low because it is clear that oriental bittersweet is still in its early "lag" phase of forest invasion when occurrences are scattered and populations are low (table 15.1).

Invasive Grasses and Bamboos

Nonnative grasses and bamboos continue to spread along highway rights-of-way and gain access to adjoining lands. Because herbicide treatments of southern highways do not extend to the outer margins, they become an invasive plant "free-zone" and a conduit for rapid spread. Most invasive grasses are highly flammable, increasing fire intensity and subjecting firefighters to higher risk; and then spreading rapidly after a wildfire or prescribed burn. Invasive grasses have compromised wildlife management efforts because they have low general nutritive value and leave little room for native plants (Barnes 2007). Repeated applications of herbicides are required for control of invasive grass infestations often followed by establishment of native plants to suppress the grasses that survive.

Nepalese browntop—Nepalese browntop or Japanese stiltgrass (*Microstegium vimineum*) is the most widely distributed invasive grass in eastern forests. The earliest herbarium specimen collected for this species in the United States was found in 1919 by G.G. Ainslee along a creek bank at Knoxville, TN (Fairbrothers and Gray 1972). This is a sprawling, dense mat-forming annual grass even under forest canopies, 0.5 to 3 feet long with stems growing to 1 to 3 feet in height. It bends over and roots at nodes to form extensive entangled infestations that remain during winter dormancy. It has alternate, lanceolate leaf blades to 4 inches long with off-center veins and thin seed heads in summer and autumn. Hidden, self-pollinated seeds within leaf sheaves are produced in early summer. Each plant produces 100 to 1,000 seeds that can remain viable in the soil for up to 3 years (Barden 1987). It is flood tolerant and flourishes on the alluvial floodplains and streamsides where its seeds have been dispersed, mostly colonizing flood-scoured banks (Touchette and Romanello 2010). It is also common in forest edges, roadsides, and trailsides, as well as damp fields, swamps, lawns, and ditches. It spreads along trails and recreational areas by seeds hitchhiking on hikers' and visitors' shoes and clothes. It occurs up to 4,000 feet elevation and is very shade tolerant to invade partly shaded and fully shaded habitats (Flory and others 2007).

Nepalese browntop has been emigrating from the Northeastern States and therefore occurs mostly in the Appalachian-Cumberland and Piedmont subregions (fig. 15.18). Infestations also are concentrated in the deep silt bluffs west of the Mississippi River Alluvial Flood Plain where westward spread currently stops. Scattered infestations are popping up all across the region in every State. Linear spread projections are 10,000 plus acres per year (table 15.1). Estimates of spread rates with climate change scenarios are reported in a later section.

Tall fescue—Tall fescue (*Schedonorus phoenix*) is one of the region's most important forage crops for cattle and sheep with the discovery of the Kentucky 31 variety in 1931, even though it is a severe invasive in all other land uses. Tall fescue (formerly *S. arundinaceus*, *Lolium arundinaceum*,

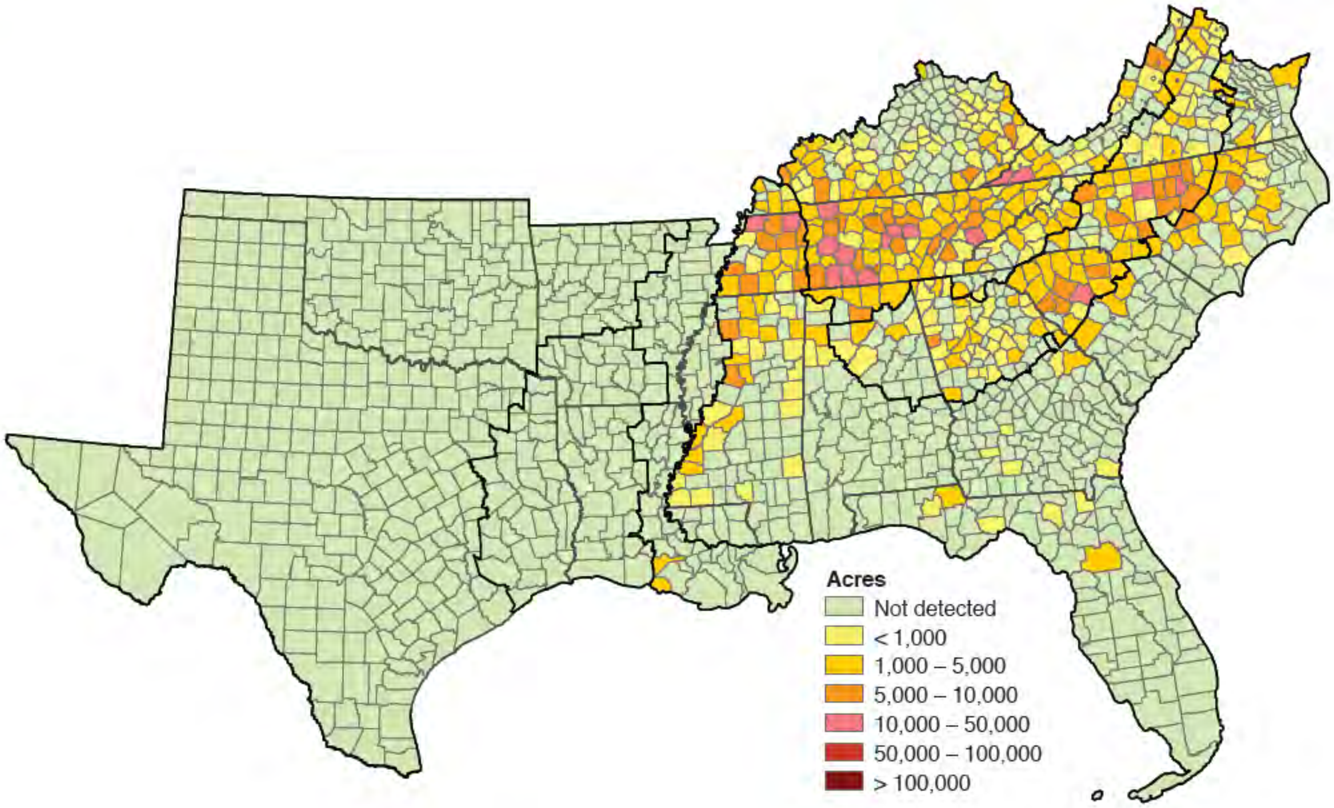


Figure 15.18—Nepalese browntop: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Festuca arundinacea, and *F. elatior*) is an erect, tufted cool-season perennial grass, 2 to 4 feet in height that occurs throughout the United States. It has whitish-eared areas where leaf blades connect to the stem, and each stem has one or two swollen whitish nodes. Dark-green seed stalks and leaves appear in late winter, usually flowering in spring (infrequently in late summer). This grass is dormant by midsummer. Most tall fescue is infected with a fungus that can reduce weight gains and lower reproductive rates in livestock (Ball and others 1993), while also adversely affecting the nutrition of songbirds and the Canada goose (*Branta canadensis*) (Conover and Messmer 1996). Tall fescue monocultures are generally poor habitat for wildlife, especially ground nesting birds (Barnes and others 1995) and vigorously compete with loblolly pine seedlings (Smith 1989). It is still sold and widely planted for soil stabilization, pastures, and reclamation, with many cultivars available. Tall fescue spreads by expanding root crowns, plantings, and somewhat less by natural seeding.

A cool season grass, tall fescue infestations are most severe in the forests of Kentucky, Virginia, and central Tennessee (fig. 15.19). Satellite populations are present throughout much of the South, with most congregated in the Coastal Plain of Mississippi and the Piedmont of South Carolina. Tall fescue is forecasted to remain the fourth most occupying invasive plant of forests in 2060 (table 15.1).

Cogongrass—Cogongrass (*Imperata cylindrical*) is one of the most aggressive, colony-forming invasive grasses in the region, a century after accidental introduction in southern Alabama (Dozier and others 1998). Dense swords or circular and linear infestations of cogongrass now occur along highway and utility rights-of-way and in preserves, pastures, prairies, hayfields, orchards, lawns, underused lands, and all forest types in eight Southern States along the Gulf of Mexico (Center for Invasive Species and Ecosystem Health 2010). The 66,000 acres currently recorded in forests (table 15.1) is a small component of a broader invasion (fig. 15.20). Cogongrass is a Federal and State listed Noxious Weed, and is considered to be one of the "World's worst 10 weeds" since it is invasive in most tropical and semitropical countries (Holm and others 1977, MacDonald 2004). There were at least three introductions of cogongrass into the United States. The first was an accidental introduction to Alabama from Japan in 1912, as packing material in a shipment of orange trees; and an intentional importation occurred in 1921 from the Philippines to Mississippi and Florida for forage testing (Dickens and Buchanan 1975; Tabor 1949, 1952). In about 1935, cogongrass was taken without authorization from

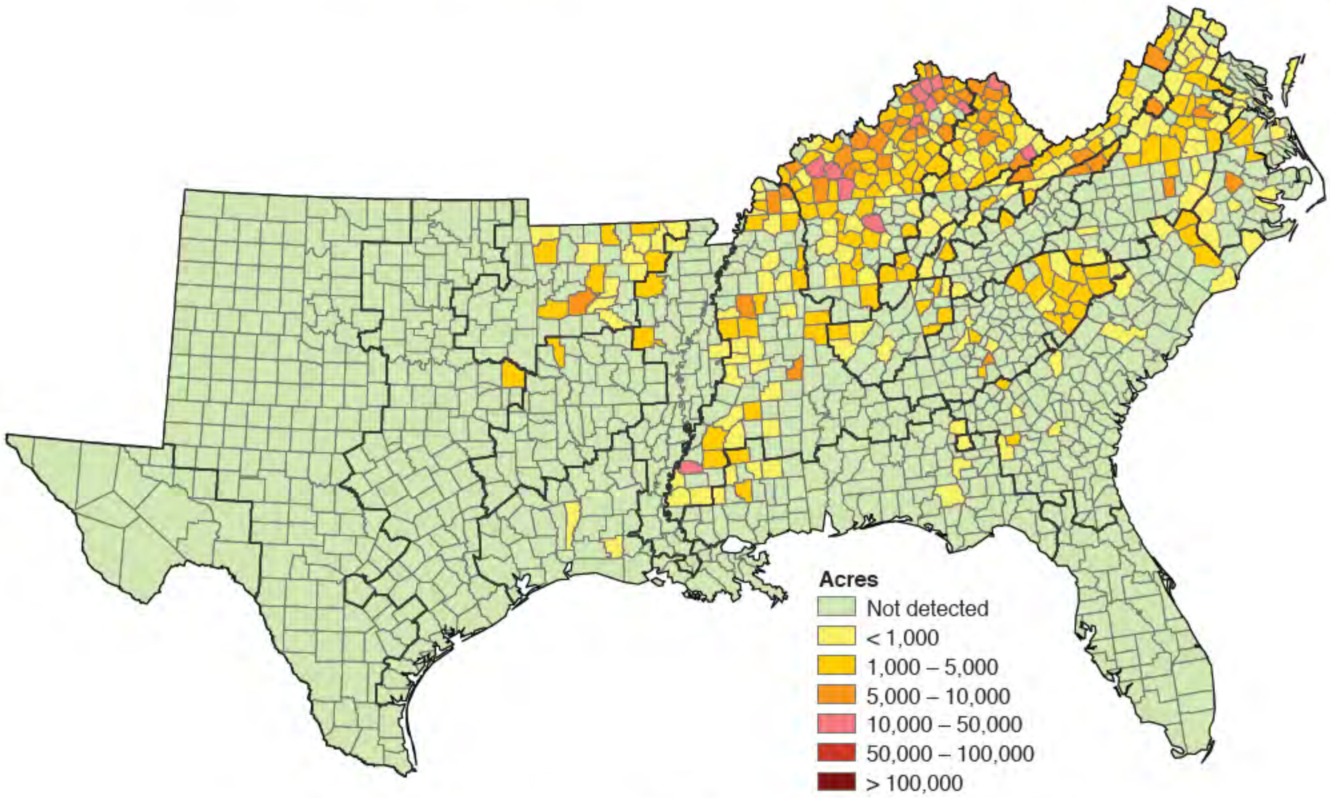


Figure 15.19—Tall fescue: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

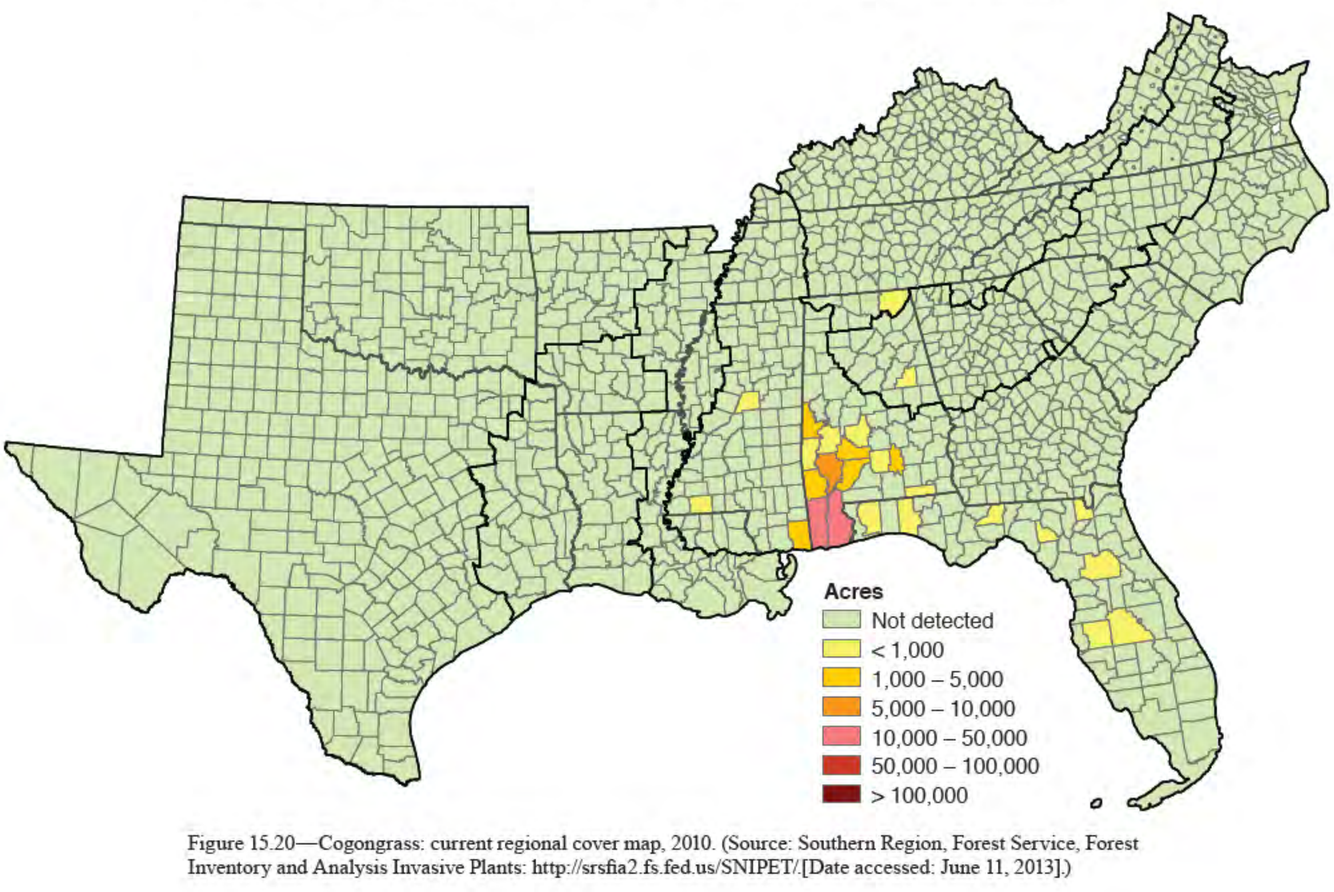


Figure 15.20—Cogongrass: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

the Florida Experiment Station at Gainesville and planted in northwest Florida for pastures and surface reclamation (Tabor 1949). In the 1990s red varieties were developed as ornamentals with cold tolerance for northern gardens and sold as "Japanese Blood Grass," "Rubra," and "Red Baron" (Greenlee 1992). Although no viable seeds have been reported for these red varieties, their viable pollen can impart cold tolerance to nearby invasive populations and reversion to aggressive green plants have been observed as far north as Idaho. In response, several Southern States prohibit the sale of these red varieties (Miller and others 2010b).

Cogongrass is a dense erect perennial grass 1 to 6 feet high with tufts of long leaves from short stems, yellow-green leaf blades (each with an off-center whitish mid-vein and finely saw-toothed margins), and silver-plumed flowers and seeds in spring (sporadically year-round after disturbance) (MacDonald 2004). Cogongrass leaf and inflorescence dimensions vary widely (Bryson and others 2010). Abundant plumed seeds are dispersed by wind and on contaminated clothing, equipment, and products like pinestraw mulch and fill materials. Seed viability is up to a year (Brook 1989). Cogongrass was found to occur on a full range of soils in Mississippi, which indicates that most southern soils can support this invasive plant unless they are permanently flooded (Bryson and others 2010, King and Grace 2000). Dense stands of dried plants remain standing during winter to prevent natural succession and present a severe fire hazard. Cogongrass can remain green year-round in central and southern Florida where infestations have been estimated at over a million acres (MacDonald 2004). Infestations form dense mats of underground stems with buds every one-half inch, making eradication difficult, because abundant shoot and rhizome buds usually sprout after treatment or lay dormant to sprout within months (Williard and others 1996). New invasions occur as circular patches; they are thought to become more difficult to control as they mature (Miller 2003). Federal and State funded control programs have been under way in all infested States for several years. These programs were upgraded in 2010 with Recovery Act funding and are aimed at stopping the spread by eradication of outliers and treating the advancing fronts and selected epicenter infestations in South Carolina, Georgia, Alabama, Mississippi, Tennessee, and Texas. Through these cooperative efforts all known infestations in Tennessee, Texas, and South Carolina are thought to have been eradicated in 2011.

The epicenter of cogongrass infestations remains near the point of initial introductions in coastal Alabama and nearby Mississippi with another in central Florida (fig. 15.20). These multiple introductions have gradually hybridized in South Alabama where fertile seeds are most common (Capo-chichi and others 2008). Because it thrives in the wide range of climates and habitats, northward spread is likely unless dramatic eradication efforts are undertaken (MacDonald 2004). The 60,000 acres infesting forest lands (table 15.1) is just a small percent of the total southern occupation on pastures, hay fields, natural preserves, and urban and rural home landscapes.

Golden and other invasive bamboos—Nonnative bamboos (*Phyllostachys* spp. and *Bambusa* spp.) form exclusive dense stands scattered throughout the region from past plantings. Golden bamboo, the mostly widely occurring species in the South, was first planted in Alabama in 1882 (Lady Bird Johnson Wildflower Center 2007). Invasive bamboos are perennial infestation-forming canes 16 to 40 feet in height. They have jointed cane stems and bushy tops of grass-like leaves in fan clusters on jutting branches, often golden-green. Plants rise from large branched rhizomes (underground stems) that must be killed for eradication. Infestations rapidly expand after disturbance through rhizome extensions. Seeds rarely, if ever are produced—potentially once every 50 to 100 years. Bamboos are still sold and planted as ornamentals and golden bamboo stems have value in Asia for construction, paper, fishing equipment, ski poles, javelins, irrigation pipes, musical instruments, furniture, and handles for umbrellas and fans (Barkworth and others 2007). Rivercane or switchcane (*Arundinaria gigantea* and other *Arundinaria* spp.) are the only native bamboo-like canes in the South, and are distinguished by a lower height—usually only 6 to 8 feet—persistent sheaths on the stem, and absence of long opposite horizontal branches. Invasive bamboos are actively being promoted as a potential biomass crop, but supporting research has yet to appear in scientific literature.

Invasive bamboos occur throughout the region in scattered dense infestations (fig. 15.21) on the edges of forests, fields, and rights-of-way—the result of past plantings over a 130-year period for various structural uses, fishing poles, and more recently as managed roosting sites for migrant black bird species that have been shown to be vectors for the human respiratory disease, histoplasmosis (Glahn and others 1994). The potential exists for a broad general flowering and seeding, which characterizes bamboo forests in their native ranges.

Chinese silvergrass—A locally invasive plant, Chinese silvergrass (*Miscanthus sinensis*) is a tall, densely tufted, perennial grass, 5 to 10 feet in height that grows from a perennial root crown. It has long, slender, and upright-to-arching slender leaves with whitish upper mid-veins and many loosely plumed panicles turning silvery-to-pink in autumn. Dried stalks, some with seed heads, remain standing with during winter, but seed viability is variable depending on cultivar and location. This species requires pollination by another cultivar to produce viable seeds and fertile offspring. This results in extensive infestations that

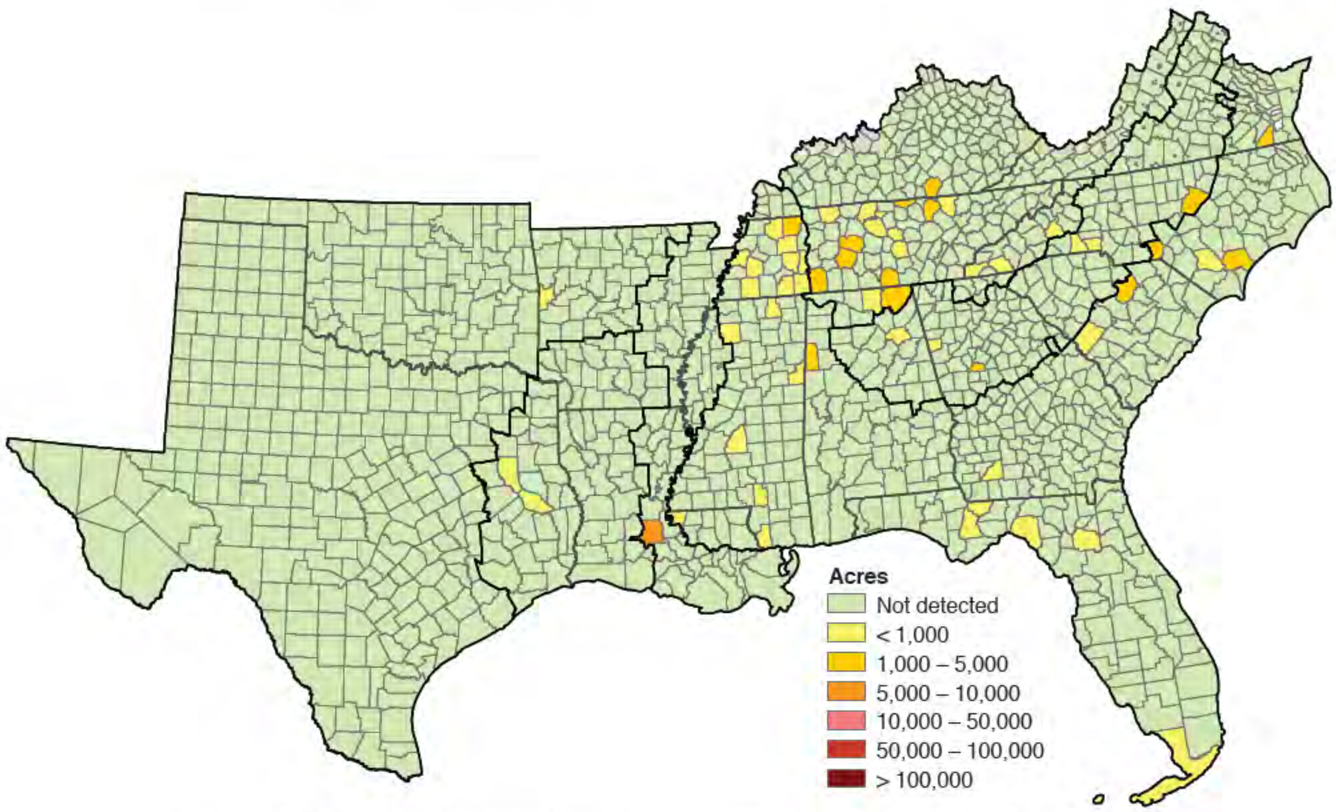


Figure 15.21—Invasive bamboos: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

escape along roadsides, forest margins, rights-of-way, and adjacent disturbed sites, especially after burning. Although introduced in 1904, escaped plants were not noted until 1957, in waste areas and tidewater in the Virginia and Maryland Piedmont. (Gilman 1957). Proposed widespread plantings of hybrids and giant silvergrass (*M. xgiganteus*) for biomass and biofuels could result in aggravated problems. Infestations, although they occur as dense monocultures, have only been found in scattered locations (fig. 15.22), with an epicenter in eastern Kentucky.

Nonnative Forbs

Forbs are broadleaf herbaceous plants that usually reproduce by seed and can be perennial with root crowns that persist over winter. Invasive forbs form dense monocultures that hinder or stop forest regeneration and plant diversity (table 15.2). Control treatments are usually by foliar spraying of herbicides. Persistent seeds in the soil and underground stems and rhizomes make control a lengthy and exacting process that involves eradication and rehabilitation.

Garlic mustard—Garlic mustard (*Alliaria petiolata*) is an upright cool-season biennial forb that is shade tolerant and increasingly occurs in small-to-extensive colonies under forest canopies and along roadsides in the Central Appalachians and the Northeastern United States (Meekins and McCarthy 2001, Rogers and others 2008, Shuster and others 2005). Even without bare soil (Slaughter and others 2007), it can become established and form dense infestations of basal rosettes and broadly arrowhead-shaped leaves with wavy margins in the first year (remaining green during winter). The second year produces 2- to 4-foot stalks with terminal clusters of self-fertilizing small white flowers that yield stalks of many upward jutting thin pods 1 to 5 inches long (Drayton and Primack 1999). The plant dies after June, and its pods ballistically broadcast their seeds up to 10 feet, with seedlings germinating in spring. The average spread from one plant has been measured at 18 feet per year (Nuzzo 1999), but farther distribution also occurs by water and when seeds cling to humans and animals. Seeds can lie dormant for 2 to 6 years (Drayton and Primack 1999), which prolongs the period of control.

Stand density varies yearly depending on germination requirements of seeds in the soil seed bank, with a single crop germinating over a 2- to 4-year period. Persistent infestations exclude most herbaceous cohorts probably by the release of inhibitory chemicals in tops and roots (Roberts and Anderson 2001, Vaughn and Berhow 1999). Foliage has been shown to also produce chemical barriers to feeding by a select group of larval insects (Renwick and others 2001).

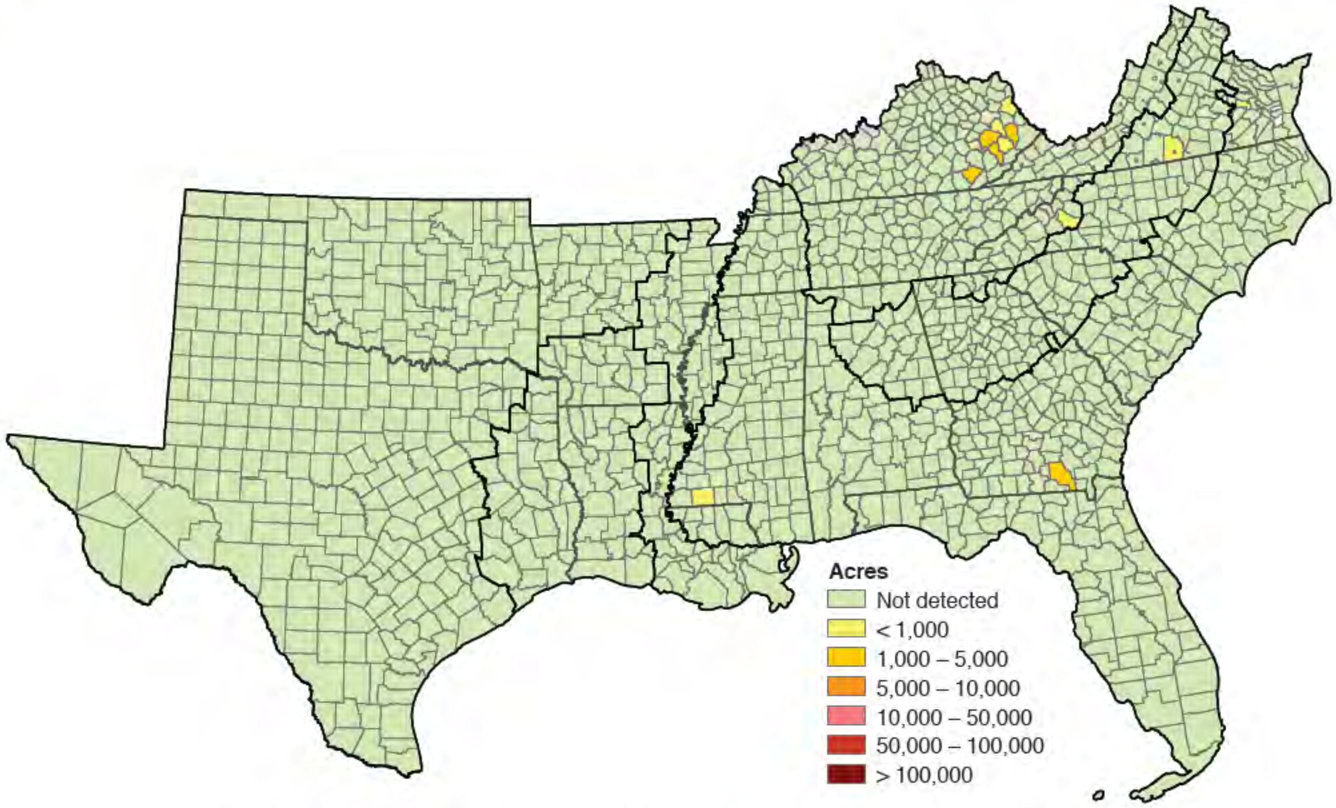


Figure 15.22—Chinese silvergrass: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

Current data show high infestations in scattered counties of the Appalachian-Cumberland highlands with outliers in northern Coastal Plain areas west of the Mississippi River (fig. 15.23). The current 6,000 acres is projected to increase by 45 percent in 50 years (table 15.1).

Other Invasive Plants in the South

These 35 groups, although the most prevalent now, are only part of the more than 300 terrestrial invasive plants in the South in various phases of spread (Miller and others 2010a). Many of the other invasive plants, although not as formidable, threaten special habitats and will combine to form exclusive invasive communities, like those that comprise our common lawns and roadsides.

Projected Increases in Infestations

Invasive plants cover more than 19 million acres of forests in all Southern States and are spreading at an average rate of 147,000 acres per year (table 15.1). Over half of all infested forested lands have Japanese honeysuckle (10.3 million acres), a common companion of many other invasive species. Privet species are the second most pervasive invasive plants, followed by Nepalese browntop and tall fescue grasses. The invasive lespedezas, tallowtree, and invasive roses, each occupies over 700,000 acres. Several other invasive species currently capture over 100,000 acres: tree-of-heaven, chinaberrytree, bush honeysuckles, Japanese climbing fern, and kudzu (table 15.1). By growth form, vines have the greatest coverage at 11 million acres (led by Japanese honeysuckle), followed by shrubs at 4.9 million acres, grasses at 1.8 million acres, and trees at 1.2 million acres (table 15.1). The only invasive forb covered here, garlic mustard, covers 6,000 acres.

A simple linear projection of occupancy by invasive plants in 2060 forecasts an approximate 40 percent increase with coverage of 26.6 million acres. Japanese honeysuckle is expected to cover over 13.5 million acres. Because of the tendency for multiple occupancy by invasives, Japanese honeysuckle is forecasted to entangle 4 million acres of privets with 353,000 acres of kudzu. Based on the regressions, the invasive with the largest projected spread is tropical soda apple at 227 percent, followed by winged burning bush at 167 percent, and Old World climbing fern, sacred bamboo, and Chinese silvergrass, which will double in coverage. Several others are predicted to increase by

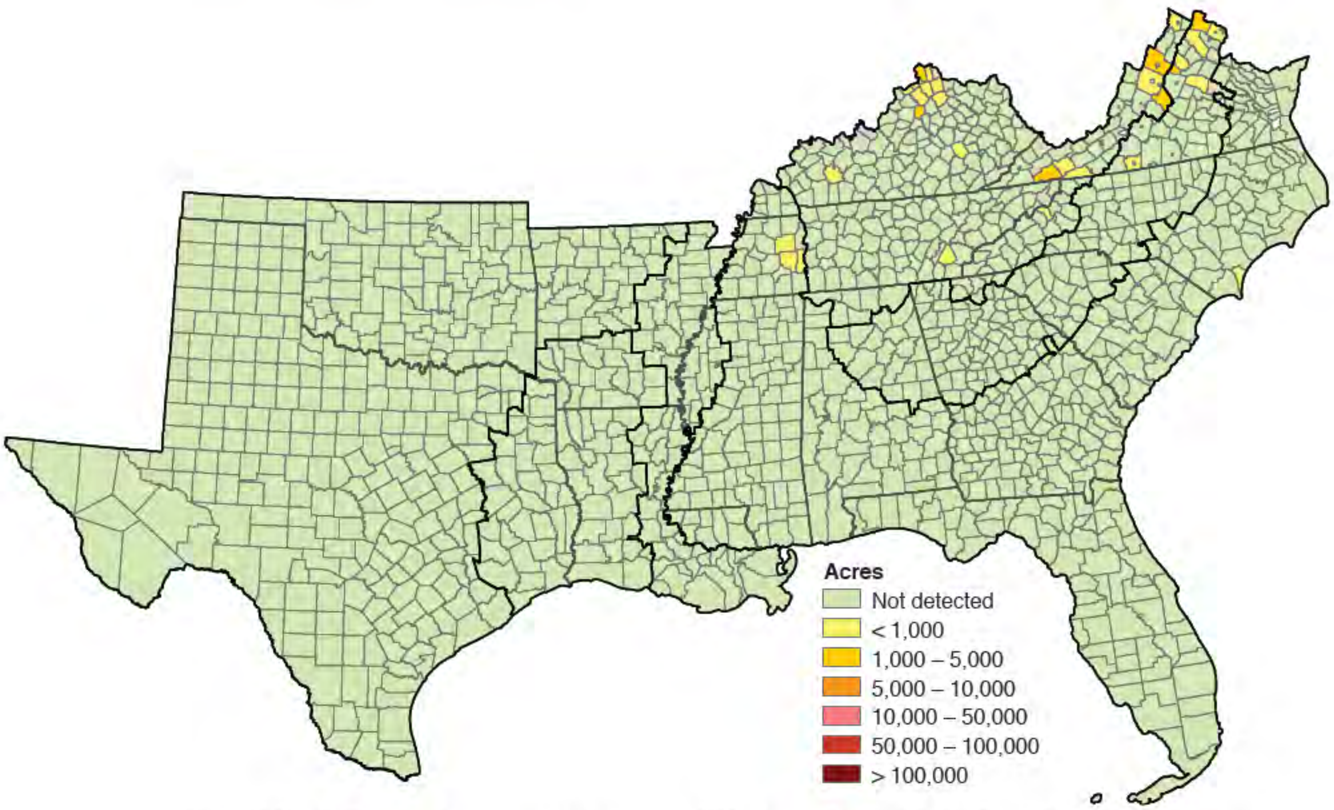


Figure 15.23—Garlic mustard: current regional cover map, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/.[Date accessed: June 11, 2013].)

about 60 percent: melaleuca, bush honeysuckle, invasive elaeagnus, sacred bamboo, winged burning bush, tall fescue, cogongrass, and Chinese silvergrass.

Geographic Distribution of Infestations

Figure 15.24 shows the percent of counties that are occupied by one to four invasive plants. Counties with the highest occupations occur in the long inhabited and highly disturbed mining regions of north central Alabama in the Southern Piedmont, extending north into central Tennessee's Interior Low Plateau, and northeast along the Southern Ridge and Valley of the Appalachian-Cumberland highlands. Invasive species were planted in the past and continue to be used for reclamation because of their tolerance to difficult site conditions. From the 1920s through the 1960s, Federal programs encouraged the planting of invasive species on erodible and eroding soils on the over-farmed lands in the Black Belt Prairie across central Alabama and northwestern Mississippi, the Southern Appalachian Piedmont in northern Georgia, and the Middle Gulf Coastal Plain in Mississippi, Alabama, and north Georgia. The abundance of invasive plants in South Carolina stems from a long-standing tradition of producing, promoting, and planting invasives for soil stabilization and wildlife habitat improvement. Other scattered highly infested counties occur as testament to the long-term "success" of government cost-share and incentives programs aimed at promoting nonnative invasive plants for a multitude of purposes.

Model Predictions of Current and Future Potential Habitat

The predictive models for five invasive plants of high threat indicate their current potential range and intensity could be greater than their current occupation. This means that none of these species have spread to all suitable habitats and are limited by vectors (figs. 15.26, 15.28, 15.30, 15.32, and 15.34). The extent of their spread will be influenced by a number of factors (table 15.3).

Tallowtree—A subtropical-to-temperate species, tallowtree is likely to be limited in its northern range by minimum temperatures (Dirr 1998). The modeled distribution of tallowtree had high AUCs and low omission rates, suggesting a strong model. The model for the potential distribution if current trends continue (figs. 15.1 and 15.25) indicates that further spread is possible along the Atlantic Coast into North

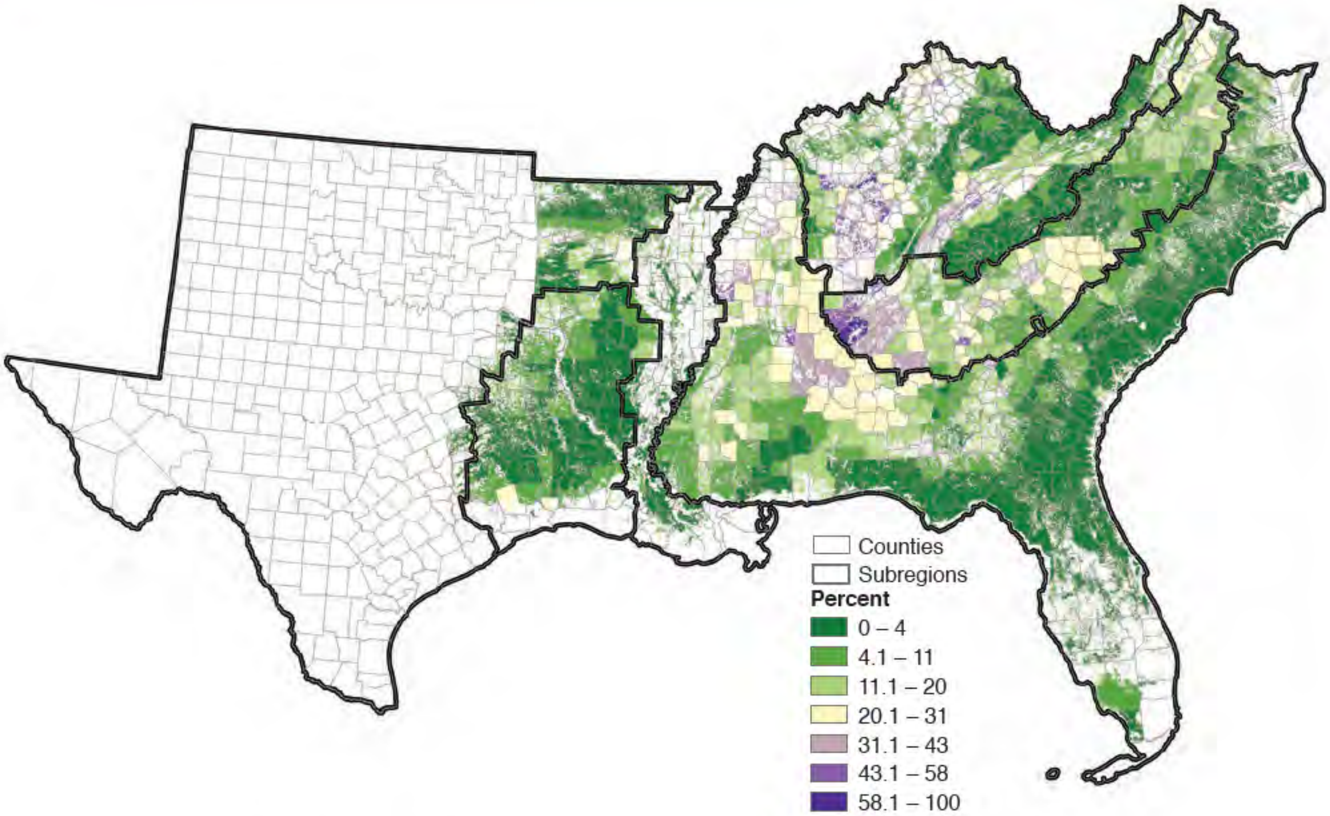


Figure 15.24—Percent of survey plots within a county occupied by one to four invasive plants, 2010. (Source: Southern Region, Forest Service, Forest Inventory and Analysis Invasive Plants: http://srsfia2.fs.fed.us/SNIPET/. [Date accessed: June 11, 2013].)

Table 15.3—The contribution weight and direction for significant variables by species used in modeling the potential for invasion (+ positive relationship, - negative relationship, ∩ binomial, N polynomial)

Variable (unit)	Variable range of data	Tallowtree	Silktree	Roses	Japanese Climbing Fern	Nepalese Browntop
Mean minimum temperature in Jan. (°F)	6 – 65	∩	-	-	∩	∩
Mean annual rainfall (inches)	9 – 104	+	∩		∩	N
Elevation (feet)	0 – 6900	-	∩	-	-	-
Distance to interstates (mile)	0 – 17.8		-			
Distance to roads (mile)	0 – 5.75		-			
People per square mile	0 – 2676		∩			
Proportion of forest in county (percent)	0 – 100		+			∩
Proportion of pasture in county (percent)	0 – 100			+		

Contribution to the model

- Dominant (50 to 100 percent)
- High (20 to 50 percent)
- Moderate (10 to 20 percent)
- Low (5 to 10 percent)

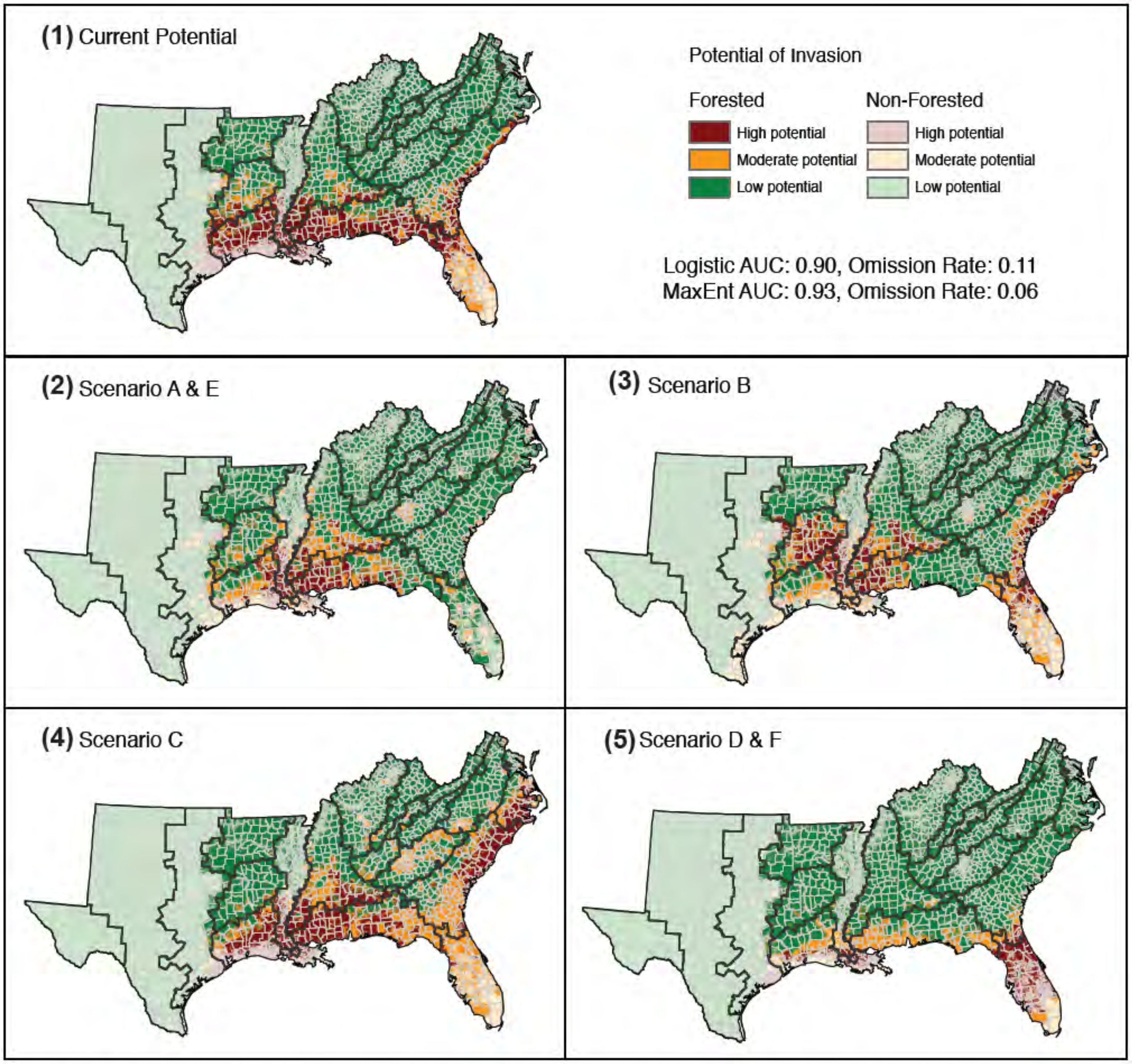


Figure 15.25—Tallowtree: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) cooling and drying conditions, Cornerstones D and F.

Carolina, across northern Florida and southern Georgia, and in the Black Belt Prairies across central Alabama and northwestern Mississippi—with specimen trees already reported for southern North Carolina and southern Arkansas (North Carolina State University 2010). Tallowtree's western limits in Texas appear to have been reached, and northward migration from the Gulf of Mexico is unlikely under current conditions. However, the density of cover across the South has a high potential to increase from the current three percent of forests occupied to 20 percent (fig. 15.26), with a 43 percent increase within the Mississippi Alluvial Valley, and a 33 percent increase in the Coastal Plain, particularly north Florida. The model identified three main variables that influence the occurrence of tallowtree (table 15.3). Mean minimum temperature in January was the strongest, followed by elevation and annual rainfall greater than 40 inches. Minimum temperature represents 42 percent of the model for tallowtree, with ranges below 30 °F and above 50 °F diminishing the likelihood of occurrence, while higher elevations decrease the probability of tallowtree. Gan and others (2009) also found elevation and minimum temperature to be prime variables and reported no occurrences on plots with temperatures below 10 °F and none above 500 feet elevation. And a common garden experiment (Pattison and Mack 2009) showed that tallowtree seeds can germinate and grow in temperatures as low as 25 °F. These results suggest that our model may be a little conservative.

With moderate-to-maximal warming of the South (fig. 15.26) described in chapters 2 and 3, the potential for tallowtree is expected to be greater than its current occupation (Cornerstones A, B, C, and E). With the exception of those that predict decreasing minimum temperature (Cornerstones D and F), all futures would permit a slightly more northerly distribution (fig. 15.25)—an outcome supported both by Gan and others (2009) and by Pattison and Mack (2008). Under the Cornerstones that predict reduced rainfall along the Gulf of Mexico (A, E, and B), tallowtree would have a more limited distribution but would still be more than twice its current potential (table 15.3). With the land-cover variables used in this model, tallowtree is absent only at the extremes: in areas of very low urbanization and pasture, and at the upper extreme, in areas with more than 65 percent urbanization or 85 percent pasture.

Under the significantly warmer and drier climate of Cornerstones A and E, tallowtree could move up the Mississippi Alluvial Valley but would remain in Mississippi and Alabama, with decreased rainfall reducing the potential for occupation eastward into Florida, and along the Atlantic Coast. The moderate warming and similar rainfall to current

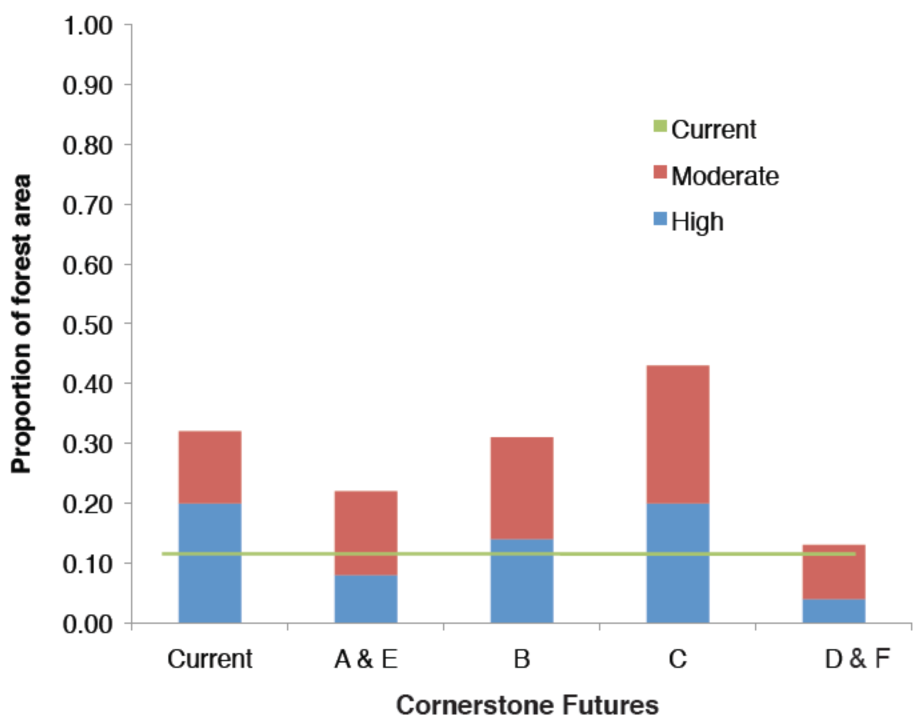


Figure 15.26—Tallowtree: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

in the mid-Mississippi valley, Florida and along the Atlantic Coast under Cornerstone B would allow tallowtree to exist in these locations. A predicted drier zone in Coastal Alabama and along northern Florida would nullify invasion potential in these areas. The areas of increase potential are related to rainfall. Cornerstone C would have the largest potential distribution of tallowtree with high or moderate potential of occurrence on 43 percent of forestland (fig. 15.26), a range that could expand westward from the Atlantic Coast and northward from the Gulf of Mexico, and an increase in inland pockets with medium potential. Cornerstones D and F, with decreasing minimum temperatures and a slightly drier Gulf Coastal Plain would have the lowest potential distribution (13 percent, combined higher and moderate potential), but still higher than the current occupation. Similar local conditions as now would confine tallowtree to Florida and the coastal areas of Alabama, Mississippi, and Louisiana.

Silktree—Our model for silktree was one of the weakest, but was still statistically significant with AUC of 0.75 and 0.80 and omission rates of 0.15 and 0.26. Seven variables had moderate contribution (table 15.3), ranging from 6 to 25 percent. A number of these variables, such as proximity to roads, were not addressed when the Cornerstones were developed, reducing the confidence in predictions. The two strongest variables were temperature (24 percent) and distance to interstates (25 percent). Silktree has some tolerance to cold weather but cannot withstand winters below -5 ºF (Dirr 1998). Herbarium specimens have been collected from throughout the region except south Florida, which supports the current potential range (fig. 15.27). Its current preference to roadways is widely evident, both visually when driving and by its web-like pattern of potential occurrence on the maps (fig. 15.27). The next most dominant variables are rainfall at 14 percent and elevation at 13 percent contribution (fig. 15.28). These variables have a binomial relationship, with silktree preferring intermediate levels for both. Under all Cornerstones, silktree showed much greater potential (16 to 28 percent at high potential) than its current occupation of 2 percent (fig. 15.28). Compared to the status quo prediction, potential would diminish under Cornerstones A, E, and B, primarily of increasing temperatures and decreasing rainfall, The current potential distribution range would push, but not extend, the range northward. Under the minimal decreases in rainfall of Cornerstones C, D, and F the potential of silktree increases the most compared to the current potential, although by only a few percentage points. It is clear that silktree thrives with human habitation and the roadway systems that will likely increase.

Invasive roses—Invasive roses currently predominate in the upper portion of the South, with a few areas scattered through the Coastal Plain and in the Black Belt Prairie across central Alabama and northwestern Mississippi (fig. 15.7). Of the five species modeled, roses had the highest occurrence on forested FIA plots (5 percent). They include a number of species with the principal one being multiflora rose (Miller and others 2010a), which is also one of the most pervasive invasive plants in the Midwest and Northeast United States and Ontario. The model drops out Macartney and Cherokee roses, which are concentrated in Louisiana and the Black Belt Prairie across central Alabama and northwestern Mississippi (figs. 15.7 and 15.29). The statistics on the models show they are reasonable with AUCs of 0.86 and omission rates of around 0.15. The model is highly influenced by minimum temperature, which is different for multiflora and the more southern adapted Macartney and Cherokee roses which were selected, bred, and widely planted for this reason. The status quo model predicts that 40 percent of the forests in the South have a high to moderate potential of habitats suitable for invasive roses (fig. 15.30). In the Appalachian-Cumberland highlands, this potential increases to 90 percent of forests. The model is dominated by a strong negative relationship (63 percent) to minimum temperature and a weaker negative relationship (12 percent) to elevation (table 15.3). Field observations show heavy infestations in high-elevation plots along the Blue Ridge Parkway in North Carolina, raising questions about the true elevational relationships. The only other variable with a reasonable contribution to the model is the positive relationship to the amount of pasture in a county (table 15.3). This is also supported by findings of Glasgow and Matlack (2006) that a higher percentage of pasture lands increases the expectation for invasive roses. Federal and State programs from 1930 to 1950 promoted the planting of multiflora rose as a "living fence" around pastures, where it eventually spread into pastures (Bergmann and Swearingen 2009). It is possible that such planting at high elevations predated the construction of the Blue Ridge Parkway on lands reclaimed from subsistence farming (and presumably grazing), explaining the difference between model output and field results.

Under the cooling of minimum winter temperatures of Cornerstones D and F, the potential for occupation gets as high as 87 percent (fig. 15.30). The potential distribution of invasive roses is smaller than the current potential under all other Cornerstones. With the warmer Cornerstone C, the potential (4 percent) all but disappears, falling below the current occupation level (fig. 15.30).

Japanese climbing fern—Japanese climbing fern currently occurs on 4 percent of FIA plots in northern Florida and southern Louisiana, Mississippi, Georgia, and Alabama (figs. 15.15 and 15.32). The prediction of current potential shows moderate expansion into Florida with a few isolated areas further up the Atlantic Coast (fig. 15.31), a sizable increase of 18 percent at the high potential and 10 percent at the moderate potential (fig. 15.32). This model was one of the strongest (AUCs of over 90 and omission rates near

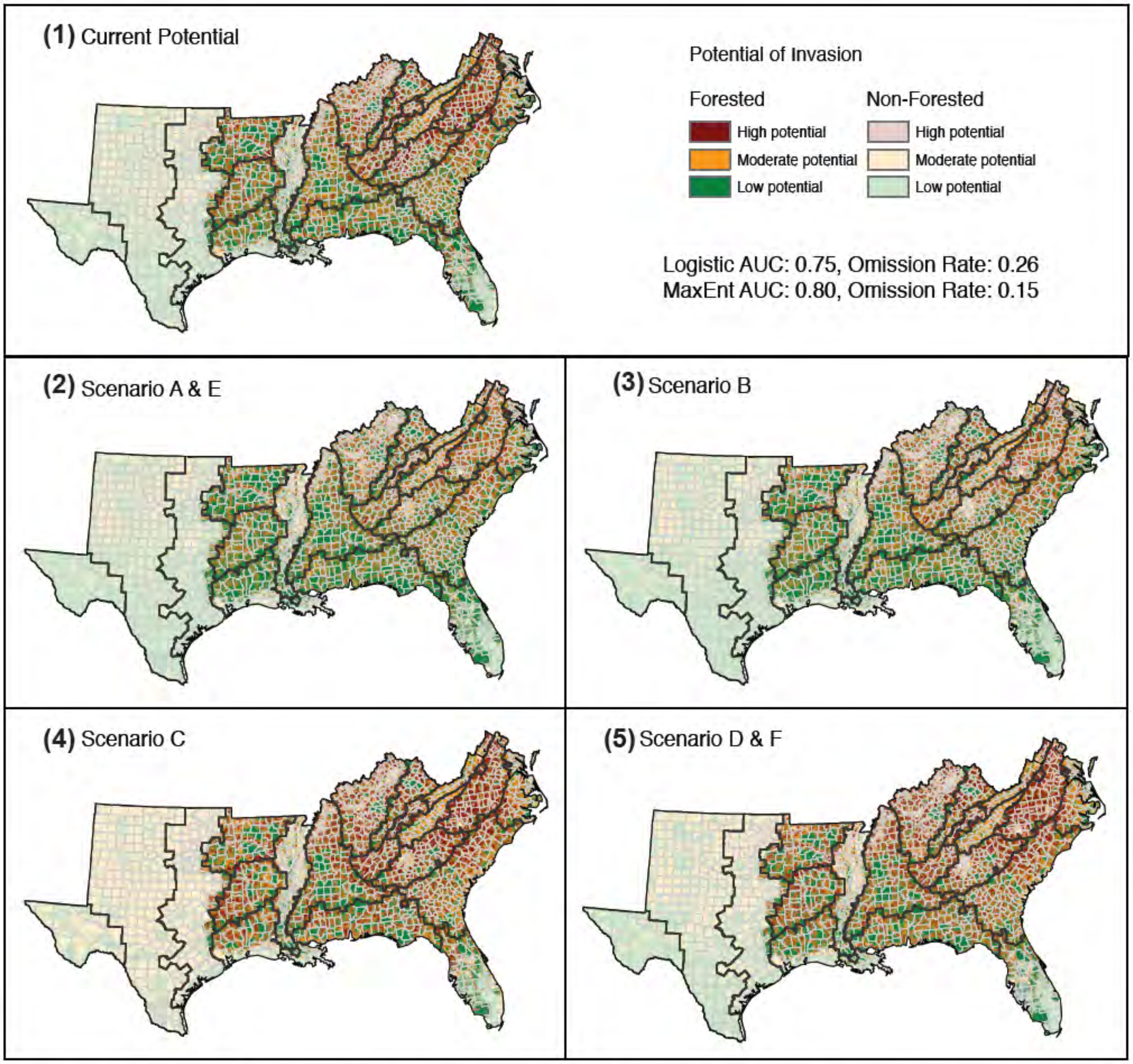


Figure 15.27—Silktree: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

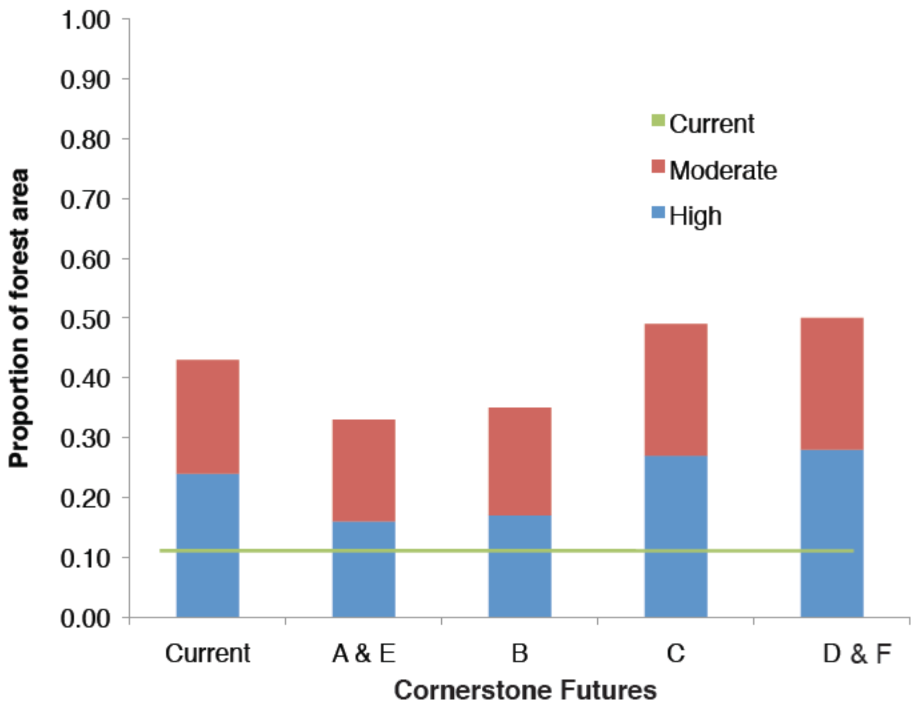


Figure 15.28—Silktree: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

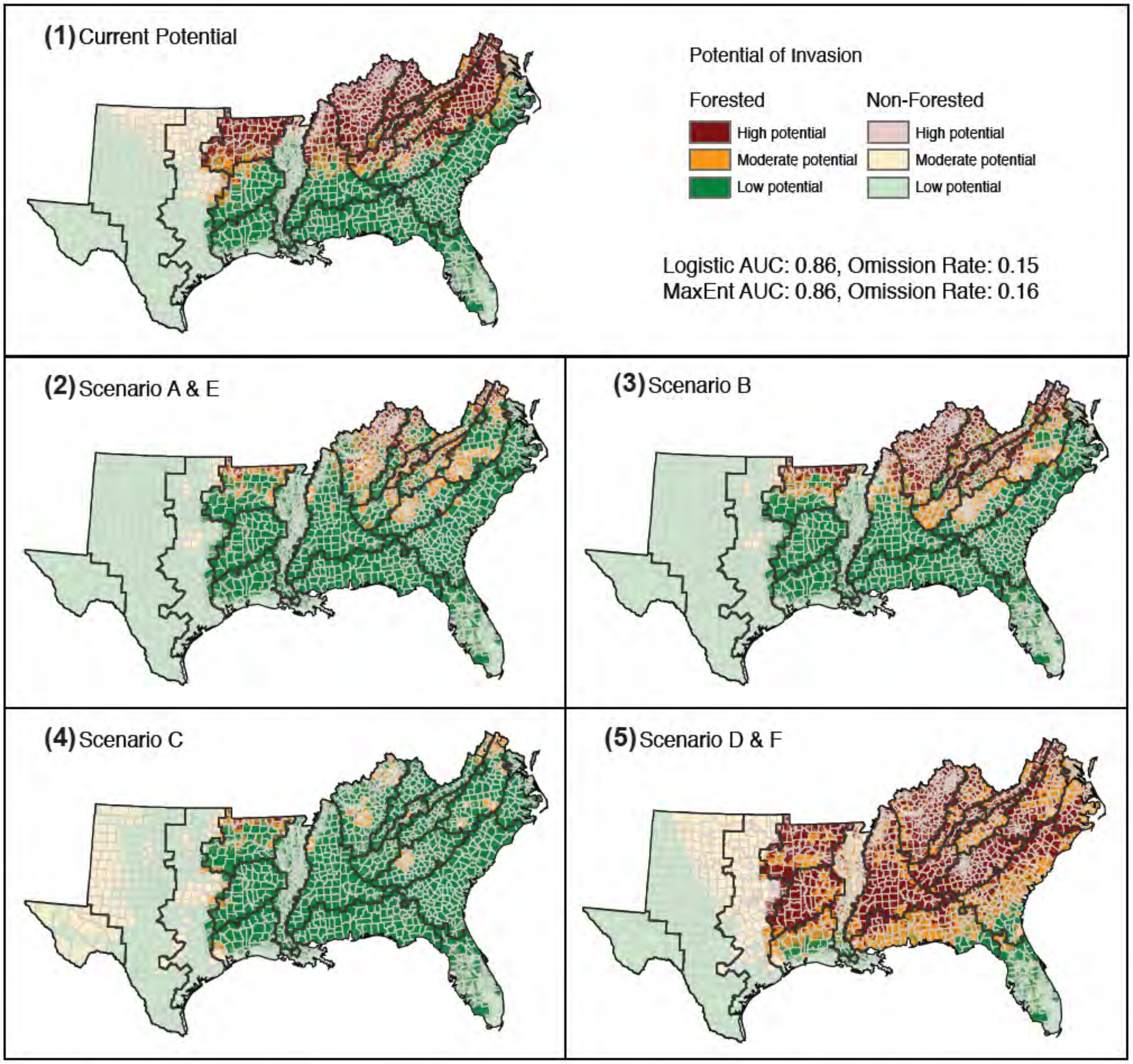


Figure 15.29—Invasive roses: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

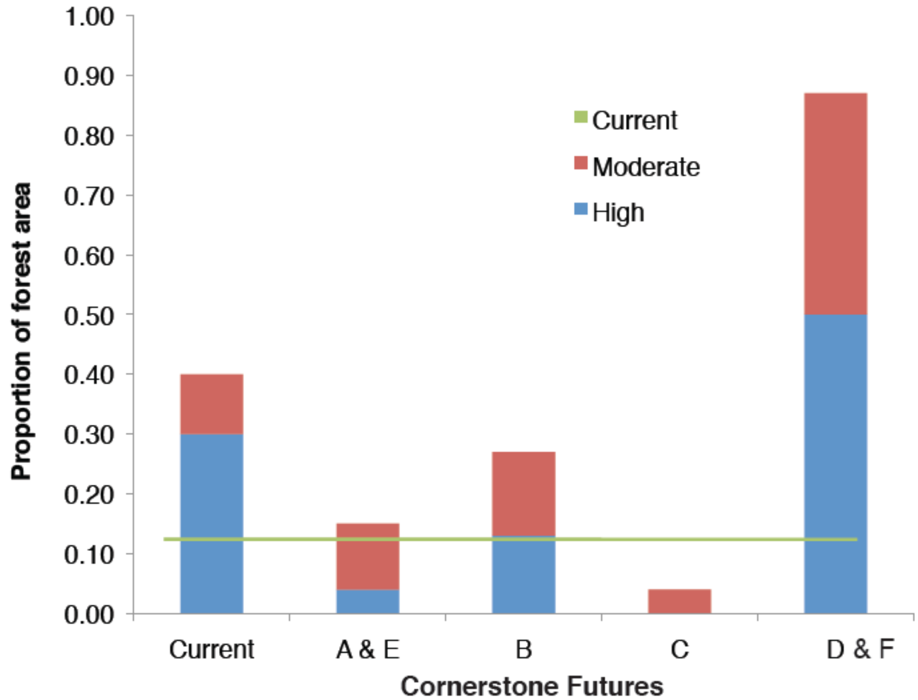


Figure 15.30—Invasive roses: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

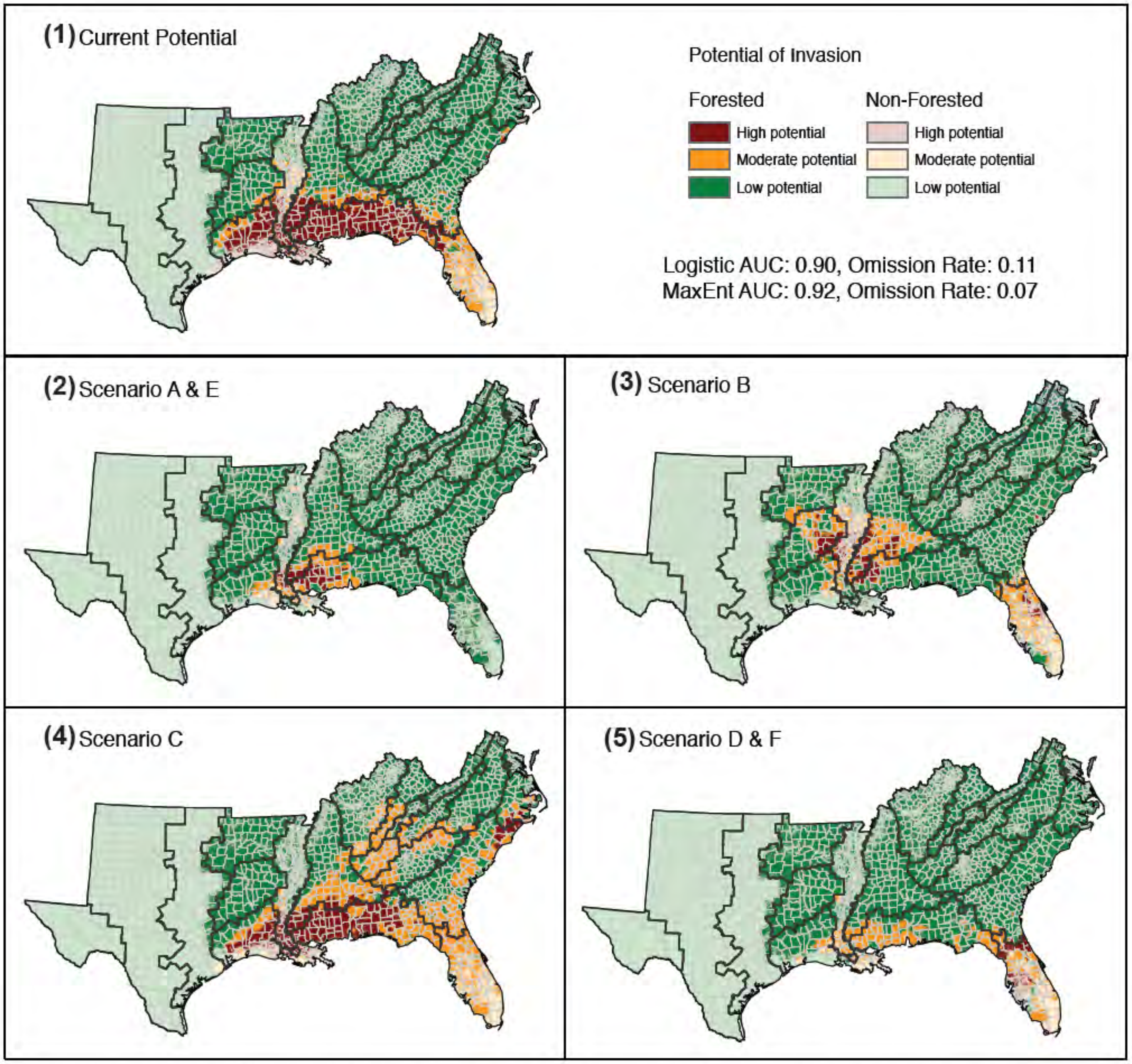


Figure 15.31—Japanese climbing fern: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

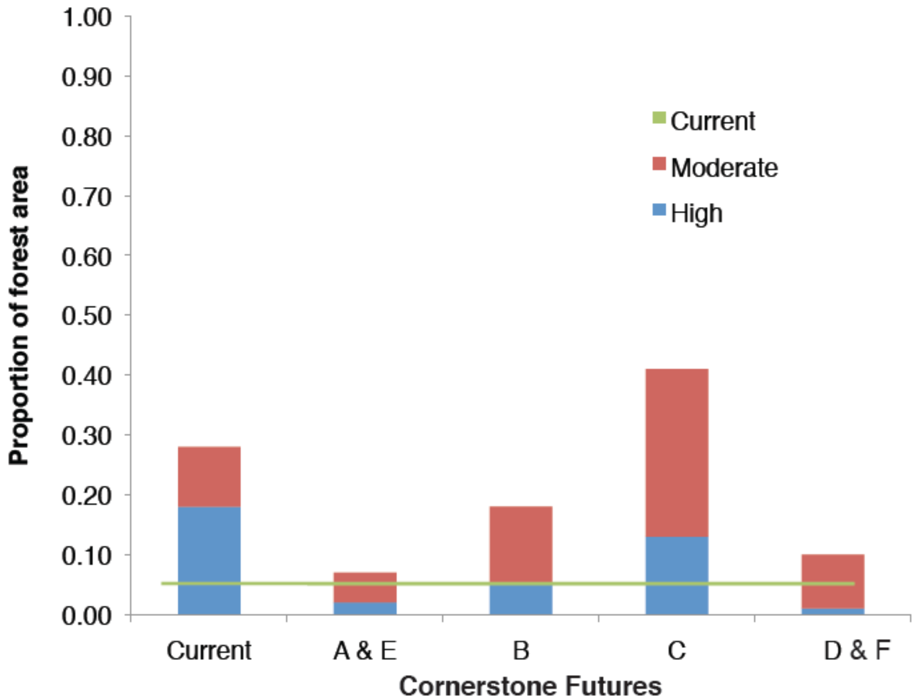


Figure 15.32—Japanese climbing fern: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

0.10), with rainfall, temperature, and elevation dominating (table 15.3). Potential for Japanese climbing fern becomes higher as temperature and rainfall increase, although this effect diminishes at the extremes of both. The negative relationship to elevation may be an artifact of the dataset limitations, as populations currently only occur at low elevations. The potential distributions under the varying climate forecasts seem primarily driven by rainfall, with reduced rainfall within the current potential distribution and in Cornerstones A, E, and B limiting distribution (fig. 15.31). Under Cornerstone A, B, and E the areas of high potential are lower than the status quo prediction (fig. 15.32). Under Cornerstone C the area of moderate potential extends to as far as Tennessee—the result of sustained rainfall patterns from the central Gulf to Appalachia coupled with a minimal increase in temperature. Under Cornerstones D and F cooler temperatures in winter are expected to reduce the potential significantly, pushing the distribution mainly into Florida.

Nepalese browntop—The potential habitat range for Nepalese browntop under current conditions is projected to occupy up to 41 percent more forest land than its current distribution of 3 percent (fig. 15.33 and 15.34). The models had reasonable statistics with AUCs around 0.85 and omission rates of 0.24 and 0.14. The dominant variables in the model are minimum temperature, rainfall, elevation, and proportion of forest (table 15.3). Temperature is the biggest contributor at 62 percent, with a bimodal relationship of minimum temperature preferences ranging from 21 ºF to 32 ºF. The other dominant variables suggest the highest potential occurs at lower elevations with intermediate forest cover and moderate rainfall (table 15.3). Under Cornerstones A, E, and C, Nepalese browntop all but disappears in the South (fig. 15.33), driven predominantly by the higher temperatures pushing its range northward. Cornerstone B, with minimal warming, has some reduction but is most similar to the current potential. Under Cornerstones D and F, with reduced winter temperatures and slightly less rainfall, the potential for southern expansion is greatly increased (91 percent).

South-wide projections—Overall, the current proportion of forest invaded (2 to 5 percent) is substantially lower than the current potential (28 to 44 percent) for all five species, and predictions of potential suitable habitats for most Cornerstones are also lower than the status quo predictions. Nevertheless, in only 2 of the 20 high-moderate projections (figs. 15.26, 15.28, 15.30, 15.32, and 15.34) are the Cornerstones lower than the current portion of forest invaded (Cornerstone C for invasive roses and Nepalese browntop). Both of these species have current distributions in the upper reaches of the South, and warming temperatures that extend to the northern part of the South (less so with Cornerstone A or B) will push their ranges further north.

With these models at the regional level, the dominant variables were temperature, rainfall, and elevation. Overall, these models suggest that the probable distribution of suitable habitats for these invasive species increases under most climate forecasts.

Treatments for Integrated Management of Invasive Plants

A successful program for invasive plant management usually involves a combination of treatment methods integrated into an approach that considers the invader and the site. Many methods are available to manage invasive plants leading to site rehabilitation, and more are under development. Current treatment options for specific areas involve herbicides, prescribed fire, prescribed grazing, mechanical, and manual removal (Miller and others 2010b). Fire, grazing, and mechanical cutting treatments usually control only the above-ground plant parts, resulting in reduced height, but not resulting in permanent suppression.

Herbicidal Control Methods

Most nonnative invasive plants in the South are perennials with extensive roots, tubers, or rhizomes. This means that effective herbicide applications offer the best means of containment or eradication, because herbicides can kill roots without baring soil, protecting the site from reinvasion and erosion and leaving the soil seed bank in place for native plant reestablishment. Research has found that herbicides tested and registered with the U.S. Environmental Protection Agency are safe for humans and animals when stored, transported, and applied according to label directions. For successful herbicide treatments:

- Use the herbicide most effective for the targeted species and appropriate for safety to non-target species and situation.
- Follow, in detail, the application methods prescribed on the label. Adhere to all label prohibitions, precautions, and safety requirements during herbicide transport, storage, mixing, and application.
- Choose the optimum time for applications. For foliar-applied herbicides to non-evergreen woody plants, the best time is usually midsummer to early autumn and not later than a month before expected frost. Evergreens and semi-evergreens with leaves can be treated effectively until they lose their leaves (Frey and others 2007). The optimum time of application for each specific herbicide on each specific invasive has not been fully researched; future findings should greatly improve prescription efficacy.
- After application, watch for herbicidal activity—detectable as yellowing of foliage or as leaves with dead spots or margins—which may take a month or longer.

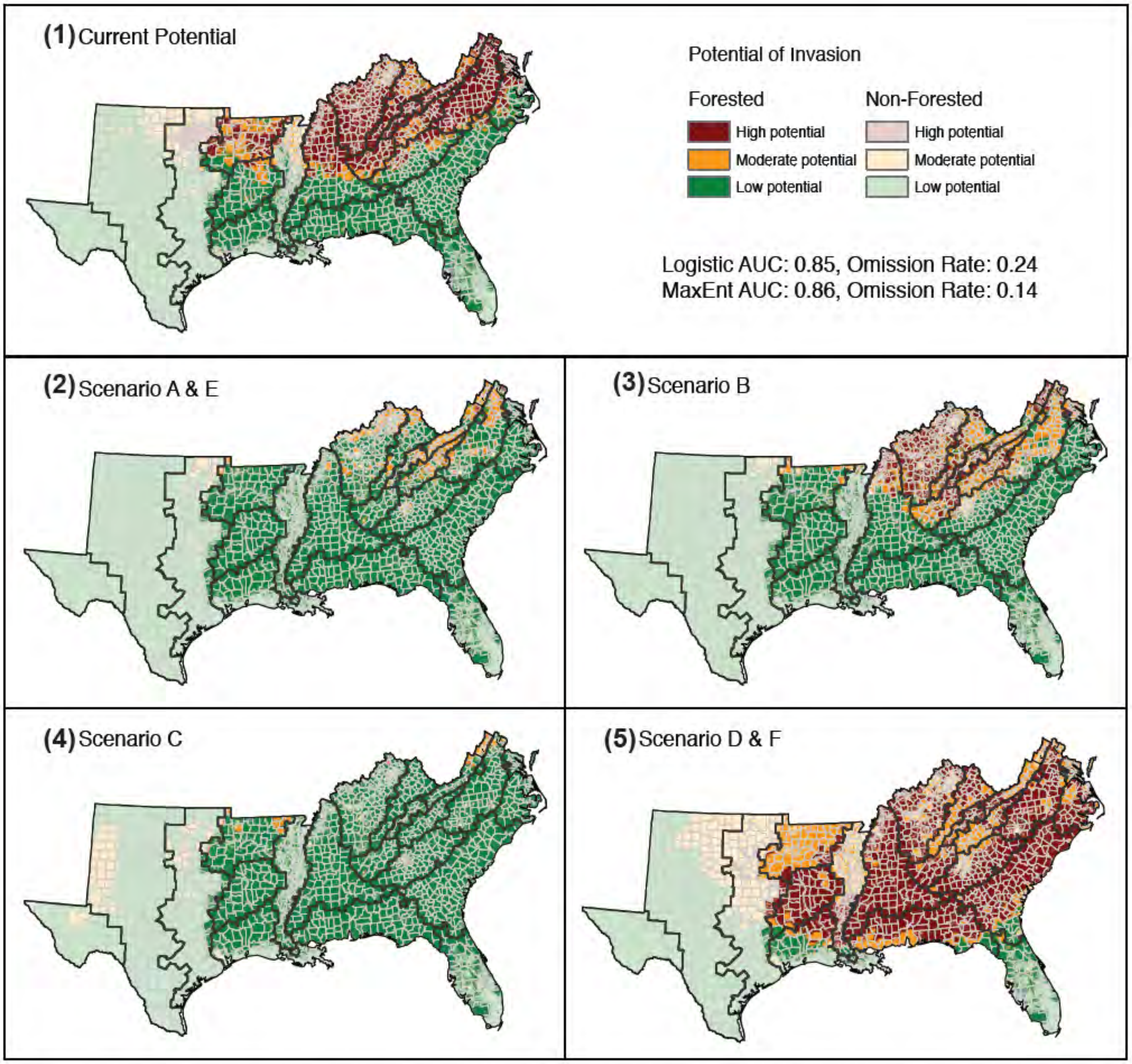


Figure 15.33—Nepalese browntop: potential for occupation into 2060 under (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) minimal warming with increased rainfall, Cornerstone B; (4) moderate warming and minimal drying conditions, Cornerstone C; and (5) minimal warming and drying conditions, Cornerstones D and F.

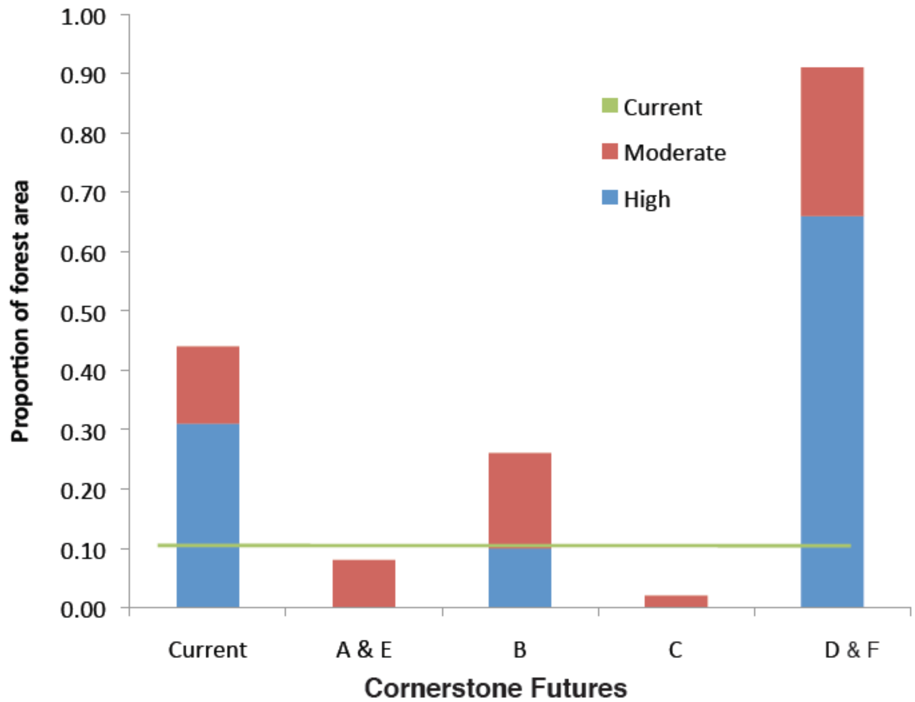


Figure 15.34—Nepalese browntop: the actual current proportion of survey plots (line), (1) current potential if current climate continues; (2) maximal warming and drying conditions, Cornerstones A and E; (3) moderate warming and minimal drying conditions, Cornerstone C; (4) minimal warming with increased rainfall, Cornerstone B; and (5) cooling and drying conditions, Cornerstones D and F at high (agreement of both models) and moderate (predicted by one model) probability.

Allow herbicides to work for several months to a year before resorting to other treatment options. Consult the herbicide label for timing of expected response of treated vegetation, but if green foliage reappears, retreatment should follow.

Specific herbicide prescriptions for invasive plants of southern forests are provided in manuals (Langeland and others 2009, Miller and others 2010b, Tennessee Exotic Pest Plant Council 1996) and on Web sites (www.invasive/org/ species/weeds.cfm, http://www.nps.gov/plants/alien/factmain.htm, http://www.srs.fs.fed.us/pubs/gtr/gtr_srs131.pdf). The use of nonselective herbicides can damage non-target native plants, hindering recovery efforts (Carlson and Grochov 2004); this realization is leading to refined prescriptions that support restoration (Flory 2010).

Selective herbicide applications—Although treating extensive inaccessible infestations may require broadcast treatments of herbicide sprays or pellets by helicopter or tractor-mounted application systems, the most effective approach is usually selective applications to target nonnative plants while avoiding or minimizing application to desirable plants (Miller and others 2010b). Selective methods include directed foliar sprays and wipes, basal sprays and wipes, stem injection, cut stem applications, and soil spots. Directed treatments of nonnative vines and forbs usually involve foliar sprays using backpack sprayers.

Broadcast herbicide applications—Many infestations of nonnative plants are too extensive or dense to permit selective herbicide applications, and instead require broadcasting of sprays and pellets. Herbicides with appropriate selectivity can be used to minimize damage when native species have herbicide tolerance to the active ingredient. In pockets of non-target native plants, broadcast applications can be discontinued in favor of the selective methods described above. In special plant habitats, small desirable plants can be protected by plastic covers during broadcast treatment. Broadcast sprays of foliar active herbicides (no soil activity) can be applied on evergreen or early greening invasives when native plants are dormant (Johnson and others 2009). Many equipment types are available for mounting broadcast application systems, depending on the situation: utility skid and trailer-mounted sprayers, all-terrain-vehicle and recreation-vehicle mounted sprayers, tractor-mounted sprayers, roadside sprayers, and helicopter sprayers.

Other Treatments

Manual treatments—Manual methods include hand pulling and using a wide array of tools for cutting, chopping, wrenching, and girdling. Manual methods are most effective on woody invasive plants when they are small. Eradication is only possible when the root crown or roots that can sprout are completely extracted and seedlings are pulled or eliminated following germination. Because it is difficult and even impossible to extract all of the shallow roots, stolons, and rhizomes of many invasives, re-sprouting usually occurs. Unless an herbicide is applied to cut surfaces, merely pulling small plants and cutting top growth will result only in short-term control before stump or root sprouting occurs. Manual treatments are labor-intensive and can only be used on small-sized plants, resulting in limited but effective use on special habitats (such as recreational trails or nature preserves).

Mechanical treatments—In many situations, hand labor is unavailable or cost prohibitive and more horsepower is needed. Specific machines developed for forestry and land clearing operations are available to clear large or dense infestations (Klepac and others 2007). Skid-steer loaders, mulchers, mowers, and tractors and bulldozers having special attachments can be used to reduce invasive woody plants (Miller and others 2010b). Tree shears, root-rakes, and harrows have been used to cut and dislodge woody and rhizomatous plants, but can leave soil bare for probable reinvasion and possible erosion. These methods can complement and increase the efficiency of herbicide treatments, but merely cutting above ground parts can aggravate plants—such as cogongrass (Willard and others 1996) and Chinese lespedeza (Brandon and others 2004)—that have surviving rootcrowns or rhizomes. Although highly disturbing, mechanical treatments have been used to clear dense infestations of multi-species of invasive woody plants and prepare the way for other more selective followups.

Cultural treatments—Several cultural practices, including prescribed burning and water level manipulation, can reduce or control nonnative invasive plant populations. However, if not applied with care, these practices may have undesirable impacts to soils, animal habitat, and native species, so care in planning and enactment must be exercised. Burning to weaken woody invasives is most effective in the late spring after plants begin using their root reserves for early growth. Burning in late winter or spring leaf-out can minimize the period of bare soil, while summer burns are the hottest and can maximize consumption of standing plants. Burning can predispose a forest stand or opening to invasion, even though prescribed burning increasingly is favored for native plant and longleaf pine ecosystem restoration as well as fuel reduction. A close evaluation of the benefits and risks is demanded before applying prescribed burning to avoid unexpected consequences (Brooks and Lusk 2008, Glasgow and Matlack 2006). A propane spot burner can be used to kill individual or small groups of herbaceous or woody invasives. Commercial kits are available for attaching propane cylinders to a backpack frame and fitting the cylinder with a flame nozzle. Other units are available for mounting propane cylinders on tractors. When plant and wet fuel conditions permit, the flame is directed at herbaceous and woody invasives.

In areas where water level can be manipulated, flooding or drawdowns can reduce invasive plant populations in aquatic and wetland habitats but these are species- and site-specific and usually not effective as stand-alone treatments (Allen and others 2007). They require an understanding of the biology of both invasive and native plants in the treatment area.

Mulching and solarization—Mulching involves covering the soil surface with materials that block light, thereby preventing weed germination and growth. Although application of mulches and landscape fabrics is common for reseeding and soil stabilization in restoration operations, mulching for control of tough invasive plants will not be effective unless adequate amounts of materials are applied. Mulching is most effective on small seeded species and marginally effective on established re-sprouting perennials such as kudzu. Many types of mulches are available, including natural ones such as straw, bark, sawdust, crop residues, and grass clippings; and artificial ones such as paper, cardboard, and plastic. Although mulch applications are not commonly used to control invasives on a large scale, they are still useful. Tallowtree and Chinese privet suppression have been achieved by chipping standing trees and dense shrubs into a deep mulch layers (Donahue and others 2006, Klepac and others 2007). In soil solarization, polyethylene sheeting covers low-growing, cultivated, mowed, or chopped invasive infestations and traps solar energy to kill and suppress invasive plants by heating the soil and air underneath the sheeting. Two or more years of summer cover are needed to suppress most invasive plants by 90 percent. Other, more desirable, plants are also killed by this method—it is not selective.

Biological Controls

Biological control methods range from prescribed grazing to the introduction of insects, pathogens, and other agents that feed solely on target species. Classical bio-control involves finding agents from the home range (or similar habitat) of the invasive plant, followed by intensive research on feeding habits and reproduction and a planned introduction into infested areas. The goal is to identify predators that are host-specific to the target invasives, will avoid attacking native plants, and will increase and spread in the new range to permanently suppress the invasive species. The process is usually expensive, often involving lengthy searches for the right agent, extensive feeding tests in special quarantine facilities, coordinated releases that are strictly controlled and documented under Federal oversight, and long-term monitoring. Following release, non-target damage is very rare but has occurred (Moran and others 2005). In general, scientific evaluations of past releases have shown that the benefits from bio-control over a region outweigh the threats (Messing and Wright 2006).

Prescribed or targeted grazing is an approach that relies on cattle, sheep, goats, or horses to reduce infestations. Grazing is a potential control treatment only if the invasive is palatable and not poisonous to the animal. Grazing can either promote or reduce plant abundance at a particular site. By itself, grazing will rarely, if ever, completely eradicate invasive plants. However, when combined with other control techniques, such as herbicides or bio-control, grazing can reduce severe infestations and eliminate small ones. Grazing by cattle and horses is limited to herbaceous invasive plants. Sheep and goats both feed on woody plants as well, but goats can also eat bark and thorny vegetation and are able to reach higher areas of shrubs, saplings, and small trees. The animal species is important, as is the breed, with the most effective being larger and able to handle difficult situations, such as hair goats and range cattle. Best results come from leaving an appropriate number of animals on a site long enough to reduce the infestation, and then reintroducing them at intervals when invasive regrowth appears (Luginbuhl and others 1999).

Rehabilitation, Restoration, and Reclamation

The promotion and establishment of desirable vegetation during the latter phases of control and eradication treatments is one of the most important phases of an integrated invasive plant management program (Hartman and McCarthy 2004). The severity of infestation, site degradation, and desired future outcome determine whether a rehabilitation, restoration, or more stringent reclamation effort is appropriate. Rehabilitation is effective when soil, stream, and wetland damage is minimal and native plants are present or will enter from surrounding areas. Genetically improved loblolly pine seedlings or other fast-growing native tree species can be planted to suppress regrowth of invasive plants. Restoration is a much more involved process that combines soil and streambank stabilization methods with planting and seeding of desirable species to create a planned landscape. Reclamation is appropriate for surface-mined lands, large road construction projects, and other severely altered sites to reshape landform, replace surface soils, and establish fast-growing plants—often in conjunction with mulches and fertilizers. Invasive plants have been most often planted on reclamation sites and now warrant control efforts. Native or noninvasive, nonnative plants are substitutes now available and recommended for reclamation operations.

The goal of all three approaches is to establish and/or release fast-growing native plants that can outcompete and outlast any surviving nonnative plants while stabilizing and protecting soil and water (Hartman and McCarthy 2004, Kaeser and Kirkman 2010). At times, nonnative plants must be used to suppress invasives—then eradicated—to facilitate native plant establishment; an example is planting bahiagrass after herbicide treatments to suppress cogongrass regrowth (Ewel and Putz 2004). The ultimate goal is to replace invasive plants with native alternatives (Burrell and others 2006).

If the soil seed bank remains intact, native plant communities will naturally become established and regenerate during eradication of nonnative plants (Barnes 2007). Light-seeded native species are usually present in the seed bank, and heavier seeded plants will gradually be deposited on a site by birds and other animals. Continued surveillance and follow up treatments are often required to control nonnative plant infestations. Select herbicides and other treatments such as mowing and prescribed burning can play a role in continued suppression (Barnes 2007).

DISCUSSION AND CONCLUSIONS

Examination of survey data, literature, and modeling shows that invasive plants are not an issue that is going away. Using dates of introduction and current levels of occupation we predict that in the next 50 years the acres of invasives will increase from the current 19 million acres to 27 million acres. This conservative estimate does not take fully into account the growing amounts of land disturbance, fragmentation, parcelization, and urbanization that foster invasive plant spread, or effects of potential climate changes. Of the five species evaluated with modeling, none were close to their full potential of occupation. This is supported by other research (Bryson and Carter 2004, Gan and others 2009, Simberloff 1996). Also, we have only considered those species already present in the South that have already been identified as high threats.

Common Traits of Invasive Plants

Nonnative plants when they escape cultivation usually remain at low levels as scattered occurrences of small infestation size with low populations and numbers of individuals, known as the "lag phase." Further generations are better adapted to their new environment through cross pollination and selection pressures and then reproduce and spread more successfully at increasing speed (fig. 15.35). Invasive traits can be enhanced

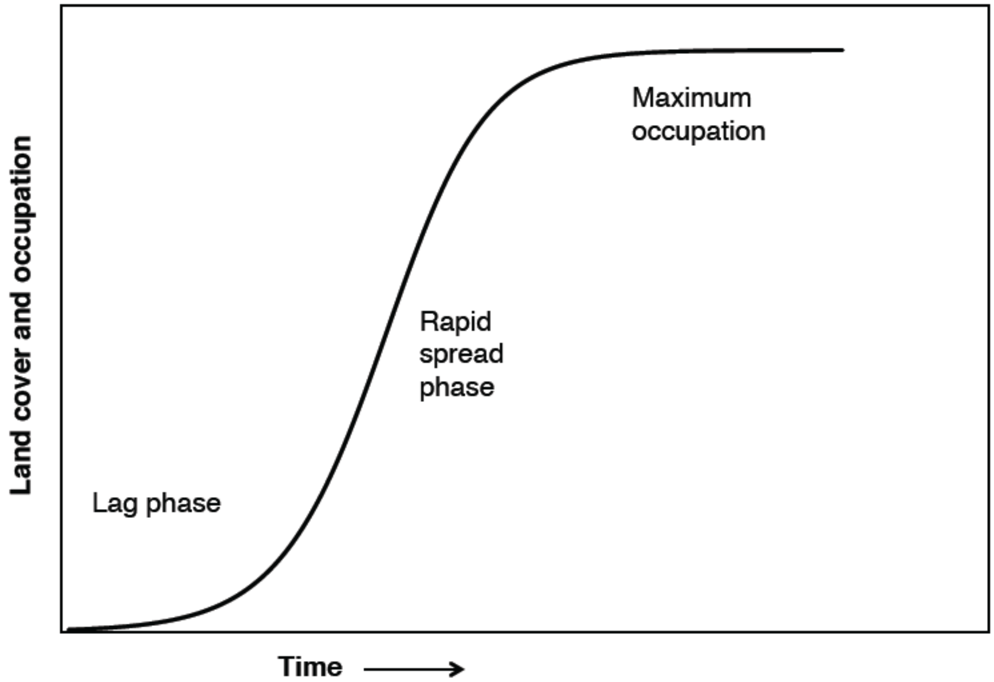


Figure 15.35—A logistic schematic showing the typical progression of nonnative invasive species as they escape and spread from their original planting sites.

through hybridization with native or nonnative plants of the same genus. There are nonnative plants at every stage of invasion in the Southeast while across the region none are thought to be at the "maximum occupation" phase. Many escaped nonnative plants are currently considered "naturalized" plants and occur in the early lag phase. They will likely become invasive due to hybridization, adaptation, and increased disturbed habitat.

Nonnative plants become invasive for many reasons. Early introduction in the 1700s and 1800s resulted in a long period of use, spread, hybridization, and adaptation (table 15.1). They were used for forage, as ornamentals and herbal plants by hundreds of thousands of small farms and remained after the great exodus to cities in the late 1800 and early 1900s.

Nonnative plants can outpace native cohorts because of their rapid early growth rates, abundance of often-evergreen leaf area, longer growing seasons, and tolerance to shade, drought, a wide range of soil conditions, and flooding. Dominance increases after disturbance and storms (Butterfield and others 2004, Jones and McLeod 1990).

Roots or rhizomes of many nonnative plants persist and resprout after herbicide applications, cutting, or burning. They grow outward above or below the soil to yield clonal infestations with one or few genotypes (Capo-chichi and others 2008). Many species adapt and spread in a new site through a "sit-and-wait" strategy that takes advantage of disturbance to spread after prior establishment (Greenberg and others 2002). Others occur as infestations with multiple invasive plants, especially in Piedmont forests (fig. 15.36).

Nonnative plants have few native predators and are resilient to predation by insects, pathogens, and mammals (Rogers and Siemann 2003, Siemann and Rogers 2003, Zou and others 2008). Many can suppress other plants' seed germination and growth by releasing allelopathic chemicals through their foliage and roots. Examples are tree-of-heaven (Gomez-Aparicio and Canham 2008), Brazilian peppertree (Morgan and Overholt 2005), and garlic mustard (Vaughn and Berhow 1999).

Many nonnative plants produce abundant fruit and seeds at a young age (Bruce and others 1995). Seeds are readily spread by wind, water, birds, and mammals (Renne and others 2000) and can remain viable in the soil for more than a year and even up to decades (Flory and Clay 2009).

Most nonnative plants can establish and spread in sites of periodic disturbance, such as urbanized forests (Burton and Samuelson 2008, Loewenstein and Loewenstein 2005), fragmented forests with expanding lengths of forest edge (Honu and Gibson 2008) and rights-of-way (Hansen and Clevenger 2005, Merriam 2003), along stream and river

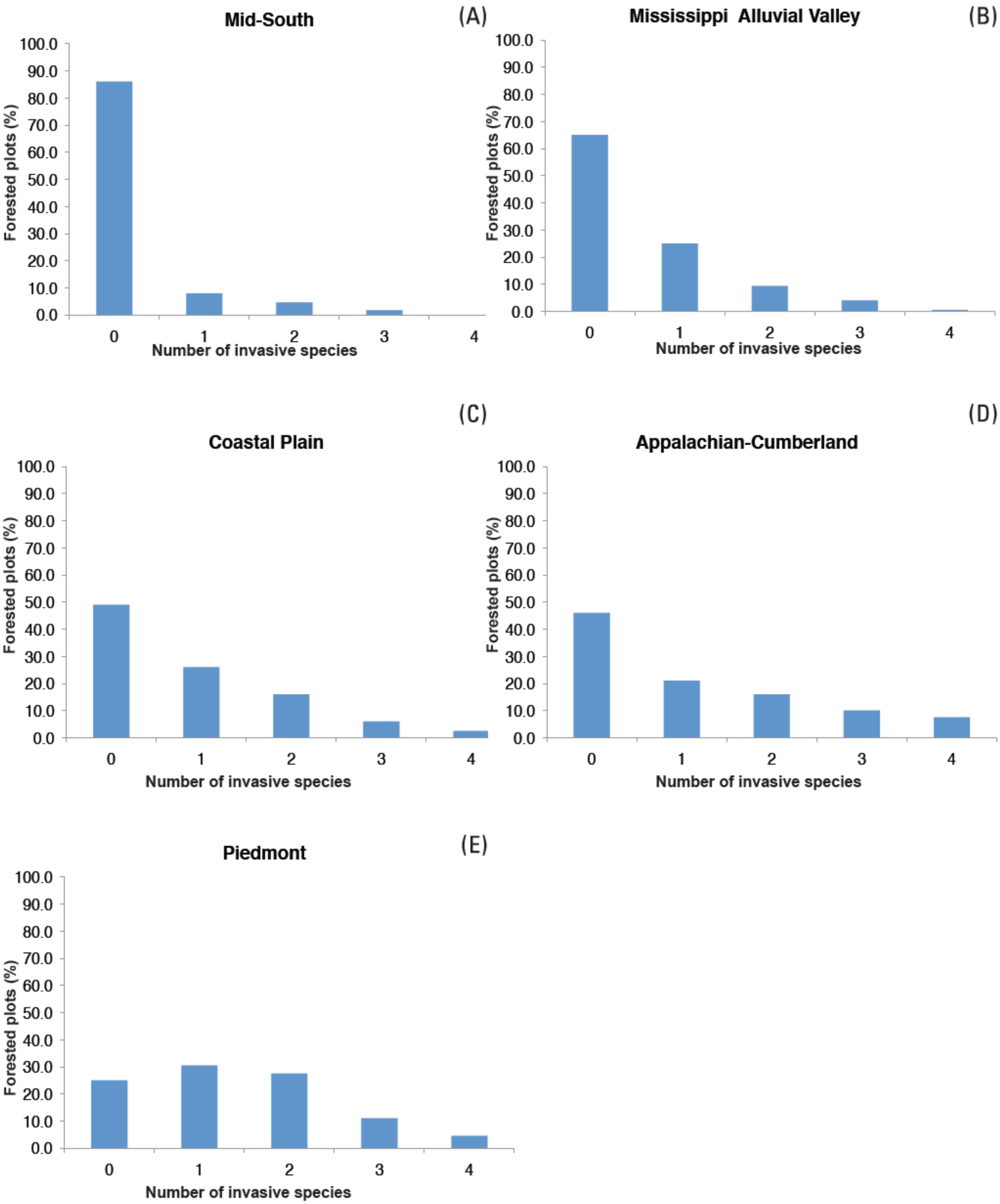


Figure 15.36—Percentage of survey plots in which one to four nonnative invasive plant species were reported in the Mid-South, Mississippi Alluvial Valley, Coastal Plain, Appalachian-Cumberland highlands, and Piedmont.

banks (Gan and others 2009), and in abandoned crop and pasture lands (Stapanian and others 1998).

Having more of these traits increases the likelihood that a nonnative plant species will succeed in establishing itself, spreading, and resisting control and eradication.

Damages Caused by Invasive Plants

The damages and impacts of nonnative invasive plants are numerable and have not been completely determined. The costs of damage and control of invasive species has been estimated in the billions of dollars (Pimentel and others 2000, U.S. Congress OTA 1993) while no economics exist to evaluate the more widespread ecological and sociological effects of invasive plants (Holmes and others 2009, Perrings and others 2002).

- Dense infestations of most invasive plants limit or stop productive land management and especially regeneration of forests, such as cogongrass's severe competition with planted pines (Jose and others 2002), Japanese honeysuckle's allelopathic impacts to young pine regeneration (Shulman and others 2004), Nepalese browntop's physical completion with natural hardwood regeneration (Oswalt and others 2007), and Chinese privet's suppression of tree regeneration in mixed hardwood forests (Merriam and Feil 2002). Infestations replace native plant strata in forest communities (table 15.2).
- Invasions may initially increase species richness and diversity upon first entry (Gan and others 2009). However, with intensified infestations, they displace and permanently decrease biodiversity, even among insects (Ulyshen and others 2010), they are especially harmful to rare plants and animal habitat, and they hybridize with native plants to dilute genetic traits (Heywood 1989, Pooler and others 2002, Stohlgren and others 1999, Wilcove 1998). A few harbor plant diseases (Swearingen 2000) and several are toxic to people, wildlife, and livestock (Everest and others 1996, Turner and von Aderkas 2009, Williams 1980). Flowering Brazilian peppertree and English ivy can cause respiratory difficulties and contact dermatitis in sensitive individuals (Morton 1978).
- Some invasive plants produce overabundant pollen that causes widespread allergenic reactions in humans.
- Invasive plant occupation alters vital ecological processes such as soil formation and wetland function (Ehrenfeld 2003). For example, tallowtree changes soil and litter chemical properties (Cameron and Spencer 1989), cogongrass lowers soil pH and potassium (Collins and Jose 2009), and melaleuca greatly alters soil microbial processes and litter in ways to maintain site dominance (Martin and others 2009). Soils invaded by kudzu have exceptionally high levels of nitrogen through nitrogen fixation by root bacteria; they release excess nitrogen as minerals in soil water and as gases that contribute to ground level ozone (Hickman and others 2010). In an opposite manner, soils invaded by Nepalese browntop have slower nitrogen internal cycling (DeMeester and Richter 2010).
- Invasive-plant alterations to wildlife habitat favor more common species over those that are at-risk, complicating restoration efforts (Asland and Rejmanek 2010, Cipollini and others 2009, Schmidt and Whelan 1999).
- Most invasive plants grow formidable barriers of vegetation that limit land access for recreation such as hiking, fishing, hunting, and bird watching. They can cause psychological anxiety though a sense of the inability to control one's surroundings (Blaustein 2001).
- Some invasive plants present extreme fire hazards to forests, preserves, and homes, such as cogongrass and giant reed (*Arundo donax*).

The damages and costs are both ecological and societal, with many complex linkages that stymie economic analysis. Mack and others (2000) concluded that the threat of large nonnative infestations is largely the unintended consequences of uninformed decisionmaking, and Perrings and others (2002) added that the threat is compounded by societal resistance to change.

Potential Uses of Invasive Plants

Because of their increasing replacement of usable forest species, we are faced with the challenge to discover uses for the widespread or abundant invasive plants, determine how to efficiently harvest and process wild populations, or learn how to cultivate them in plantations or farms to lower harvesting and transportation costs.

Many invasive plants are being proposed, considered, bred, propagated, and experimentally planted in plantations for biomass and potential biofuel production due to their rapid juvenile growth and pest resistance: tallowtree (Scheld and Cowels 1981), Chinese and giant silvergrass (*M. floridus*) (Jessup 2009), melaleuca (Wang and others 1982), giant reed (Lewandowski and others 2003), golden bamboo (Scurlock and others 2000), princesstree, and kudzu (Sage and others 2009). The Invasive Species Advisory Council (2009) considers this a high-risk use with escapes to surrounding natural and productive landscape eventually inevitable. The same concerns exist for the existing commercial plantations of princesstree in the southern region, recognizing that mature straight trees, rarely produced in the region, only have a high value in Japan at this time (Tang and others 1980). On another front, research has found that tallowtree can be used for all three composite panel types meeting various American National Standards Institute grades (Shupe and others 2006) and has value as a source of drying oil (Howes 1949). The current coverage of all these invasive species, with the possible exception of tallowtree, would have to be increased in plantations to make economically viable operations, bringing a high probability of additional escapes.

Extracts from kudzu, Brazilian peppertree, and Chinese yam have traditional medicinal uses, while the leaves of garlic mustard and kudzu and the root starch from kudzu are valued Asian cooking ingredients (Shurtleff and Aoyagi 1985). Dietary root extracts from kudzu have been found to regulate blood pressure, high cholesterol, and blood glucose in lab rats predisposed to these conditions (Peng and others 2009). Autumn olive fruits have 3 to 15 times more of the lycopene anti-oxidant than tomatoes (Fordham and others 2001). Thus, utilization of invasive plants is in its infancy with probable increases likely.

General Concepts for Managing Nonnative Invasive Plants

How we manage invasive plants will ultimately determine the severity of damages and costs. The most effective and efficient strategy is early detection and effective early treatment of initial invaders. Three overarching concepts provide powerful ways to get organized and counter invasive plant takeovers: collaboration, adaptation, and restoration (Buck and others 2001, Schelhas and others 2001, Miller and Schelhas 2008). Collaboration with adjacent and area landowners is essential because invasive plant infestations most often occur across ownership and political boundaries. Communication networks can link local, county, State, and regional programs (Meyerson and Reaser 2003). Adaptation, or adaptive resource management, is a community shared cyclical process of learning by doing (Foxcroft 2004) that consists of goal setting, learning from the experience and research findings of others, monitoring actions and outcomes, and then rapidly incorporating new knowledge into refined goals and actions. This process is useful for decisionmaking in the face of uncertainty, because it reduces uncertainty over time by monitoring results of actions and making careful adjustments. Its effectiveness can be enhanced by monitoring print and Web resources for new and forthcoming information (Jordan and others 2003). Restoration of infested lands to healthy and productive ecosystems is the guiding objective, involving the establishment and monitoring of desirable and useful plants that protect soil, produce needed resources and habitats, and safeguard to prevent a resurgence of invasive plants. Restoration approaches for most invasive plants are just being developed and will require adaptive management cycles in order to perfect them (Hartman and McCarthy 2004, Sauer 1998).

Organizing Across Borders

The common elements of successful regional, State, and local invasive plant management programs include developing:

- Scientifically based and coordinated invasive plant lists that recognize that priorities will differ by subregion as well as frequency and severity of infestations
- Multi-level, cooperative knowledge networks that link stakeholders, land managers, scientists, and policymakers, provide real-time information and connectivity (Jordan and others 2003), and encourage timely actions and communication by all participants regardless of their roles
- Collaborative prevention strategies and programs, including legislative, policies, and public outreach components (Britton and others 2005), "good neighbor" programs among rights-of-way managers and adjacent landowners (Randall 2007), sanitization protocols (Fleming 2005), and safeguards against the spread of contaminated products (Evans and others 2006)
- Early detection and rapid response networks to identify and map high-risk sites and new introductions, verify the invasive species, and facilitate communication, eradication, and restoration (Westbrooks 2004)
- A Web-accessible interactive survey, inventory, and mapping system to corporately track existing and spreading invasions (Bargeron and Moorhead 2007)
- Coordinated control, containment, and eradication programs that establish cycles of integrated treatments, share successes and mistakes (Miller and Schelhas 2008), raise public awareness, close known pathways, and facilitate regional biological control programs (Messing and Wright 2006)
- Restoration treatments that suppress new invasions, maintain ecosystem functions and services, incorporate adaptive information cycles, and provide for continued surveillance and monitoring with timely re-intervention if necessary (Miller and others 2010b)
- A continuous cycle of research, research syntheses, practical application of findings, and a feedback mechanism for communicating additional research needs (Miller and Schelhas 2008)

The spread of invasive plants from State to State means that State-level plans need to include common elements that assure regional protection, including working elements and programs for adaptive collaborative restoration. The most effective strategies for constraining invasions and restoring ecological services are unified and readily shared through collaborative networks that define zones of occupation severity and show areas where different strategies should be employed (fig. 15.37).

Managing outlier areas—Outlier (or satellite) infestations exist beyond highly infested areas due to long distance movement of plants or plant reproductive parts. Outlier infestations must be detected and eradicated early if containment is to be successful. Early detection rests with public awareness as well as organized search and surveillance efforts and strong reporting networks.

Movement of contaminated equipment and materials must be effectively prevented to stop new outlier infestations from being established.

Managing the advancing front—All infestations along the advancing front must be found, mapped, and documented through intensive search and surveillance programs. The search and surveillance programs must include all ownerships. To stop seed dispersal from worsening the situation, treatments must be timely and persistent. For all work near or inside infested areas, extra care must be taken to ensure sanitation of equipment and personnel to prevent spread. Special habitats of rare plants and animals within the advancing front zone should be carefully treated to save them from ultimate loss. The front must be held and then pushed back.

Managing severely infested areas—Surveys employing sampling techniques are required to quantify the acres of infestation. Concerted programs in cooperation with landowners including funding assistance are needed to fully implement, support, and maintain management programs in severely infested zones. Equipment and personnel sanitation as well as quarantines of product movement out of severely infested areas must be strictly regulated to prevent both short- and long-distance movement of plants and reproductive parts. Any forest and nursery product movement must be monitored for contamination. Special habitats of rare plants and animals must be safeguarded from destruction and restored using special techniques. People's homes must be safeguarded against wildfire by highly flammable invasive plants.

Small Scale Stewardship

Invasive plant strategies and programs ultimately depend upon the eradication and restoration of one infestation at a time at the local level and preventing new entries. Following these principles will greatly increase the chances of success.

Prevent entry and spread—Do not plant invasives such as those covered in this book, others listed in the appendix in Miller and others 2010b, entitled "Nonnative Invasive Plant Species Not to be Used or Recommended for Wildlife Food Plots and Bird Viewing Plots," and those on your State's noxious and invasive plant lists. For wildlife food plots, soil stabilization, and ornamentals, plant only native plants of local origin when possible or choose noninvasive alternatives. Employ sanitation practices to avoid introducing or spreading invasive plants.

Make a plan—Base your planned treatments on stated objectives and the best information, then schedule and acquire resources that support your plan. Devise a timeline for implementation of your plan's action items, and add some "wiggle room" for contingencies. Devise both a short- or long-term plan to include both specific infestation treatment regimes and ideas for how these fit into a general land management plan. Your maps of infestation locations and priority ratings of invasive species will assist the planning process.

An eradication and rehabilitation program for specific invasive plant infestations usually requires several years of treatments and many more years of surveillance to check for rhizome and root sprouts, seed germinates, or new invaders. Newer infestations and smaller plants require much less time than extensive and dense infestations.

Prioritize treatments by targeting the worst of the plants first. Remember that the worst plant may not be the one with the highest level of infestation but the one that has the greatest potential for spreading. Balance eradication of first entries of high-priority invasive plants with persistent treatment of extensive infestations (see www.invasive.org/south/ for a regional list of High Priority Invasive Species of Southern Forests and Grasslands). Monitor the effectiveness of treatments, retreating as needed.

During the treatment and retreatment phase, take steps to safeguard, promote, or establish desirable vegetation. To effectively combat plant invasions and restore lands, you will need to carefully plan for each step in the program by incorporating primary and contingency schedules of enactment. You should project a minimum of 4 years and up to 10 years for older infestations when less than maximum effective treatments are used. You can use short-term plans to target specific areas, but you will need a long-term management plan for an increasingly invaded landscape. You must consider surrounding lands, particularly the degree of current infestation in those lands as well as the invasive plant management programs the owners and managers of those lands have in place. Also consider emerging State funding assistance programs.

Make a map and monitor results of locations—Detect invasive plants early through active surveillance of your lands. Map and mark locations of the invasive plants you find. Identify invasive plant location sites at risk, and denote treatments and their outcomes. You must positively identify those invasive plants that are present and those poised to enter from adjacent lands, determine their locations and abundance, and record this information on a sketch map or Geographic Information System (GIS) map. Gain their Global Positioning System (GPS) locations when possible. Make the locations easy to find again by marking them with flagging. Monitor the locations through repeated visits and record progress or the lack of it. Agencies should map as many acres as possible with the dollars available before investing in unorganized treatments of extensive invasions, while new entries of severe invasives should be tackled early.

The five-option Search, Survey, Inventory, Monitor, and Surveillance method, can help map, monitor, and track treatments with their results at several scales: (1) Look at the most likely points of entry, like along roads and especially near bridges, and record any occurrence of invasive plants you find in such areas. Then widen your search as time and resources permit. (2) Systematically locate plots or conduct band sampling across the landscape to determine the extent of occupation and acres covered. By mapping the survey plot findings, areas of highest infestation density and multiple invasive species can be identified. (3) Prepare an inventory by recording the location and area of every infestation and the treatments that you apply. This is the best approach for individual land ownerships. Inventories can map individual patches and plants or circle them as a group when they occur in close proximity to one another. The GPS locations can be taken and mapped, or a sketch map made to plan the program of treatment and restoration. (4) Monitor the site by revisiting inventoried points at scheduled times or resurveying tracks with scattered infestation to record and track treatment effectiveness and any further invasions. (5) Practice surveillance, a constant task for all those who work on and/or otherwise use your land. Everyone should be alert for new infestations and know how to report these when and where sighted.

A Time to Reflect, Rethink, Redouble Efforts

In an article about introduction of new species into the United States, Simberloff (2001) admonishes, "What is needed is a change in philosophy, away from innocent until proven guilty. The very nature of introduced species makes current risk assessments unreliable documents, that introductions are generally irrevocable once they are established, and that the harm some species can cause is not only staggering in economic terms but incalculable in ecological ones."

Now More Than Ever: Sanitation Is the Key

- Educate yourself, employees, and other users of your land about the invasive plants that pose major threats and how to prevent their entry. Learn how to identify both invasive and native plants in your area. The more native plants that you can identify, the easier you will spot the "plants out of place."
- Require or instruct those who work, hunt, and recreate on your lands, to minimize invasive plant spread by: (1) inspecting the site and infestation before operations especially noting the presence or absence of invasive plant fruit, seed heads, or spore clusters under climbing fern (*Lygodium* spp.) leaves; (2) when possible, avoiding driving vehicles, mowers, all-terrain vehicles (ATVs), or spray equipment through infestations bearing seed or fruit, especially of late-flowering cogongrass and musk thistle (*Carduus nutans*); (3) removing all seeds and debris from clothes, boots, socks, boot laces, soles, and personal protective equipment, avoiding cuffed pants, carrying contractor-size refuse bags to stand in while brushing and removing seeds or place contaminated gear within the bag for careful cleaning at a designated location; (4) when working in infestations, thoroughly cleaning motorized equipment (especially the undercarriage and tire surfaces, radiator front, and engine compartments), removing excess grease and oil, and modifying vehicles and equipment to prevent buildup of debris or selecting vehicles that have the least potential for contamination.
- When moving cut fruiting or seeding invasive plants offsite such as to a burn pile, always cover loads or bag before transport.
- Monitor burn pile areas for new seedlings as the fire may not consume or kill all seeds. Also, monitor any designated decontamination sites for seedlings.
- Avoid entering or working in spore-forming species such as invasive climbing fern infestations when spore clusters are present (October to November in temperate climates); if entry is unavoidable, complete sanitation of all equipment, clothing, and workers is necessary to prevent potential spread.
- Use only non-contaminated fill materials, mulches, and seeds. Inspect material sources at the site of origin for indications of contamination by invasive plants growing on or near the area. Regularly inspect areas where offsite fill materials have been used and areas used by visitors and lessees.
- Be careful not to disturb areas where there is a high probability of invasion. Most land disturbing activities raise the potential for establishment of aggressive plant invaders, especially when the invaders occur nearby.
- Practice search and surveillance at these likely points of entry: lands adjacent to yours that you do not own (such as highways, county roads, and utility rights-of-way and their edges and fencerows) especially after new construction or maintenance activities; internal roads, trails, and fire lines; lands next to streams, rivers, and lake shores, especially after recent flooding or high-flow periods; recently prepared and seeded wildlife food plots; harvested, thinned, burned, or storm-damaged areas during the years following disturbance.

Successful management of nonnative invasive plants requires recognition that the number of species, their area of occupation, and their spread are drastically increasing—and that new knowledge, approaches, and cooperation are needed. Management of undesirable plants has been a growing science and practice in intensive agriculture and horticulture, at the same time that invasive plant populations toughened by hybridization and new introductions, are spreading across land uses. Forestry, right-of-way, park, and preserve managers can borrow and modify control techniques from agriculture and from one another. Accurate identification skills of both invasive and native plants are required for precise management, as are new tools, machines, products, and techniques.

Management of invasive plants would be more effective if augmented by integrated planning, better and timelier preparation, and heightened resolve and persistence. Ownership, area, and site management plans (long range and for specific activities such as timber harvesting, stand thinning, prescribed burning, and road and firebreak maintenance) would benefit from goals and actions addressing prevention, eradication, and control of invasive infestations, especially those that minimize entry and spread of invasive plants and anticipate the possibility of new infestations. It is important to remember, however, that such plans are incomplete if they do not lead to site rehabilitation or restoration.

Preparation always has been critical to forest, roadway, and natural area managers and landowners. As invasive plant populations increase in size and density, new concepts, tools, and materials will be needed. Preparation includes having the very latest information as well as using reliable sources of uncontaminated fill dirt and rock, seed, and mulch for soil stabilization. Preparing for rehabilitation and restoration may involve extra expenditures for newly available native seeds, planting tools and equipment, landscape fabrics and fiber mats for stabilization, or consultations with professionals.

Without persistence, all efforts to control and rehabilitate infested lands will be lost. Nurturing a healthy native or noninvasive community of plants usually requires a regime that includes timed treatments and retreatment, tenacious follow through, and years of site monitoring for reappearance or new introductions.

KNOWLEDGE AND INFORMATION GAPS

There is a critical need for research and policy action to address many aspects of invasive plants in the southern forests and elsewhere (Sieg and others 2010, Simberloff and others 2005). Specific gaps include the absence of data on the degree that invasive plants impact tree and stand growth and structure for any forest type. There are essentially no data in the southern region on relationships among invasive plants, hydrology, and changes in water quality and quantity. There is a critical need for new approaches that will help managers avoid marked and permanent alterations of forest, agricultural, and conservation lands and waters as invasive plants spread from urban, suburban, and exurban lands and connecting rights-of-way (Liebhold and others 1995, NRC 2002, Simberloff 1996, Von der Lippe and Kowarik 2006).

Invasive plants thus represent a complex and perplexing societal dilemma, with need for a more comprehensive awareness, management strategies, coordinated programs, and effective laws if we are to avoid bequeathing future generations degraded ecosystems and ecosystem services. A concerted, holistic effort that integrates science with management in new ways will be required for predicting, managing, and mitigating the spread of invasive species (McPherson 2004), as will the involvement of the wider society in new approaches (Miller and Schelhas 2008).

ACKNOWLEDGMENTS

We gratefully acknowledge the following individual for his contributions to data analysis, map and table construction, and reviews: Erwin Chambliss, U.S. Department of Agriculture Forest Service, Southern Research Station.

LITERATURE CITED

Akanda, R.U.; Mullahey, J.J.; Shilling, D.G. 1996. Environmental factors affecting germination of tropical soda apple (*Solanum viarum*). Weed Science. 44: 570–574.

Allan, P.F.; Steiner, W.F. 1965. Autumn olive for wildlife and other conservation uses. Leaflet 458. Washington, DC: U.S. Department of Agriculture. 8 p.

Allard, H.A.; Leonard, E.C. 1943. The vegetation and floristics of Bull Run Mountain, Virginia. Castanea. 8: 1–64.

Allen, S.L.; Hepp, G.R.; Miller, J.H. 2007. Use of herbicides to control alligatorweed and restore native plants in managed marshes. Wetlands. 27: 739–748.

Anderson, M.L. 1921. *Lygodium japonicum* in South Carolina. American Fern Journal. 11: 90–91.

Araújo, M.B.; New, M. 2007. Ensemble forecasting of species distributions. Trends in Ecology and Evolution. 22: 42–47.

Asland, C.E.; Rejmanek, M. 2010. Avian use of introduced plants: ornithologist records illuminate interspecific associations and research needs. Ecological Applications. 20: 1005–1020.

Austin, D.l F. 1999. Ethnobotany of Florida's weedy vines. In: Jones, D.T.; Gamble, B.W., eds. Florida's garden of good and evil: Proceedings of the 1998 joint symposium of the Florida Exotic Pest Plant Council and the Florida Native Plant Society. West Palm Beach, FL: South Florida Water Management District: 171-179.

Ball, D.M.; Pederson, J.F.; Lacefield, G.D. 1993. The tall fescue entophyte. American Scientist. 81: 370–379.

Banasiak, S.E.; Meiners, S.J. 2009. Long term dynamics of *Rosa multiflora* in a successional system. Biological Invasions. 11: 215–224.

Barden, L.S. 1987. Invasion of *Microstegium vimineum* (Poaceae), an exotic, annual, shade-tolerant, C4 grass, in a North Carolina floodplain. American Midland Naturalist. 118: 40–45.

Bargeron, C.T.; Douce, G.K.; Moorhead, D.J. [and others]. 2006. Forestry images. FHTET–2005–14. www.forestryimages.org: development, methodology and technology 1995-2005. [Date accessed: December 9, 2010].

Bargeron, C.T.; Evans, C.W.; Moorhead, D.J. [and others]. 2007. Invasive plants of the United States: identification and control. [DVD–ROM]. FHTET–2007–03. Athens, GA: The University of Georgia, Bugwood network; U.S. Department of Agriculture Forest Service, Forest Health Technology Enterprise Team. 218 p.

Bargeron, C.T.; Moorhead, D.J. 2007. EDDMapS—early detection and distribution mapping system for the Southeast Exotic Pest Plant Council. Wildland Weeds. 10: 4–8.

Barkworth, M.E.; Capels, K.M.; Long, S. [and others], eds. 2007. Flora of North America north of Mexico. Magnoliophyta: Commelinidae (in part): Poaceae, part 1. New York: Oxford University Press. 911 p. Vol. 24.

Barley, F.A. 1944. *Schinus* L. Brittonia. 5: 160–198.

Barnes, T.G. 2007. Using herbicides to rehabilitate native grasses. Natural Areas Journal. 27: 56–65.

Barnes, T.G.; Madison, L.A.; Sole, J.D.; Lacki, M.J. 1995. An assessment of habitat quality for northern bobwhite in tall fescue dominated fields. Wildlife Society Bulletin. 23: 231–237.

Bergmann, C.; Swearingen, J.M. 2009. Multiflora rose fact sheet. Plant Conservation Alliance's Alien Plant Working Group: least wanted plants. 2 p. http://www.nps.gov/plants/alien/fact/romu1.htm. [Date accessed: October 27, 2010].

Blaustein, R.J. 2001. Kudzu's invasion into Southern United States life and culture. In: McNeely, J.A., ed. The great reshuffling: human dimensions of invasive alien species. Cambridge, UK: IUCN Publications Services Unit: 65–72.

Brandon, A.L.; Gibson, D.J.; Middleton, B.A. 2004. Mechanisms for dominance in an early successional old field by the invasive non-native *Lespedeza cuneata* (Dum. Cours.) G. Don. Biological Invasions. 6: 483–493.

Britton, K.O.; Duerr, D.A., II; Miller, J.H. 2005. Understanding and controlling nonnative forest pests in the South. In: Rauscher, H.M.; Johnsen, K., eds. Southern forest science: past, present, and future. Gen. Tech. Rep. SRS–75. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 133–153. Chapter 14.

Brook, R.M. 1989. Review of literature on *Imperata cylindrica* (L.) Raeuschel with particular reference to South East Asia. Tropical Pest Management. 35: 12–25.

Brooks, M.L.; D'Antonio, C.M.; Richardson, D.M. [and others]. 2004. Effects of invasive alien plants on fire regimes. BioScience. 54: 677-688.

Brooks, M.; Lusk, M. 2008. Fire management and invasive plants: a handbook. Arlington, VA: U.S. Fish and Wildlife Service. 27 p. http://www.fws.gov/invasives/pdfs/USFWS_FireMgtAndInvasivesPlants_A_Handbook.pdf. [Date accessed: July 2, 2010].

Bruce, K.A.; Cameron, G.N.; Harcombe, P.A. 1995. Initiation of a new woodland type on the Texas coastal prairie by the Chinese tallow tree [*Sapium sebiferum* (L.) Roxb.]. Bulletin of the Torrey Botanical Club. 122: 215–255.

Bruce, K.A.; Cameron, G.N.; Harcombe, P.A.; Jubinsky, G. 1997. Introduction, impact on native habitats, and management of a woody invader, the Chinese tallow-tree, *Sapium sebiferum* (L.) Roxb. Natural Areas Journal. 17: 255–260.

Bryson, C.T.; Carter, R. 2004. Biological pathways for invasive weeds. Weed Technology. 18: 1216–1220.

Bryson, C.T.; Krutz, L.J.; Erwin, G.N. [and others]. 2010. Ecotype variability and edaphic characteristics for cogongrass (*Imperata cylindrica*) populations in Mississippi. Journal Plant Sciences and Management. 3: 199–207.

Buck, L.E.; Geisler, C.C.; Schelhas, J.; Wollenberg, E., eds. 2001. Biological diversity: balancing interests through adaptive collaborative management. Boca Raton, FL: CRC Press. 465 p.

Burrell, C.C.; Marinelli, J.; Harper-Lore, B., eds. 2006. Native alternatives to invasive plants. Brooklyn, NY: Brooklyn Botanic Garden, Inc. 239 p.

Burton, M.L.; Samuelson, L.J. 2008. Influence of urbanization on riparian forest diversity and structure in the Georgia Piedmont, US. Plant Ecology. 195: 99–115.

Butterfield, B.; Rogers, W.; Siemann, E. 2004. Growth of Chinese tallow tree (*Sapium sebiferum*) and four native trees under varying water regimes. Texas Journal of Science. 56: 335–346.

Cameron, G.H.; Spencer, S.R. 1989. Rapid leaf decay and nutrient release in the Chinese tallow forest. Oecologia. 80: 222–228.

Cameron, G.N.; Glumac, E.G.; Eshelman, B.D. 2000. Germination and dormancy in seeds of *Sapium sebiferum* (Chinese tallow tree). Journal of Coastal Research. 16: 391–395.

Capo-chichi, L.J.A.; Faircloth, W.H.; Williamson, A.G. [and others]. 2008. Invasion dynamics and genotypic diversity of cogongrass (*Imperata cylindrica*) at the point of introduction in the Southeastern United States. Invasive Plant Science and Management. 1: 133–141.

Carlson, A.M.; Grochov, D.L. 2004. Effects of herbicide on the invasive biennial *Alliaria petiolata* (garlic mustard) and initial responses of native plants in a southwestern Ohio forest. Restoration Ecology. 12: 559–567.

Carrete, M.; Tella, J.L. 2008. Wild-bird trade and exotic invasions: a new link of conservation concern? Frontiers in Ecology and the Environment. 6: 207–211.

Center for Invasive Species and Ecosystem Health (CISEH). 2010. Cogongrass. www.Cogongrass.org. [Date accessed: July 20, 2011].

Chapman, E.L.; Chambers, J.Q.; Ribbeck, K.F. [and others]. 2008. Hurricane Katrina impacts on forest trees of Louisiana's Pearl River Basin. Forest Ecology and Management. 256: 883–889.

Cipollini, K.; Ames, E.; Cipollini, D. 2009. Amur honeysuckle (*Lonicera maackii*) management method impacts restoration of understory plants in the presence of white-tailed deer (*Odocoileus virginiana*). Invasive Plant Science and Management. 2: 45–54.

Clarke, M.M.; Reichard, S.H.; Hamilton, C.W. 2006. Prevalence of different horticultural taxa of ivy (*Hedera* spp., Araliaceae) in invading populations. Biological Invasions. 8: 149–157.

Collins, A.R.; Jose, S. 2009. *Imperata cylindrica*, an exotic invasive grass, changes soil chemical properties of forest ecosystems in the Southeastern United States. In: Kohli, R.K.; Singh, J.P.; Batish, D.R.; Jose, S., eds. Invasive plants and forest ecosystems. Boca Raton, FL: CRC Press: 237–247. Chapter 14.

Colton, T.F.; Alpert, P. 1998. Lack of public awareness of biological invasions by plants. Natural Areas Journal. 18: 262–266.

Conn, J.S.; Beattie, K.L.; Shephard, M.A. [and others]. 2008. Alaska *Melilotus* invasions: distribution, origin, and susceptibility of plant communities. Arctic, Antarctic, and Alpine Research. 40(2): 298–308.

Conover, M.R.; Messmer, T.A. 1996. Consequences for captive zebra finches in consuming tall fescue seeds infected with the endophytic fungus *Acremonium coenophialum*. Auk. 113: 492–495.

Conway, W.C.; Smith, L.M.; Bergan, J.F. 2002. Potential allelopathic interference by the exotic Chinese tallow tree (*Sapium sebiferum*). American Midland Naturalist. 148: 43–53.

Corley, R.N.; Woldeghebriel, A.; Murphy, M.R. 1997. Evaluation of the nutritive value of kudzu (*Pueraria lobata*) as a feed for ruminants. Animal Feed Science and Technology. 68: 183–188.

Cothran, J.R. 2004. Treasured ornamentals of southern gardens—Michaux's lasting legacy. Occassional Papers 2. Castanea: 149–157.

Davies, P.A. 1942. The history, distribution, and value of Ailanthus in North America. Transactions Kentucky Academy of Science. 9: 12–14.

Davison, V.E. 1945. Wildlife values of the lespedezas. Journal of Wildlife Management. 9: 1–9.

Deering, R.H.; Vankat, J.L. 1999. Forest colonization and developmental growth of the invasive shrub *Lonicera maackii*. American Midland Naturalist. 141: 43–50.

DeMeester, J.E.; Richter, D.B. 2010. Difference in wetland nitrogen cycling between the invasive grass *Microstegium vimineum* and a diverse plant community. Ecological Applications. 20: 609–619.

Devine, R.S. 1989. Alien invasion: America's battle with non-native animals and plants. Washington, DC: National Geographic Society. 280 p.

Dickens, R.; Buchanan, G.A. 1975. Control of cogongrass with herbicides. Weed Science. 23: 194–197.

Dirr, M.A. 1998. Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation and uses. Champaign, IL: Stipes Publishing L.L.C. 1187 p.

Donahue, C.; Rogers, W.E.; Siemann, E. 2006. Restoring an invaded prairie by mulching live *Sapium sebiferum* (Chinese tallow trees): effects of mulch on *Sapium* seed germination. Natural Areas Journal. 26: 244–253.

Donnelly, E.C. 1954. Some factors that affect palatability in sericea lespedeza (*Lespedeza cuneata*). Agronomy Journal. 46: 96–97.

Dozier, H.; Gaffney, J.J.; McDonald, S.K. [and others]. 1998. Cogongrass in the United States: history, ecology, impacts, and management. Weed Technology. 12: 737–743.

Dray, F.A., Jr.; Bennett, B.C.; Center, T.D. 2006. Invasion history of *Melaleuca quinquenervia* (Cav.) S.T. Blake in Florida. Castanea. 71: 210–225.

Drayton, B.; Primack, R.B. 1999. Experimental extinction of garlic mustard (*Alliaria petiolata*) populations: implications for weed science and conservation biology. Biological Invasions. 1: 159–167.

Drew, J.; Anderson, N.; Andow, D. 2010. Conundrums of a complex vector for invasive species control: a detailed examination of the horticultural industry. Biological Invasions. 12: 2837–2851.

Ebinger, J.E. 1983. Exotic shrubs a potential problem in natural area management in Illinois. Natural Areas Journal. 3: 3–6.

Ehrenfeld, J.G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems. 6: 502–523.

Ehrenfeld, J.G.; Kourtev, P.; Huang, W. 2001. Changes in soil function following invasions of exotic understory plants in deciduous forests. Ecological Applications. 11(5): 1287–1300.

Elith, J.; Graham, C.H.; Anderson, R.P. [and others]. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography. 29: 129–151.

Ellsworth, J.W.; Harrington, R.A.; Fownes, J.H. 2004. Seedling emergence, growth, and allocation of oriental bittersweet: effects of seed input, seed bank, and forest floor litter. Forest Ecology and Management. 190: 255–264.

Evans, C.W.; Moorhead, D.J.; Bargeron, C.T.; Douce, G.K. 2006. Invasive plants responses to silvicultural practices in the South. BW–2006–03. Athens, GA: The University of Georgia, Bugwood Network. 51 p.

Evans, J.E. 1984. Japanese honeysuckle (*Lonicera japonica*): a literature review of management practices. Natural Areas Journal. 4: 4–10.

Everest, J.W.; Powe, T.A., Jr.; Freeman, J.D. 1996. Poisonous plants of the Southeastern United States. Ext. Publ. ANR–0975. Auburn, AL: Auburn University, Agronomy Extension. 51 p.

Ewel, J.J.; Putz, F.E. 2004. A place for alien species in ecosystem restoration. Frontiers of Ecology and Environment. 2: 354–360.

Fairbrothers, D.E.; Gray, J.R. 1972. *Microstegium vimineum* (Trin.) A. Camus (Gramineae) in the United States. Bulletin of the Torrey Botanical Club. 99: 97–100.

Ferriter, A., ed. 2001. Lygodium management plan for Florida: a report from the Florida Exotic Pest Plant Council's Lygodium Task Force. Orlando, FL: Florida Exotic Pest Plant Council. 51 p.

Ferriter, A. 2007. The areawide management and evaluation of *Melaleuca* (TAME) inventory and assessment component. Gainesville, FL: University of Florida, TAME melaleuca: solutions for life. http://tame.ifas.ufl.edu/. [Date accessed: July 14, 2010].

Fleming, J. 2005. Vehicle cleaning technology for controlling the spread of noxious weeds and invasive species. 0551 1203—SDTDC. San Dimas, CA: U.S. Department of Agriculture Forest Service, Technology and Development Program, Fire Management. 27 p.

Flora of North America Association. 2009. Flora of North America: the flora. http://www.fna.org/FNA. [Date accessed: November 15, 2010].

Flory, S.L. 2010. Management of *Microstegium vimineum* invasions and recovery of resident plant communities. Restoration Ecology. 18: 103–112.

Flory, S.L.; Clay, K. 2009. Invasive plant removal methods determines native plant community responses. Journal of Applied Ecology. 46: 434–442.

Flory, S.L.; Rudgers, J.A.; Clay, K. 2007. Experimental light treatments affect invasion success and impact of *Microstegium vimineum* on resident community. Natural Areas Journal. 27: 124–132.

Fordham, I.M.; Clevidence, B.A.; Wiley, E.R.; Zimmerman, R.H. 2001. Fruit of autumn olive: a rich source of lycopene. HortScience. 36: 1136–1137.

Forseth, I.N.; Teramura, A.H. 1987. Field photosynthesis, microclimate and water relations of an exotic temperate liana, *Pueraria lobata*, kudzu. Oecologia. 71: 262–267.

Forseth, I.N., Jr.; Innis, A.F. 2004. Kudzu (*Pueraria montana*): history, physiology, and ecology combine to make a major ecosystem threat. Critical Reviews in Plant Sciences. 23: 401–413.

Fowler, S.P.; Larson, K.C. 2004. Seed germination and seedling recruitment of Japanese honeysuckle in a central Arkansas natural area. Natural Areas Journal. 24: 49–53.

Foxcroft, L.C. 2004. An adaptive management framework for linking science and management of invasive alien plants. Weed Technology. 18: 1275–1277.

Frey, M.N.; Herms, C.P.; Cardina, J. 2007. Cold weather applications of glyphosate for garlic mustard (*Alliaria petiolata*) control. Weed Technology. 21: 656–660.

Gan, J.; Miller, J.H.; Wang, H.; Taylor, J.W. 2009. Invasion of tallow tree in the Southern U.S. forests: influencing factors and implications for mitigation. Canadian Journal Forest Research. 39: 1346–1356.

Gesch, D.; Oimoen, M.; Greenlee, S. [and others]. 2002. The national elevation dataset. Photogrammetric Engineering and Remote Sensing. 68: 5–11.

Gilman, E.M. 1957. Grasses of the Tidewater-Piedmont Region of Northern Virginia and Maryland. Castanea. 22: 4-105.

Glahn, J.F.; Flynt, R.D.; Hill, E.P. 1994. Historical use of bamboo/cane as blackbird and starling roosting habitat: implications for roost management. Journal of Field Ornithology. 65: 237–246.

Glasgow, L.S.; Matlack, G.R. 2006. The effects of prescribed burning and canopy openness on establishment of two non-native plant species in a deciduous forest, southeast Ohio, USA. Forest Ecology and Management. 238: 319–329.

Gomez-Aparicio, L.; Canham, C.D. 2008. Neighbourhood analyses of the allelopathic effects of the invasive tree *Ailanthus altissima* in temperate forests. Journal of Ecology. 96: 447–458.

Gordon, D.R.; Thomas, K.P. 1997. Florida's invasion by nonindigenous plants: history, screening and regulation. In: Simberloff, D.; Schmidtz, D.C.; Brown, T.C., eds. Strangers in paradise: impact and management of nonindigenous species in Florida. Washington, DC: Island Press: 21–37.

Gray, R.S. 1950. Chinese tallow, a four-way crop. Farm Journal. 74: 124.

Greenberg, C.H.; Smith, L.M.; Levey, D.J. 2002. Fruit fate, seed germination and growth of an invasive vine—an experimental test of "sit and wait" strategy. Biological Invasions. 3: 363–372.

Greenberg, C.H.; Walter, S.T. 2010. Fleshy fruit removal and nutritional composition of winter-fruiting plants: a comparison of non-native invasive and native species. Natural Areas Journal. 30: 312–321.

Greenlee, J. 1992. The encyclopedia of ornamental grasses: how to grow and use over 250 beautiful and versatile plants. New York: Michael Friedman Publishing Group, Inc. 186 p.

Gunn, C.R. 1959. A flora of Bernheim Forest, Bullitt County, Kentucky. Castanea. 24: 61–98.

Hansen, M.; Clevenger, A. 2005. The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. Biological Conservation. 125: 249–259.

Hanula, J.L.; Horn, S.; Taylor, J.W. 2009. Chinese privet (*Ligustrum sinense*) removal and its effect on native plant communities of riparian forests. Invasive Plant Science and Management. 2: 292–300.

Harper, R.M. 1900. Notes on the flora of middle Georgia. Bulletin. Torrey Botanical Gardens Club. 27: 320–341.

Harper, F., ed. 1958. The travels of William Bartram: Naturalist's Edition. Reprint. New Haven, CT: Yale University Press, 1958. Athens, GA: University of Georgia Press, 1998. 727 p.

Harrington, T.B.; Miller, J.H. 2005. Effects of application rate, timing, and formulation of glyphosate and triclopyr on control of Chinese privet (*Ligustrum sinense*). Weed Technology. 19: 47–54.

Hartman, K.M.; McCarthy, B.C. 2004. Restoration of a forest understory after removal of an invasive shrub, amur honeysuckle (*Lonicera maackii*). Restoration Ecology. 12: 154–165.

Hawkins, G.E. 1955. Consumption and digestibility of lespedeza sericea hay and alfalfa hay plus gallotannin. Journal of Dairy Science. 38: 237–243.

Heywood, V.H. 1989. Patterns, extents and modes of invasions by terrestrial plants. In: Drake, J.A.; Mooney, H.A.; Di Castrie, F. [and others], eds. Biological invasion: a global perspective. Chichester, UK: John Wiley: 31–60.

Hickman, J.E.; Wu, S.; Mickley, L.J.; Lerdau, M.T. 2010. Kudzu (*Pueraria montana*) invasion doubles emissions of nitric oxide and increases ozone pollution. Proceedings of the National Academy of Sciences. 107: 10,115-10,119.

Holm, L.G.; Pucknett, D.L.; Pancho, J.B.; Herberger, J.P. 1977. The world's worst weeds: distribution and biology. Honolulu: University of Honolulu Press of Hawaii. 609 p.

Holmes, T.P.; Aukema, J.E.; Von Holle, B. [and others]. 2009. Economic impacts of invasive species in forests: past, present, and future. Annals of the New York Academy of Sciences. 1162: 18–38.

Honu, Y.A.K.; Gibson, D.J. 2008. Patterns of invasion: trends in abundance of understory vegetation, seed rain, and seed bank from forest edge to interior. Natural Areas Journal. 28: 228–239.

Hosmer, D.W.; Lemeshow, S. 2000. Applied logistic regression. New York: Wiley-Interscience. 392 p.

Howes, F.N. 1949. The Chinese tallow tree (*Sapium sebiferum* Roxb.)—a source of drying oil. Kew Bulletin. 4: 573–580.

Hu, S.Y. 1961. The economic botany of the Paulownias. Economic Botany. 15: 11–27.

Hu, S.Y. 1979. Ailanthus. Arnoldia. 39: 29–50.

Hunt, K.W. 1947. The Charleston woody flora. American Midland Naturalist. 37: 670–756.

Invasive Species Advisory Council. 2009. Biofuels: cultivating energy, not invasive species. The National Invasive Species Council white paper, August 11, 2009. http://www.doi.gov/NISC/home_documents/BiofuelWhitePaper.pdf. [Date accessed: September 12, 2011].

Jessup, R.W. 2009. Development and status of dedicated energy crops in the United States. Vitro Cellulose Development Biology–Plant. 45: 282–290.

Jewett, D.K.; Jiang, C.J.; Britton, K.O. [and others]. 2003. Characterizing specimens of kudzu and related taxa with RAPD's. Castanea. 68: 254–260.

Jiménez-Valverde, A. 2011. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modelling. Global Ecology and Biogeography. 21(4): 498-507.

Jiménez-Valverde, A.; Lobo, J.M. 2006. The ghost of unbalanced species distribution data in geographical model predictions. Diversity and Distributions. 12: 521–524.

Johnson, J.; Griffin, S.; Taylor, J. 2009. Aerial glyphosate application to control privet in mature hardwood stands. Macon, GA: Georgia Forestry Commission. http://www.dowagro.com/PublishedLiterature/dh_0341/0901b80380341a00.pdf?filepath=ivm/pdfs/&fromPage=GetDoc. [Date accessed: February 2, 2010].

Jones, R.H.; McLeod, K.W. 1990. Growth and photosynthetic responses to a range of light environments in Chinese tallowtree and Carolina ash seedlings. Forest Science. 36: 851–862.

Jordan, N.; Becker, R.; Gunsolus, J. [and others]. 2003. Knowledge networks: an avenue to ecological management of invasive weeds. Weed Science. 51: 271–277.

Jose, S.; Cox, J.; Miller, D.L. [and others]. 2002. Alien plant invasions: the story of cogongrass in southeastern forests. Journal of Forestry. 100: 41–44.

Jubinsky, G.; Anderson, L.C. 1996. The invasive potential of Chinese tallow-tree (*Sapium sebiferum* Roxb.) in the Southeast. Castanea. 61:226-231.

Kaeser, M.J.; Kirkman, L.K. 2010. Field and restoration guide to common native warm-season grasses of the longleaf pine ecosystem. Newton, GA: Joseph W. Jones Ecological Research Center at Ichauway. 71 p.

Kalburtji, K.L.; Mosjidis, J.A. 1992. Effects of sericea lespedeza residues on warm-season grasses. Journal of Range Management. 45: 441–444.

Kaufman, S.R.; Kaufman, W. 2007. Invasive plants: guide to identification and the impacts and control of common North American species. Mechanicsburg, PA: Stackpole Books. 458 p.

King, S.E.; Grace, J.B. 2000. The effects of soil flooding on the establishment of cogongrass (*Imperata cylindrica*), a nonindigenous invader of the Southeastern United States. Wetlands. 20: 300–306.

Klepac, J.; Rummer, R.B.; Hanula, J.L.; Horn, S. 2007. Mechanical removal of Chinese privet. Res. Pap. SRS–43. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 5 p.

Kowarik, I.; Saumel, I. 2008. Water dispersal as an additional pathway to invasions by the primarily wind-dispersed *Ailanthus altissima*. Plant Ecology. 198: 241–252.

Lady Bird Johnson Wildflower Center. 2007. *Phyllostachys aurea* Carr. ex. A. & C. Rivire. [Online]. In: Invasive plant database Texasinvasives.org. Texas Invasive Plant and Pest Council (Producer). http://www.texasinvasives.org/plant_database/detail.php?symbol=PHAU8. [Date accessed: November 10, 2010].

Landenberger, R.E.; Kota, N.L.; McGraw, J.B. 2007. Seed dispersal of the non-native tree *Ailanthus altissima* into contrasting environments. Plant Ecology. 192: 55–70.

Langdon, K.R.; Johnson, K.D. 1994. Additional notes on invasiveness of *Paulownia tomentosa* in natural areas. Natural Areas Journal. 14: 139–140.

Langeland, K.A.; Burks, K.C., eds. 1998. Identification and biology of nonnative plants in Florida's natural areas. Gainesville, FL: University of Florida. 165 p.

Langeland, K.A.; Cherry, H.M.; McCormick, C.M.; Craddock Burks, K.A. 2008. Identification and biology of nonnative plants in Florida's natural areas. Gainesville, FL: University of Florida. 193 p.

Langeland, K.A.; Ferrell, J.A.; Sellers, B. [and others]. 2009. Control of nonnative plants in natural areas of Florida. SP–242. Gainesville, FL: University of Florida, Institute of Food and Agricultural Sciences. 31 p. http://edis.ifas.ufl.edu/pdffiles/WG/WG20900.pdf. [Date accessed: August 28, 2011].

Larson, K.C.; Fowler, S.P.; Walker, J.C. 2002. Lack of pollinators limits fruit set in exotic Lonicera japonica. American Midland Naturalist. 148: 54–60.

Lawrence, J.G.; Colwell, A.; Sexton, O.J. 1991. The ecological impact of allelopathy in *Ailanthus altissima* (Simaroubaceae). American Journal of Botany. 78: 948–958.

Lewandowski, I.; Scurlock, J.M.O.; Lindvall, E.; Christou, M. 2003. The development and current status of perennial rhizomatous grasses as energy crops in the U.S. and Europe. Biomass and Bioenergy. 25: 335–361.

Liebhold, A.M.; McDonald, W.L.; Bergdahl, D.; Mastro, V.C. 1995. Invasion by exotic forest pests: a threat to forest ecosystems. Forest Science Monograph. 30: 1–49.

Lieux, M.H. 1975. Dominant pollen types recovered from commercial Louisiana honeys. Economic Botany. 29: 87–96.

Lippincott, C.L. 2000. Effects of *Imperata cylindrica* (L.) Beauv. (cogongrass) invasion of fire regime in Florida sandhill (USA). Natural Areas Journal. 20: 140–149.

Liu, C.; Berry, P.M.; Dawson, T.P.; Pearson, R.G. 2005. Selecting thresholds of occurrence in the prediction of species distributions. Ecography. 28: 385–393.

Lobo, J.M.; Jiménez-Valverde, A.; Real, R. 2008. AUC: a misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography. 17:145-151.

Loewenstein, N.J.; Loewenstein, E.F. 2005. Non-native plants in the understory of riparian forests across a land use gradient in the Southeast. Urban Ecosystems. 8: 79–91.

Logan, R.H.; Hoveland, C.S.; Donnelly, E.D. 1969. A germination inhibitor in the seedcoat of sericea [*Lespedeza cuneata* (Dumont) G. Don]. Agronomy Journal. 61: 265–266.

Luginbuhl, J-M.; Harvey, T.E.; Green, J.T., Jr. [and others]. 1999. Use of goats as biological agents for the renovation of pastures in the Appalachian region of the United States. Agroforestry. 44: 241–252.

Luken, J.O.; Thieret, J.W. 1996. Amur honeysuckle, its fall from grace. Bioscience. 46: 18–24.

MacDonald, G.E. 2004. Cogongrass (*Imperata cylindrica*)–biology, ecology, and management. Critical Reviews in Plant Science. 23: 367–380.

Mack, R.; Simberloff, D.; Lonsdale, W. [and others]. 2000. Biotic invasions: causes, epidemiology, global consequences and control. Issues in Ecology. 5: 1–21.

Maddox, V.; Byrd, J., Jr.; Serviss, B. 2010. Identification and control of invasive privets (*Ligustrum* spp.) in the middle Southern United States. Invasive Plant Science and Management. 3: 482–488.

Manel, S.; Williams, H.C.; Ormerod, S.J. 2002. Evaluating presence-absence models in ecology: the need to account for prevalence. Journal of Applied Ecology. 38: 921–931.

Martin, M.R.; Tipping, P.W.; Sickman, J.O. 2009. Invasion by an exotic tree alters above and belowground ecosystem components. Biological Invasions. 11: 1883–1894.

Marvin, D.C.; Bradley, B.A.; Wilcove, D.S. 2008. Web-based regional mapping of plant invasion based on expert opinion. http://invasive.princeton.edu. [Date assessed: January 6, 2009].

McNab, W.H.; Loftis, D.L. 2002. Probability of occurrence and habitat features for oriental bittersweet in an oak forest in the Southern Appalachian Mountains, USA. Forest Ecology and Management. 155: 45–54.

McPherson, G.R. 2004. Linking science and management to mitigate impacts of nonnative plants. Weed Technology. 18: 1185–1188.

Medal, J.; Bustamente, N.; Overholt, W.A. [and others]. 2010. Biological control of tropical soda apple (Solanaceae) in Florida: post-release evaluation. Florida Entomologist. 93: 130–131.

Meekins, J.F.; McCarthy, B.C. 2001. Effect of environmental variation on the invasive success of a nonindigenous forest herb. Ecological Applications. 11: 1336–1348.

Merriam, R.W. 2003. The abundance, distribution and edge associations of six non-indigenous, harmful plants across North Carolina. Journal of the Torrey Botanical Society. 130: 283–291.

Merriam, R.W.; Feil, E. 2002. The potential impact of an introduced shrub on native plants diversity and forest regeneration. Biological Invasions. 4: 369–373.

Messing, R.H.; Wright, M.G. 2006. Biological control of invasive species: solution or pollution? Frontiers of Ecology and Environment. 4: 132–140.

Meyerson, L.A.; Reaser, J.K. 2003. Bioinvasions, bioterrorism, and biosecurity. Frontiers of Ecology and Environment. 1: 307–314.

Miller, J.H. 1990. *Ailanthus altissima* (Mill.) Swingle, Ailanthus, Simaroubaceae, Quassia family. In: Silvics of North America, Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 101–104. Vol. 2.

Miller, J.H. 2003. Nonnative invasive plants of southern forests: a field guide for identification and control. Gen. Tech. Rep. SRS–62. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 93 p. http://www.srs.fs.usda.gov/fia/manual/exotic_pest_plants.htm. [Date accessed: July 2, 2010].

Miller, J.H.; Chambliss, E.B.; Loewenstein, N.J. 2010a (slightly revised 2013). A field guide for the identification of invasive plants in southern forests. Gen. Tech. Rep. SRS–119. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 125 p.

Miller, J.H.; Manning, S.; Enloe, S.F. 2010b (slightly revised 2013). A field guide for the management of invasive plants in southern forests. Gen. Tech. Rep. SRS–131. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 120 p.

Miller, J.H.; Edwards, B. 1983. Kudzu: where did it come from? And how can we stop it? Southern Journal of Applied Forestry. 7: 165–169.

Miller, J.H.; Schelhas, J. 2008. Adaptive collaborative restoration: a key concept for invasive plant management. In: Kohli, R.K.; Singh, J.P.; Batish, D.R.; Jose, S., eds. Invasive plants and forest ecosystems. Boca Raton, FL: CRC Press: 251–265. Chapter 15.

Moran, V.C.; Hoffmann, J.H.; Zimmermann, H.G. 2005. Biological control of invasive alien plants in South Africa: necessity, circumspection, and success. Frontiers of Ecology and Environment. 3: 77–83.

Morgan, E.C.; Overholt, W.A. 2005. Potential allelopathic effects of Brazilian pepper [(*Schinus terebinthifolius*) Raddi, Anacardiaceae)] aqueous extract on germination and growth of selected Florida native plants. Journal of the Torrey Botanical Society. 132: 11–15.

Morse, L.E.; Randall, J.M.; Benton, N. [and others]. 2004. An invasive species assessment protocol: evaluating non-native plants for their impact on biodiversity. Version 1. Arlington, VA: NatureServe. http://www.natureserve.org/library/invasiveSpeciesAssessmentProtocol.pdf. [Date accessed: October 8, 2010].

Morton, J.F. 1976. Pestiferous spread of many ornamental and fruit species in south Florida. Proceedings Florida State Horticultural Society. 89: 348–353.

Morton, J.F. 1978. Brazilian pepper—its impact on people, animals and the environment. Economic Botany. 32: 353–359.

Moser, W.K.; Barnard, E.L.; Billings, R.F. [and others]. 2009. Impacts of nonnative invasive species on U.S. forests and recommendations for policy and management. Journal of Forestry. 107: 320–327.

Mueller, T.C.; Robinson, D.K.; Beeler, J.E. [and others]. 2003. *Dioscorea oppositifolia* L. phenotypic evaluations and comparison of control strategies. Weed Technology. 17: 705–710.

Mullahey, J.J. 1996. Tropical soda apple (*Solanum viarum* Dunal), a biological pollutant threatening Florida. Castanea. 61: 255–260.

Munger, G.T. 2003. *Elaeagnus umbellata*. In: Fire effects Information System. [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). http://www.fs.fed.us/database/feis/. [Date accessed: December 29, 2010].

National Invasive Species Council. 2001. Meeting the invasive species challenge: management plan. Washington, DC: National Invasive Species Council. 74 p.

Nelson, G. 1994. Trees of Florida. A reference and field guide. Sarasota, FL: Pineapple Press. 208 p.

North Carolina State University (NCSU). 2010. Flora of the Southeastern United States. http://www.herbarium.unc.edu/seflora/about.htm. [Date accessed: October 25, 2011].

National Research Council (NRC). 2002. Predicting invasions of nonindigenous plants and plant pests. Washington, DC: National Academy Press. 194 p.

Nuzzo, V. 1999. Invasion pattern of the herb garlic mustard (*Alliaria petiolata*) in high quality forests. Biological Invasions. 1: 169–179.

O'Brien, R.E.; Skelton, D.W. 1946. The production and utilization of kudzu. Station Bulletin 438. Starkville, MS: Mississippi State College Agricultural Experiment. 25 p.

Oswalt, C.M.; Oswalt, S.N.; Clatterbuck, W.K. 2007. Effects of *Microstegium vimineum* (Trin.) A. Camus on native woody species density and diversity in a productive mixed-hardwood forest in Tennessee. Forest Ecology and Management. 242: 727–732.

Oswalt, S.N. 2010. Chinese tallow (*Triadica sebifera* (L.) Small) population expansion in Louisiana, east Texas, and Mississippi. Res. Note SRS–20. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 5 p.

Pappert, R.A.; Hamrick, J.L.; Donovan, L.A. 2000. Genetic variation in *Pueraria lobata* (Fabaceae), an introduced, clonal, invasive plant of the Southeastern United States. American Journal of Botany. 87: 1240–1245.

Patterson, D.T.; McGowan, T.M.; Mullahey, J.J.; Westbrooks, R.G. 1997. Effects of temperature and photoperiod on tropical soda apple and its potential range in the U.S. Weed Science. 45: 404–408.

Pattison, R.R.; Mack, R.N. 2008. Potential distribution of the invasive tree *Triadica sebifera* (Euphorbiaceae) in the United States: evaluating CLIMEX predictions with field trials. Global Change Biology. 14: 813–826.

Pattison, R.R.; Mack, R.N. 2009. Environmental constraints on the invasion of *Triadica sebifera* in the Eastern United States: an experimental field assessment. Oecologia. 158: 591–602.

Peng, N.; Prasain, J.; Dai, Y. [and others]. 2009. Chronic dietary kudzu isoflavones improve components of metabolic syndrome in stroke-prone spontaneously hypertensive rats. Journal of Agricultural and Food Chemistry. 57: 7268–7273.

Perrings, C.; Williamson, M.; Barbier, E.B. [and others]. 2002. Biological invasion risks and the public good: an economic perspective. Conservation Ecology. http://www.ecologyandsociety.org/vol6/iss1/art1/. [Date accessed: December 9, 2010].

Pfeiffer, J.M.; Voeks, R.A. 2008. Biological invasions and biocultural diversity: linking ecological and cultural systems. Environmental Conservation. 35: 281–293.

Phillips, S.J.; Anderson, R.P.; Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling. 190: 231–259.

Pieters, A.J. 1950. Sericea and other perennial lespedezas for forage and soil conservation. Circ. 863. Washington, DC: U.S. Department of Agriculture. 48 p.

Pimentel, D., ed. 2002. Biological invasions: economic and environmental costs of alien plant, animal, and microbe species. Washington, DC: CRC Press. 369 p.

Pimentel, D.; Lach, L.; Zuniga, R.; Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience. 50: 53–65.

Plass, W.T. 1975. An evaluation of trees and shrubs for planting surface-mine spoils. Res. Paper. NE–137. Upper Darby, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 8 p.

Pooler, M.R.; Dix, R.L.; Feely, J. 2002. Interspecific hybridization between the native bittersweet, *Celastrus scandens*, and the introduced invasive species, *C. orbiculatus*. Southeastern Naturalist. 1: 69–76.

PRISM Climate Group, Oregon State University, Northwest Alliance for Computational Science & Engineering 2008. PRISM Climate Group Maps and Data. http://www.prism.oregonstate.edu/. [Date accessed: March 18, 2010].

Radford, A.E.; Ahles, E.H.; Bell, C.R. 1964. Guide to the vascular flora of the Carolinas. Chapel Hill, NC: University of North Carolina Press. 383 p.

Randall, J.M. 2007. Partnering to mutual benefit. In: Harper-Lore, B.L.; Johnson, M.; Skinner, M.W., eds. Roadside weed management. Washington, DC: U.S. Department of Transportation, Federal Highway Administration: 20-21.

Randall, J.M.; Marinelli, J., eds. 1996. Invasive plants: weeds of the global garden. Handb. 149. Brooklyn, NY: Brooklyn Botanic Garden. 111 p.

Rehder, A. 1940. Manual of cultivated trees and shrubs. New York: MacMillan Publishing Co., Inc. 996 p.

Renne, I.J.; Barrow, W.C.; Johnson-Randall, L.A.; Bridges, W.C. 2002. Generalized avian dispersal syndrome contributes to Chinese tallow tree (*Sapium sebiferum*, Euphorbiaceae) invasiveness. Diversity and Distributions. 8: 285–295.

Renne, I.J.; Gauthreaux, S.A, Jr.; Gresham, C.H. 2000. Seed dispersal of the Chinese tallow tree [*Sapium sebiferum* (L.) Roxb.] by birds in coastal South Carolina. American Midland Naturalist. 144: 202–215.

Renwick, J.A.A.; Zhang, W.; Haribal, M. [and others]. 2001. Dual chemical barriers protect a plant against different larval stages of an insect. Journal of Chemical Ecology. 27: 1575–1583.

Roberts, K.J.; Anderson, R.C. 2001. Effect of garlic mustard [*Alliaria petiolata* (Beib. Cavara & Grande)] extracts on plants and arbuscular mycorrhizal (AM) fungi. American Midland Naturalist. 146: 146–152.

Rodgers, C.L.; Shake, R.E. 1965. Survey of vascular plants in Bearcamp Creek watershed. Castanea. 30: 149–166.

Rogers, V.L.; Stinson, K.A.; Finzi, A.C. 2008. Ready or not, garlic mustard is moving in: *Alliaria petiolata* as a member of Eastern North American forests. BioScience. 58: 426–436.

Rogers, W.E.; Siemann, E. 2003. Effects of simulated herbivory and resources on Chinese tallow tree (*Sapium sebiferum*, Euphorbiaceae) invasion of native coastal prairie. American Journal of Botany. 90: 243–249.

Sage, R.F.; Coiner, H.A.; Way, D.A. [and others]. 2009. Kudzu [*Pueraria montana* (Lour.) Merr. variety *lobata*]: a new source of carbohydrate for bioethanol production. Biomass and Bioenergy. 33: 57–61.

Sasek, T.W.; Strain, B.R. 1988. Effects of carbon dioxide enrichment on the growth and morphology of kudzu (*Pueraria lobata*). Weed Science. 36: 28–36.

Sauer, L.J. 1998. The once and future forest: a guide to forest restoration strategies. Washington, DC: Island Press. 380 p.

Scheld, H.W.; Cowles, J.R. 1981. Woody biomass potential of the Chinese tallow tree. Economic Botany. 35: 391–397.

Schelhas, J.; Buck, L.; Geisler, C. 2001. Introduction: the challenge of adaptive collaborative management. In: Buck, L.; Geisler, C.; Schelhas, J.; Wollenberg. E., eds. Biological diversity: balancing interests through adaptive collaborative management. Boca Raton, FL: CRC Press: 19–35.

Schierenbeck, K.A. 2004. Japanese honeysuckle (*Lonicera japonica*) as an invasive species: history, ecology, and context. Critical Reviews in Plant Sciences. 23: 391–400.

Schittler, E.J. 1973. Introduction to vinca alkaloids. In: Taylor, W.; Farnsworth, N., eds. The vinca alkaloids. New York: Mariel Dekker, Inc.: 1–34.

Schmidt, K.A.; Whelan, C.J. 1999. Effects of exotic *Lonicera* and *Rhamnus* on songbird nest predation. Conservation Biology. 13: 1502–1506.

Scurlock, J.M.O.; Dayton, D.C.; Hames, B. 2000. Bamboo: an overlooked biomass resource? ORNL/TM–1999/264. Oak Ridge, TN: Oak Ridge National Laboratory. 34 p.

Shelton, M.G.; Cain, M.D. 2002. Potential carry-over of seeds from 11 common shrub and vine competitors of loblolly and shortleaf pines. Canadian Journal of Forest Research. 32: 412–419.

Shulman, B.W.; Mattice, J.D.; Cain, M.D.; Gbur, E.E. 2004. Evidence for allelopathic interference of Japanese honeysuckle (*Lonicera japonica*) to loblolly and shortleaf pine regeneration. Weed Science. 52: 433–439.

Shupe, T.F.; Groom, L.H.; Eberhardt, T.L. [and others]. 2006. Mechanical and physical properties of composite panels manufactured from Chinese tallow tree furnish. Forest Products Journal. 56: 64–67.

Shurtleff, W.; Aoyagi, A. 1985. The book of kudzu, a culinary and healing guide. Wayne, NJ: Avery Publishing Group Inc. 102 p.

Shuster, W.D.; Herms, C.P.; Frey, M.N. [and others]. 2005. Comparison of survey methods for an invasive plant at the subwatershed level. Biological Invasions. 7: 393–403.

Sieg, C.H.; Denslow, J.S.; Huebner, C.D.; Miller, J.H. 2010. The role of the Forest Service in nonnative invasive plant research. In: Dix, M.E.; Britton, K., eds. A dynamic invasive species research vision: opportunities and priorities 2009–29. Gen. Tech. Rep. WO–79. Washington, DC: U.S. Department of Agriculture Forest Service: 35–42.

Siemann, E.; Rogers, W.E. 2003. Reduced resistance of invasive varieties of the alien tree *Sapium sebiferum* to a generalist herbivore. Oecologia. 135: 451–457.

Simberloff, D. 1996. Impacts of introduced species in the United States. Consequences. 2: 1–13.

Simberloff, D. 2001. Biological invasions—how are they affecting us, and what can we do about them? Western North American Naturalist. 61: 308–315.

Simberloff, D.; Ingrid, M.P.; Windle, P.N. 2005. Introduced species policy, management, and future research needs. Frontiers of Ecology and Environment. 3: 12–20.

Skulman, B.W.; Mattice, J.D.; Cain, M.D.; Gbur, E.E. 2004. Evidence for allelopathic interference of Japanese honeysuckle (*Lonicera japonica*) to loblolly and shortleaf pine regeneration. Weed Science. 52: 433–439.

Slaughter, B.S.; Hochstedler, W.W.; Gorchov, D.L.; Carlson, A.M. 2007. Response of *Alliaria petiolata* (garlic mustard) to five years of fall herbicide application in a southern Ohio deciduous forest. Journal of the Torrey Botanical Society. 134: 18–20.

Smith, A.E. 1989. Interference with loblolly pine (*Pinus taeda*) seedling growth by three grass species. Weed Technology. 3: 696–698.

Stapanian, M.A.; Sundberg, S.D.; Baumgarden, G.A.; Liston, A. 1998. Alien plant species composition and association with anthropogenic disturbance in North American forests. Plant Ecology. 139: 49–62.

Stohlgren, T.; Binkley, D.; Chong, G. [and others]. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs. 69: 25–46.

Stromayer, K.A.K.; Warren, R.J.; Johnson, A.S. [and others]. 1998. Chinese privet and the feeding ecology of white-tailed deer: the role of an exotic plant. Journal of Wildlife Management. 62: 1321–1329.

Sturkie, D.G.; Grimes, J.C. 1939. Kudzu, its value and use in Alabama. Circular 83. Auburn, AL: Auburn University, Agricultural Experiment Station of the Alabama Polytechnic Institute. 20 p.

Swearingen, J.M. 2000. English ivy fact sheet. Plant Conservation Alliance's Alien Plant Working Group: least wanted plants. 6 p. http://www.nps.gov/plants/alien/fact/hehe1.htm. [Date accessed: July 23, 2002].

Swingle, W.T. 1916. The early European history and the botanical name of the tree-of-heaven, *Ailanthus altissima*. Journal of the Washington Academy of Sciences. 6: 409-498.

Tabor, P. 1941. Seed production of kudzu (*Pueraria thunbergiana*) in the Southeastern United States during 1941. American Society of Agronomy. 34: 389.

Tabor, P. 1949. Cogongrass, *Imperata cylindrica* (L.) Beauv., in the Southeastern United States. Agronomy Journal. 41: 270.

Tabor, P. 1952. Comments on cogon and torpedograsses: A challenge to weed workers. Weeds. 1: 374–375.

Tang, R.C.; Carpenter, S.B.; Wittwer, R.F. [and others]. 1980. Paulownia–a crop tree for wood products and reclamation of surface-mined land. Southern Journal Applied Forestry. 4: 19–24.

Tennessee Exotic Pest Plant Council (TN–EPPC). 1996. Tennessee exotic plant management manual. Nashville, TN: Tennessee Exotic Pest Plant Council, Warner Parks Nature Center. 118 p.

Touchette, B.W.; Romanello, G.A. 2010. Growth and water relations in a central North Carolina population of *Microstegium vimineum* (Trin.) A. Camus. Biological Invasions. 12: 893–903.

Trusty, J.L.; Goertzen, L.R.; Zipperer, W.C.; Lockaby, B.G. 2007. Invasive wisteria in the Southeastern United States: genetic diversity, hybridization and the role of urban centers. Urban Ecology. 10: 379–395.

Turner, N.J.; von Aderkas, P. 2009. The North American guide to common poisonous plants and mushrooms. Portland, OR: Timber Press. 375 p.

Ulyshen, M.D.; Horn, S.; Hanula, J.L. 2010. Response of beetles (Coleoptera) at three heights to the experimental removal of an invasive shrub, Chinese privet (*Ligustrum sinense*), from floodpain forests. Biological Invasions. 12: 1573–1579.

University of Florida, Institute of Food and Agricultural Sciences. 2007. TAME melaleuca: solutions for your life Web site. http://tame.ifas.ufl.edu/. [Date accessed: June 23, 2010].

U.S. Census Bureau, Geography Division. 2000. Census 2000 TIGER/Linefiles. http://www.census.gov/geo/www/tiger/tgrcd108/tgr108cd.html. [Date accessed: December 10, 2010].

U.S. Congress, Office of Technology Assessment (OTA). 1993. Harmful non-indigenous species in the United States. OTA–F–565. Washington, DC: U.S. Government Printing Office. 391 p.

U.S. Department of Agriculture Forest Service. 2008a. Nonnative invasive plant data tool. http://srsfia2.fs.fed.us/data_center/index.shtml. [Date accessed: January 6].

U.S. Department of Agriculture Forest Service. 2008b. Nonnative invasive species of southern forests and grasslands, compiled by a southern regional task force for the assessment of nonnative invasive species. http://www.invasive.org/south/taskforce.html. [Date accessed: June 25, 2010].

U.S. Department of Agriculture Forest Service, Natural Resources Conservation Service. 2010. The PLANTS database. http://plants.usda.gov. [Date accessed: July 12, 2010].

Vaughn, S.F.; Berhow, M.A. 1999. Allelochemicals isolated from tissues of the invasive garlic mustard (*Alliaria petiolata*). Journal of Chemical Ecology. 25: 2395–2503.

Vellend, M. 2002. A pest and an invader: white-tailed deer (*Odocoileus virginianus* Zimm.) as a seed dispersal agent for honeysuckle shrubs (*Lonceria* L.). Natural Areas Journal. 22: 230–234.

Volin, J.C.; Lott, M.S.; Muss, J.D.; Owen, D. 2004. Predicting rapid invasion of the Florida Everglades by Old World climbing fern (*Lygodium microphyllum*). Diversity and Distributions. 10: 439–446.

Von der Lippe, M.; Kowarik, I. 2006. Long-distance dispersal of plants by vehicles as a driver of plant invasions. Conservation Biology. 21: 986–996.

Vines, R.A. 1960. Trees, shrubs, and woody vines of the Southwest. Austin, TX: University of Texas Press. 1104 p.

Wang, S.C.; Huffman J.B.; Rockwood D.L. 1982. Qualitative evaluation of fuelwood in Florida—a summary report. Economic Botany. 36: 381–388.

Wells, E.F.; Brown, R.L. 2000. An annotated checklist of the vascular plants in the forest at historic Mount Vernon, Virginia: a legacy from the past. Castanea. 65(4): 242-257.

Westbrooks, R. 1998. Invasive plants, changing the landscape of America: fact book. Washington, DC: Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW). 109 p.

Westbrooks, R.G. 2004. New approaches for early detection and rapid response to invasive plants in the United States. Weed Technology. 18: 1469–1471.

White, O.E.; Bowden, W.M. 1947. Oriental and American bittersweet hybrids. Journal of Heredity. 38: 125–127.

Wilcove, D.S.; Rothstein, D.; Dubow, J. [and others]. 1998. Quantifying threats to imperiled species in the United States: assessing the relative importance of habitat destruction, alien species, pollution, overexploitation, and disease. BioScience. 48: 607–615.

Wilcox, J.; Beck, C.W. 2007. Effects of *Ligustrum sinense* Lour. (Chinese privet) on abundance and diversity of songbirds and native plants in a southeastern nature preserve. Southeastern Naturalist. 6: 535–550.

Willard, T.R.; Shilling, D.G.; Gaffney, J.F.; Currey, W.L. 1996. Mechanical and chemical control of cogongrass (*Imperata cylindrica*). Weed Technology. 10: 722–726.

Williams, M.C. 1980. Purposefully introduced plants that have become noxious or poisonous weeds. Weed Science. 28: 300–305.

Williams, C.E.; Railey, J.J.; Taylor, D.H. 1992. Consumption of seeds of the invasive amur honeysuckle, *Lonicera maackii* (Rupr.) Maxim., by small mammals. Natural Areas Journal. 17: 86–89.

Winberry, J.J.; Jones, D.M. 1973. Rise and decline of the “miracle vine” kudzu in the southern landscape. Southeastern Geographer. 13: 61–70.

Yurkonis, K.A.; Meiners, S.J. 2004. Invasion impacts local species turnover in a successional system. Ecology Letters. 7: 764–769.

Zou, J.; Rogers, W.E.; Siemann, E. 2008. Increased competitive ability and herbivory tolerance in the invasive plant *Sapium sebiferum*. Biological Invasions. 10: 291–302.

CHAPTER 16.
Invasive Pests—Insects and Diseases

Donald A. Duerr and Paul A. Mistretta[1]

KEY FINDINGS

- Nonnative pest species have increasing impacts in the South regardless of climate change, patterns of land ownership, or changes in the composition of vegetation.
- "New" nonnative invasive insects and diseases will have serious impacts on southern forests over the next 50 years. Some species such as emerald ash borer, laurel wilt, and thousand cankers disease are expanding rapidly; they threaten the ecological viability of their hosts throughout large areas of the South.
- Given the trend in introductions of nonnative insect pests and plant pathogens over the last 100 years, we can expect additional introductions of previously undocumented pests (insects, fungal pathogens, plant parasitic nematodes, etc.) from foreign countries that will have serious consequences for some native forest plant species.
- When host material for a given insect or disease is projected to increase over the next 50 years as a result of climate change or management choice, we can expect more pest activity; for example, more pine acreage enables more southern pine beetle damage. Conversely, if host material decreases, the overall impact of pests utilizing that host material will likely decrease.
- Very few indisputable projections can be made about the effects of climate change on native or naturalized pests. Although climate-change-induced host abundance is expected to increase the activity of some pests, others (such as gypsy moth) may become less active with warmer temperatures despite relatively similar levels of host availability.
- The scientific literature and the body of expert opinion are inconclusive in predicting the effects of climate change on many pests' activity levels, often even lacking historic trend data. However, based on anecdotal reports from professionals, and in the absence of other data, we generally assume that pest activity levels over the next 50 years will be similar to the past 50 years with respect to impact on preferred hosts.
- A significant source of uncertainty in projecting pest impacts is the adequacy of prevention and suppression methods: how effective are existing methods, compared with those that might be available in the future; how willing and able are land managers or landowners to adopt management/control methods; how much funding is available compared to the amount needed for implementation.
- Under the influence of climate warming host plants, pests and pest complexes are expected to migrate northward and to higher elevations. Because migration rates differ among the affected species, migrating plants are expected to form new associations, which will then affect the pests, their host populations, and the interactions among them. Unexpected pests very likely will become important, while some that are currently active will be less severe in their new habitats. As host plants "migrate" to the north an increase in the incidence of decline syndrome of plants in their previous range is expected.
- Although not expected to be a significant problem in the next 50 years, the migration of lower elevation plants to higher elevations could ultimately eliminate or at least severely restrict the host ranges of current high elevation plant associations. Pests that act on a restricted host base, such as the balsam woolly adelgid and butternut canker, could become far more significant ecologically in areas of relict host populations.
- Climate change will lead to extra uncertainty in decision making, especially in areas where the changes cause increased variability in local (fragmented) climate regimes that exceed historical variability of local weather patterns.

INTRODUCTION

An important part of the southern forested landscape is the array of insect and disease pests that significantly affect the management of forest resources on a relatively broad scale. The list of 21 key pests that were documented less than a decade ago (Ward and Mistretta 2002) has already expanded to 30.

The goal of this chapter is to project the behavior of insect and disease pests that we anticipate will affect forest resources over the next 50 years, based on changing climate,

[1]Donald A. Duerr is the Staff Entomologist and Paul A. Mistretta is a Staff Pathologist and Regional Pesticide Specialist, Southern Region, U.S. Department of Agriculture Forest Service, Atlanta, GA 30309.

human activity, and biologic factors. Our primary focus is on climate change and its sub-elements of temperature régime (dominated by temperature extremes), overall pattern of solar radiation, and rainfall pattern. All available climate change scenarios predict an environment in which we expect vegetation changes to occur (Iverson and others 1999). Concurrent with ecological changes will be a shift in the pests that function within an altered vegetative landscape under changed temperature, rainfall, and other climatic conditions. The impacts on pest activity, in turn, may influence the direction or scope of other changes in forest type and structure.

The focus of this chapter is the 30 species of pest insects or fungal pathogens that cause diseases projected to be of future concern, with emphasis on the following key issues:

- The historical and forecasted future spread of high threat insects and diseases
- Other pests invading southern forests and other high threat species poised to enter the region
- Expected consequences of the spread of high-threat pest species for forest productivity, ecosystem composition and biodiversity, threatened and endangered species and their habitats, watershed and soil health, carbon storage, and fire dynamics
- Potential severity of pest species threats relative to other threats and to future forest sustainability
- Forest species or populations that are likely to be lost or dramatically degraded by pests; the resulting changes in the composition of southern forests over the next 50 years; and the degree of certainty in these outcomes
- Adaptive strategies and methods for invasive pest management that could mitigate the effects of predicted future outbreaks

METHODS

In response to the issues developed above, we present a brief extract of relevant information about the pests that are well established in southern forests (Ward and Mistretta 2002); we add more detailed descriptions of several new pests or pest complexes that have emerged in the past few years; we apply the results of past research on pests and pest management to expected changes in southern forests over the next 50 years; we identify management strategies for responding to pests in a changing environment; and we identify research needed to improve our knowledge about pests with their hosts and their interactions with their changing environment, thereby enabling a more quantitative approach to forecasting in the future.

DATA SOURCES

Information for this chapter is derived from two primary sources, selected items from the extensive body of published scientific literature, and the experience of the authors and their colleagues in State and Federal agencies, universities, and other public or private organizations that are engaged either in research or field-based pest management activities. Additional information about forest pests and their control is readily available from State and Federal forestry agencies or on the Internet (two good starting points are http://fhpr8.srs.fs.fed.us/ and http://www.na.fs.fed.us/spfo/pubs/fth_pub_pages/fidl.htm). Also, appendix C contains additional resources (References) not cited here but which provide valuable additional background for understanding the biology and ecology of the pests discussed.

RESULTS

The scientific literature on climate change and other environmental considerations is summarized in appendix C, which also provides the background information on our approach to pest modeling and future projection of impacts. Below we address the pests projected to influence the forests of the South over the next 50 years, their potential damage, potentially effective management strategies, and research needed to better understand and manage them (table 16.1).

Of the 30 forest pests in the South discussed below, 21 are well established and 9 are relative newcomers. Pests are roughly evenly divided between those affecting softwoods and those affecting hardwoods.

Insect Pests of Softwoods

Balsam woolly adelgid—Impacts of balsam woolly adelgid, *Adelges piceae*, were first documented in 1957 on Fraser fir in the Southern Appalachians. The five major areas of high-elevation, spruce-fir forest in North Carolina, Tennessee, and Virginia are highly valued for their scenic and recreation values, attracting several million visitors annually (Ward and Mistretta 2002). In addition, several species of flora and fauna rely on mature spruce-fir habitat for survival, and many are found only in this environment. The balsam woolly adelgid has infested Fraser fir in all five areas. Damage caused by the adelgid has degraded scenery and recreation value and put this habitat of dependant tree species at great risk.

Table 16.1—Important insect and disease pests of southern forests

Pest	Pest's scientific name	Type of pests / abiotic factors	Origin	Forest type or species affected
Annosum root disease	*Heterobasidion annosum*	Fungus	Native	Pines in the loblolly-shortleaf and longleaf–slash forest types
Asian longhorned beetle	*Anoplophora glabripennis*	Insect	China	Most hardwoods, but especially maples.
Baldcypress leafroller	*Archips goyerana*	Insect	Native	Baldcypress in oak-gum-cypress forest type
Balsam woolly adelgid	*Adelges piceae*	Insect	Europe	Fraser fir in the spruce-fir forest type
Bark beetles (other than southern pine beetle)	*Ips avulsus, I. calligraphus, I. grandicolli,* & *Dendructonus terebrans*	Insect	Native	Pine in the loblolly-shortleaf and longleaf–slash forest types
Beech bark disease	*Nectria coccinea* var. *faginata, N. galligena* (fungi); 2 (at least) insect vectors	Complex of insects and fungi	Unknown	American beech in the oak-hickory forest type
Brown spot needle disease	*Scirrhia acicola*	Fungus	Native	Longleaf pine in the longleaf–slash forest type
Butternut canker	*Sirococcus clavigignenti-juglandacearam*	Fungus	Unknown	Butternut in the oak-hickory forest type
Chestnut blight	*Cryphonectria parasitica*	Fungus	Asia	American chestnut, chinquapins, several species of oak in the oak-hickory forest type
Dogwood anthracnose	*Discula destructiva*	Fungus	Unknown	Dogwood in the oak-hickory forest type
Dutch elm disease	*Ophiostoma ulmi* (formerly called *Ceratocystis ulmi)* & *Ophiostoma novo-ulmi* (fungi); two bark beetles	Complex of fungi and insects	Europe	All elm species
Emerald ash borer	*Agrilus planipennis*	Insect	Asia	All ash species
Forest tent caterpillar	*Malacosoma disstria*	Insect	Native	Hardwoods in the oak-gum-cypress forest type
Fusiform rust	*Cronartium fusiforme f.* sp. *fusiforme*	Fungus	Native	Loblolly and slash pines in the loblolly-shortleaf and longleaf slash types
Gypsy moth	*Lymantria dispar*	Insect	Europe and Asia	Hardwoods (all types)

(Continued)

Table 16.1—(continued) Important insect and disease pests of southern forests

Pest	Pest's scientific name	Type of pests / abiotic factors	Origin	Forest type or species affected
Hardwood borers	Various	Insect	Native	All species of hardwoods
Hemlock woolly adelgid	*Adelges tsugae*	Insect	Asia	Hemlocks
Laurel wilt	*Raffiella lauricola* (fungus), *Xyleborus glabratus* (insect)	Complex of an insect and fungus	Asia	Lauraceae, especially Redbay
Littleleaf disease	*Phytophthora cinnamomi, Pythium* sp.	Tree decline complex; fungi and site factors	Southeast Asia (likely)	Shortleaf and loblolly pines in the loblolly-shortleaf forest type
Loblolly pine decline	*As a minimum: various fungi (Lophodermium* spp.*)* and insects *(Hylastes* spp.*)*	Tree decline complex; insect and fungi	Unknown	Pines
Nantucket pine tip moth	*Rhyacionia frustrana*	Insect	Native	Pines
Oak decline	*Armillaria* sp., and other secondary fungi	Tree decline complex; site conditions and fungi	Mixed	Oaks
Oak wilt	*Ceratocystis fagacearum*	Fungus	Native	Oaks in the oak-hickory forest type
Pine reproduction weevils	*Hylobius pales, Pachylobius picivorus*	Insect	Native	Pines
Sirex woodwasp	*Sirex noctilio* (insect), *Amylostereum areolatum* (fungus)	Complex of an insect and fungus	Europe, Asia, northern Africa	Pines
Soapberry borer	*Agrilus prionurus*	Insect	Mexico	Western soapberry
Southern pine beetle	*Dendroctonus frontalis*	Insect	Native	Pines
Sudden oak death	*Phytophthora ramorum*	Fungus	Unknown	Oaks
Texas leafcutting ant	*Atta texana*	Insect	Central and South America	Pine (reproduction)
Thousand cankers disease	*Geosmithia* sp. (fungus), *Pityophthorus juglandis* (insect)	Complex of an insect and fungus	Unknown	Black walnut

The spruce-fir forests of the Southern Appalachians are declining (Dull and others 1988, Hollingsworth and Hain 1991, Nicholas and Zedaker 1990). Balsam woolly adelgid has eliminated 95 percent of mature Fraser firs, and mortality continues at a steady rate. The residual population consists of trees generally younger than 40 years. Several laws enacted to maintain limited or threatened ecosystems and preserve spruce-fir forests direct the management of Fraser fir and provide decisionmaking guidance for resource managers. Insecticides are effective for control of this adelgid in Christmas tree plantations, but they are not feasible in forested settings.

Increased temperature and decreased precipitation will likely have the effect of both shrinking the range of spruce-fir forests now isolated on mountaintops and increasing adelgid activity and damage. If these trends continue unabated, natural populations of southern Fraser fir could disappear over the next 50 years. In addition, northern firs in the Lake States, New England, and Canada may become more susceptible to infestation as a result of milder winters and greater survival of the insect.

Hemlock woolly adelgid—Hemlock woolly adelgid, *Adelges tsugae*, an Asian native, was first identified in the early 1950s in Richmond, VA. Over the past 20 years, it has expanded rapidly into the southern range of eastern hemlock (*Tsuga canadensis*) (fig. 16.1). Hemlocks generally die within five years of initial infestation by this adelgid (McClure 1987), however some trees may live longer before succumbing.

Eastern hemlock is an important component of riparian ecosystems, providing streams with cooling shade and nutrient-rich litterfall, and wildlife with winter shelter. This tree may also be important as a feeding and nesting niche for neotropical migrant birds (Rhea and Watson 1994). The ecology of Carolina hemlock, *T. caroliniana*, is less understood. Although it generally occupies drier sites on ridges and rock outcrops, it is as likely as the eastern

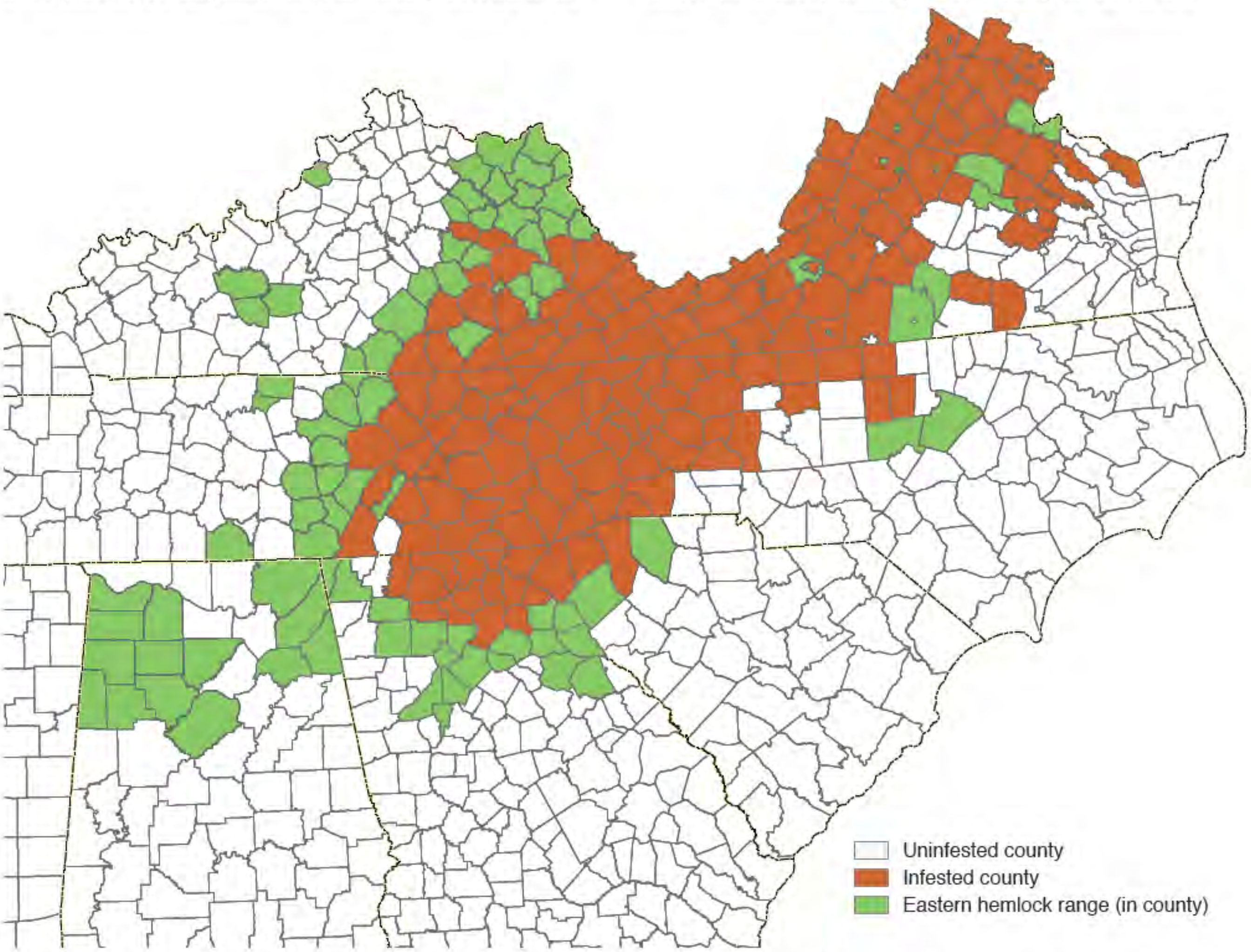


Figure 16.1—County-level distribution of established hemlock woolly adelgid populations, as reported by State forest health officials in 2010; populations are not distributed evenly within infested counties (adapted from USDA Forest Service 2010). Note: This map is undergoing rapid change due to the ongoing expansion of the range of this disease.

hemlock to serve as cover and nesting habitat for birds and small mammals.

Given the adelgid's current rate of spread, it could infest nearly the entire southern range of eastern hemlock and Carolina hemlock within the next 50 years. Some isolated areas within the infested range and some areas of hemlocks that are separated from the main range (in northwestern Alabama, for example) may escape infestation. In all likelihood, within the next 50 years hemlock woolly adelgid will kill most of the hemlocks that are alive today in the South. The loss of hemlock will be one of the major impacts caused by nonnative invasive species to Southern forests in the next 50 years.

A number of suppression tactics show some promise for preventing the loss of significant numbers of hemlocks over the next 50 years. Treatment of trees with imidacloprid effectively controls hemlock woolly adelgids for several years (Cowles and others 2006). Distribution of the insecticide into tree crowns is more effective with soil drench or injection than with stem injection (Dilling and others 2010). Dinotefuran is also being used with success. Current insecticide treatments are applied to individual trees and function primarily as a temporary protection measure for a relatively small number of trees. At this time, insecticide application over large areas is neither logistically feasible nor cost-effective. Several biological control agents (beetle predators) have been and are being released, and some are successfully establishing (Mausel and others 2010). More time is likely needed before conclusive impacts of biological control agents on the health of hemlock forests can be shown. Establishment of a complex of natural enemies in a given area is desired to achieve long-term success. In June 2009, researchers and forest health professionals began evaluating the efficacy of *Lecanicillium muscarium*, an insect-killing fungus that is registered as a bio-pesticide in Europe (Grassano 2008).

Research and work is being done on hemlock host resistance and ex-situ conservation of hemlock seedlings and genetic diversity (Bentz and others 2002, Jetton and others 2008, Jetton and others 2010, Montgomery and others 2009, Pooler and others 2002). These efforts may allow scientists and land managers to reintroduce adelgid-resistant hemlocks in the future.

Climate change is unlikely to reverse the spread of hemlock woolly adelgids. In the northern part of the hemlock woolly adelgid range, low minimum winter temperatures can significantly knock back populations and appear to limit spread. Therefore, we can assume that climate warming would likely promote a northward expansion of the adelgid (Paradis and others 2008). The southern range of hemlock is currently not benefitting from much cold winter knockback—a warming climate would presumably only exacerbate the situation.

Nantucket pine tip moth—The Nantucket pine tip moth, *Rhyacionia frustrana*, is one of the most common forest insects in the South (Berisford 1988). Although it is usually considered a southern pest, its range includes most of the eastern half of the United States.

Most commercial pine species are susceptible to attack by the Nantucket pine tip moth, but there are considerable differences in relative susceptibility. Among the southern pines, longleaf nursery seedlings and all ages of shortleaf, loblolly, and Virginia pines are highly susceptible, while slash and older longleaf pines are highly resistant.

Damage is normally transitory or negligible in forest stands but can be severe for seedlings and saplings younger than 5 years, resulting in deformities and loss of growth.

Based on the warmer and possibly drier climate that is expected over the next 50 years, the activity and damage levels of Nantucket pine tip moth are likely to increase in the South and extend to northern areas (Midwest, New England) where tip moth has not been much of a management concern. Activity may increase and continue into the winter months, as could the number of generations per year. Nantucket pine tip moths are primarily a problem in young loblolly monocultures. To the extent that land managers increase the planting of loblolly monocultures in the next 50 years, damage from the Nantucket pine tip moth is likely to increase.

A number of effective, chemical control options exist for this pest (Asaro and others 2003). If population levels are monitored in a timely and regular fashion, and are followed up by appropriate insecticide applications, tip moth damage can be minimized. Chemical control options are effective, especially the new systemic insecticides. However, they are often prohibitively expensive and will probably not be adopted under most commonly accepted climate scenarios unless tip moth population pressure becomes quite high.

Other bark beetles—Although the southern pine beetle is the most damaging insect in southern pine forests, it is only one of five pine bark-beetle species of concern for forest managers in the South. The others are the six-spined engraver, *Ips calligraphus*, the southern pine engraver, *Ips grandicollis*, the small southern pine engraver, *Ips avulsus,* and the black turpentine beetle, *Dendructonus terebrans.* These beetles are usually considered secondary pests because they normally infest only stressed, weakened, damaged, or downed pines. They also colonize pines that have been attacked by southern pine beetles or another bark beetle species. Host species in the South include loblolly, shortleaf, Virginia, longleaf, eastern white, pitch, slash (*P.*

elliotii), and sand (*P. clausa*) pines. Both pure pine and oak-pine stands may be affected (Conner and Wilkinson 1983, Smith and Lee 1972, USDA Forest Service 1985a).

Attacks by black turpentine beetles may continue for several months but infestation is not always fatal. Multiple attacks around the entire circumference of the tree are required to cause mortality (Smith and Lee 1972, Staeben and others 2010, USDA Forest Service 1985a).

The small southern pine engraver and the six-spined engraver are the most aggressive and may kill small groups of trees. Losses may be extensive during periods of drought (Conner and Wilkinson 1983, USDA Forest Service 1985a).

The secondary bark beetles play a vital role in shaping forest structure and may have a greater impact on regulating pine stands than southern pine beetles (Paine and others 1981, Thatcher 1960a). They attack weakened or severely stressed trees and those reaching senescence. Large infestations develop only occasionally, usually after widespread environmental stress, such as that caused by drought, storm damage, or wildfire. Their action serves to thin the pine forests, reducing competition, leaving the stronger trees, and decreasing the risk of southern pine beetle (SPB) outbreaks.

The impact of these beetles depends largely on management activities (Coulson and others 1986). Engravers also breed in downed material, so it is difficult to substantially reduce populations, but prevention methods (such as lowering planting densities, thinning stands, and cutting and removing groups of infested trees) can reduce damage.

In unmanaged stands, they attack single trees or small groups of pines and reduce pine basal area. They provide openings for pine reproduction or for established hardwoods to grow. The effects are often not noticeable except during periods of extended drought, after storm damage, or at the end of SPB epidemics.

Increased temperature and decreased precipitation would stress pines and could therefore increase the impacts of these bark beetles, but it is unlikely that they will become primary pests that kill large areas of trees. These four bark beetle species may move northward as winters become warmer.

Pine reproduction weevils—Pales weevil *(Hylobius pales)* and pitch-eating weevil *(Pachylobius picivorus*) are two of the most damaging insect pests of pine seedlings in the Southeastern United States. In southern forests, they are found wherever pine occurs. Adult weevils of both species are attracted to newly harvested sites, where they breed in logging slash, stumps, and old root systems; they cause economic losses by feeding on the bark and often killing planted seedlings. If seedlings are planted on or adjacent to sites with fresh stumps or damaged trees, it is common to have 30 to 60 percent weevil-caused mortality among first-year seedlings, with instances of 90 percent or more mortality recorded (Thatcher 1960b). A third species, the eastern pine weevil (*Pissodes nemorensis*), is generally less common but is known to kill terminal and lateral branches and girdle the stems of small trees (Doggett and others 1977, Nord and others 1984). The reproduction weevils are almost never a problem in forest management unless seedlings have been planted on or adjacent to sites with fresh stumps or damaged trees. Foresters usually avoid this problem on cutover sites by delaying planting or by planting treated seedlings.

Pales and pitch-eating weevils prefer loblolly, shortleaf, pitch, and eastern white pines. They almost never attack longleaf and slash pines, but on rare occasions have been observed feeding on hardwoods. Although the eastern pine weevil prefers cedar, it also attacks most southern yellow pines, such as loblolly, slash, and shortleaf. Pales and eastern pine weevils may serve as vectors for various pathogenic fungi.

The future outlook for the activity and damage levels of reproduction weevils is similar to the recent past. A warmer climate may allow these insects to extend their ranges north into Canada. Warmer southern winter months may allow them to increase and/or prolong activity and to produce more generations per year. Decreased precipitation may reduce their activity. The impacts of these pests are more dependent on stand management (and whether seedlings were treated with insecticides) than on climatic conditions. If pines are planted and then left unmanaged over the next 50 years, we can expect increased damage from pine reproduction weevils.

Sirex woodwasp—Sirex woodwasp, *Sirex noctilio*, is native to Europe, Asia and northern Africa and has been introduced to North America, South America, New Zealand, Australia, and South Africa. In Australia, South Africa, and South America, it is considered an important pest, causing significant mortality (Oliveira and others 1998) in stands planted with North American pines, especially Monterey pine (*P. radiata*) and loblolly pine. Haugen and Hoebeke (2005) report that other known susceptible pines include slash, shortleaf, ponderosa (*P. ponderosa*), lodgepole (*P. contorta),* and jack (*P. banksiana*).

Females can produce up to 450 eggs and deposit them (mostly singly) below the surface of the bark close to the cambium. The female also deposits mucus and a basidiomycete symbiotic fungus, *Amylostereum areolatum*, which grows rapidly and excretes wood-digesting enzymes. When the larvae hatch they bore into the wood, but feed on wood already colonized by the fungus. The fungus and mucus act together to kill the tree and create an environment suitable for the development of the larvae.

Sirex woodwasp has not caused widespread mortality in the North American areas where it is established, nor have any populations been reported in the South. However within the next 50 years, it is very likely that natural or human-aided spread will introduce this pest to southern forests. Many of the South's most important pine species are susceptible to *Sirex* and many trees will succumb if attacks are as aggressive as they are in South America and Australia. Although this scenario could result in catastrophic ecological and economic losses, the complexity of southern forests (mixed stands, high biodiversity, many possible competitors, predators and parasitoids) contrasts with the monoculture pine plantations in other countries where the pest has been most damaging. Many studies are underway to assess the potential level of danger to southern forests. A national risk map for Sirex has been developed (see http://www.fs.fed.us/foresthealth/technology/invasives_sirexnoctilio_riskmaps.shtml) and risk maps specific to the South are in development.

If the Sirex woodwasp becomes established in the South and acts as a primary "tree killer," effective prevention and suppression techniques are available, including the current practice of thinning stands to increase growth and vigor and reduce susceptibility to bark beetles. In other countries, Sirex woodwasp has been successfully managed using biological control agents. The key agent is a parasitic nematode, *Deladenus siricidicola*, which infests Sirex woodwasp larvae, and ultimately sterilizes the adult females. Infested adult females lay infertile eggs that are filled with nematodes, which further spreads the nematode population. The nematodes can effectively regulate the woodwasp population below damaging levels. As Sirex woodwasp establishes in new areas, this nematode can be easily mass-reared in the laboratory and introduced by inoculating it into infested trees. Biological control employing these nematodes is being evaluated for use in U.S. forests. If effective, it should provide a good control option for southern landowners and land managers.

The effects of changes in temperature, carbon dioxide, and precipitation on Sirex woodwasp activity and aggressiveness are unknown. If pine acreage increases throughout the South or in certain areas of the South, susceptibility of these areas to attack will increase.

Southern pine beetle—Southern pine beetle (SPB), *Dendroctonus frontalis,* is the most destructive insect pest of pine forests in the South (Thatcher and Conner 1985). Populations build rapidly during periodic outbreaks and kill large numbers of trees. For example, during the outbreak of 1999 to 2002, SPB killed more than a million acres of pines valued at greater than $1.5 billion. However, during periods of low activity, SPB populations may be so low that it is difficult to locate a single infested tree (Thatcher and Barry 1982, Thatcher and others 1980) or capture beetles in pheromone traps (Billings and Upton 2010).

The SPB, which attacks all species of pines, prefers loblolly (*Pinus taeda)*, shortleaf (*P. echinata*), Virginia (*P. virginiana*), slash (*P. elliottii*) pond (*P. serotina)*, and pitch (*P. rigida*) pines but seldom attacks longleaf pine (*P. palustris*). SPB has been observed to successfully infest eastern white (*P. strobus*) and Table Mountain (*P. pungens*) pines. Mature trees in pure, dense stands have long been considered most susceptible to SPB attack, but in recent years unthinned pine plantations have increasingly supported SPB infestations (Cameron and Billings 1988). Attacks are rare for trees younger than 5 years or smaller than 2 inches in diameter at breast height (d.b.h.).

During outbreaks, SPB activity peaks in early summer in States on the Gulf of Mexico and in late summer and early autumn farther north.

In the last five decades, large acreages of pine plantations have been established in the South. Even-aged, single-species plantations become increasingly susceptible to SPB infestations as they age. Millions of acres of pine across the South are at high hazard for SPB attack as shown by regional and State maps (Nowak [N.d.]). SPB hazard maps and information about their development can be viewed at: http://www.fs.fed.us/foresthealth/technology/nidrm_spb.shtml.

SPB impacts over the next 50 years are expected to be significant, especially if the pine acreage increases in the South, high-susceptibility species are planted in dense plantations, and the plantations are left unthinned. A warmer, drier climate is likely to increase SPB activity and impacts. Warmer temperatures will likely allow an increase in the number of SPB generations per year as well as the portion of the year that the beetles are active. The northern edges of the southern region and pine stands that are farther north than the historical SPB range (such as in the Lake States, New England, and Canada) are almost certain to experience SPB activity and impacts that are unprecedented or at least significantly greater than in the past.

There is some uncertainty and debate about the potential effects of a warmer climate on SPB (Tran and others 2007), and general predictions are difficult to make. An increase in temperature (particularly warmer winters) would allow more generations per year. Gan (2004) and Rivera Rojas and others (2010) predict outbreaks to become more frequent as climate changes, although lack of landscape-scale data on host abundance and distribution may have led Gan to overestimate future SPB activity. Very high summer temperatures may increase brood mortality, reduce spot growth rates, and hinder predation. Warmer winter temperatures may disrupt synchronization of the life cycles required for concentrated spring emergence that favors initiation of large, new infestations (Billings and Kibbe 1978).

The impact of outbreaks in the 1980s was magnified by an abundance of contiguous mature stands of sawtimber, many of which have been replaced with young plantations, at least on non-Federal lands. If increased forest fragmentation, a younger age class distribution, and more thinning of plantations occur in the next 50 years, SPB impacts could be lower in the future, despite increases in temperatures. And although it is generally accepted that increased temperatures will increase SPB activity and damage, other factors (for example forest composition, forest management, direct suppression, etc.) may be more meaningful in determining future SPB activity and damage (Friedenberg and others 2008).

Similar to temperature's effect on SPB, the potential of moisture regime to increase or decrease SPB problems is open to conjecture and not fully understood. Some experts believe that drought is a major enhancer of SPB outbreaks, whereas others point to too much moisture as a primary facilitating factor. If the frequency of precipitation extremes (years of extreme wetness or dyness) increases throughout the South over the next 50 years, it is probable that pines will become stressed and increased SPB activity and damage will result.

In addition to the effects that forest composition, temperature, and moisture will have on the SPB outlook, forest management will play a defining role. Planting the proper species for a given site, lower planting densities, and thinning of pine stands can increase stand vigor and resiliency and possibly reduce SPB damage. When outbreaks do occur, damage can be minimized by early detection and monitoring of spots, followed by prompt direct suppression of active spots (Billings 1980).

Texas leafcutting ant—The Texas leafcutting ant, *Atta texana,* targets first- and second-year pine plantations in eastern Texas and west central Louisiana. In local areas where the ants are abundant, it is nearly impossible to establish pine plantations unless the ant colonies are eliminated. The annual loss of pine seedlings to Texas leafcutting ants is nearly 12,000 acres (Cherret 1986, Texas Forest Service 1982).

A warmer climate may lead to an increase and/or continuation of leafcutting ant activity during winter months. Decreased precipitation would likely have the opposite effect. Because this ant has a strong preference for well-drained, deep sandy soils (Moser 1984, Vilela 1986), climate-induced spread beyond its current distribution is unlikely. Although leafcutting ants are limited by average low temperatures (warmer temperatures would lessen this limiting factor), their spread into new, northern areas is going to be limited due to the lack of preferred soils for the ant. There is a possibility that a warmer climate would allow northward movement into areas of Oklahoma and Arkansas that have deep, sandy soils. A new fipronil control product, PTM™ was registered in 2009, and an insecticidal bait is on the horizon. Regular and consistent application of these products has the potential to reduce the impacts of Texas leafcutting ants from historical levels.

Insect Pests of Hardwoods

Asian longhorned beetle—Asian longhorned beetle, *Anoplophora glabripennis*, was discovered attacking hardwood trees in the United States in the mid-1990s. Tunneling by beetle larvae girdles tree stems and branches. Repeated attacks lead to dieback of the tree crown and, eventually, death of the tree. The beetle probably travelled to the United States inside solid wood packing material from China. This pest beetle has been intercepted at ports and found in warehouses throughout the United States and is currently infesting trees in New York City, New Jersey, Worcester (MA), and Toronto (Ontario, Canada). It was successfully eradicated from the Chicago area following a lengthy and aggressive campaign of detection and removal of infested trees (Antipin and Dilley 2004).

This beetle is a serious pest in China, where it kills hardwood trees in roadside plantings, shelterbelts, and plantations. In the United States the beetle prefers maple species, including boxelder (*A. negundo*), Norway (*A. platanoides*), red (*A. rubrum*), silver (*A. saccharinum*), and sugar (*A. saccharum*) maples. Other preferred hosts are birches (*Betula* spp.), Ohio buckeye (*Aesculus glabra*), elms (*Ulmus* spp.), horsechestnut (*Aesculus hippocastanaeum*), and willows (*Salix* spp.). Occasional-to-rare hosts include ashes, European mountain ash (*Sorbus* sp.), London planetree (*Platanus* sp.), mimosa (*Albizia julebrissin*), and poplars (*Populus* spp.). A complete list of host trees in the United States has not been compiled.

Asian longhorned beetles produce one generation per year. Adult beetles are usually present from July to October, but can be found later in the fall if temperatures are warm. Adults usually stay on the trees from which they emerged or disperse short distances to a new host to feed and reproduce. Each female usually produces 35 to 90 eggs (or more) during her lifetime. Eggs hatch in 10 to 15 days. The larvae feed under the bark in the living tissue of their host and then bore deep into the wood to pupate. Adults emerge by boring a tunnel and creating a large round exit hole in the tree (USDA Forest Service and Animal and Plant Health Inspection Service 2008).

Currently, the only effective means to eliminate Asian longhorned beetle is to remove infested trees and destroy them by chipping or burning. To prevent further spread of the insect, quarantines are established to prevent transportation of infested trees and branches from the area. Early detection of infestations and rapid treatment response are crucial. Systemic insecticides can provide protection for individual trees or small numbers of trees, but individual tree treatment is not feasible in forested settings.

The future impact of Asian longhorned beetles on southern forests is unknown for several reasons. First, the pest may or may not spread into the South over the next 50 years. Significant eradication and containment efforts are being pursued in areas where trees are under attack. Although the beetle disperses slowly—it does not fly great distances and tends to remain in the same area until hosts are exhausted—it may be spread great distances in firewood or by movement of other infested material.

A wide variety of southern hardwood trees (especially maples) is at risk. It is unlikely, however, that vast areas of hardwoods would be killed within the next 50 years because the beetle takes several years to kill host trees and it is a slow disperser. If spot infestations are discovered early enough, the beetle can be eradicated before it becomes widely established. Successful eradication efforts require much time, funding, personnel, and strength of will.

Effects of southern climate on Asian longhorned beetle are completely unknown. Extreme heat in some parts of the South may inhibit activity and success. However, there is also the possibility that warmer temperatures would lead to quicker completion of the beetle's life cycle, which would mean larger populations and more damage to southern trees.

Baldcypress leafroller—Formerly named the fruittree leafroller, the baldcypress leafroller, *Archips goyerana*, periodically defoliates baldcypress in Louisiana and Mississippi. Kruse (2000) describes the baldcypress leafroller, and summarizes its biology and its effects on its host. This native insect causes growth reduction and dieback, but only causes mortality when multiple other stressors are at work.

The baldcypress leafroller was first recorded in 1983 in Louisiana, where it feeds almost exclusively on baldcypress. It annually defoliates an average of 35,000 acres in the oak-gum-cypress forest type. Although this insect is mainly a pest of flooded baldcypress, it can move into drier upland and urban settings during periods of heavy infestation.

Baldcypress trees of all sizes display canopy dieback and significant reductions in diameter growth resulting from repeated annual defoliation. Pole-sized to small sawtimber-sized trees growing on forest edges or in dense stands are most severely affected. In areas where chronic saltwater intrusion is a problem, trees die after as few as two consecutive years of defoliation.

Temperature and precipitation changes are unlikely to directly affect baldcypress leafroller's activity and impacts. However, higher sea levels resulting from warmer temperatures would further stress baldcypress trees because of increased saltwater intrusion, significantly increasing the likelihood that defoliation would damage and kill host trees. Human alterations to southern Louisiana's hydrology, greater saltwater intrusion, nutria feeding, defoliation by baldcypress leafroller, and other stressors are all combining to threaten the baldcypress resource in southern Louisiana. Although unlikely to disappear in the next 50 years, this resource is expected to continue to be compromised.

Emerald ash borer—Emerald ash borer, *Agrilus planipennis*, is a devastating, wood-boring beetle native to Asia. It was first found infesting trees in North America in southeastern Michigan and adjacent areas of Ontario, Canada, in 2002 (Various 2010). Within the core infested area of Michigan, Indiana, and Ohio, more than 50 million ash trees are estimated to be dead, dying, or infested (Smith and others 2009). Elsewhere, the emerald ash borer already has killed tens of millions of ash trees, and continues to pose a serious threat to the ash resource of North America.

The emerald ash borer was first found in the United States in 2002, but it was likely introduced into the area around Detroit in the early 1990s (Kovacs and others 2009), probably in solid wood packing material from Asia. Soon after detection, five counties in Michigan were placed under quarantine. However, in the years before detection, infested material—such as nursery stock, unprocessed ash logs, firewood, and other ash commodities—was most likely moved to many areas around the United States. Inadvertent movement by humans continues into the present in spite of Federal and State quarantines restricting the export of potentially infested materials once the borer is detected in a county (U.S. Department of Agriculture Animal and Plant Health Inspection Service 2003, 2006). Surveys made in 2003 found infestations in 12 counties in Michigan and 3 counties in northern Ohio. By early 2011 infestations were located in an additional 13 States: Indiana, Illinois, Iowa, Maryland, Pennsylvania, Missouri, Virginia, West Virginia, Wisconsin, Kentucky, Minnesota, and New York (fig. 16.2). In Canada, infestations now occur in several areas of Ontario and Quebec (USDA Animal and Plant Health Inspection Service 2011).

Since its introduction, the emerald ash borer has had a significant negative impact on the ecology and economy of infested areas, with all 16 species of North American ash appearing to be susceptible. Ash trees are an important part of the rural and urban forests of the United States, valued at more than $282 billion (USDA Animal and Plant Health

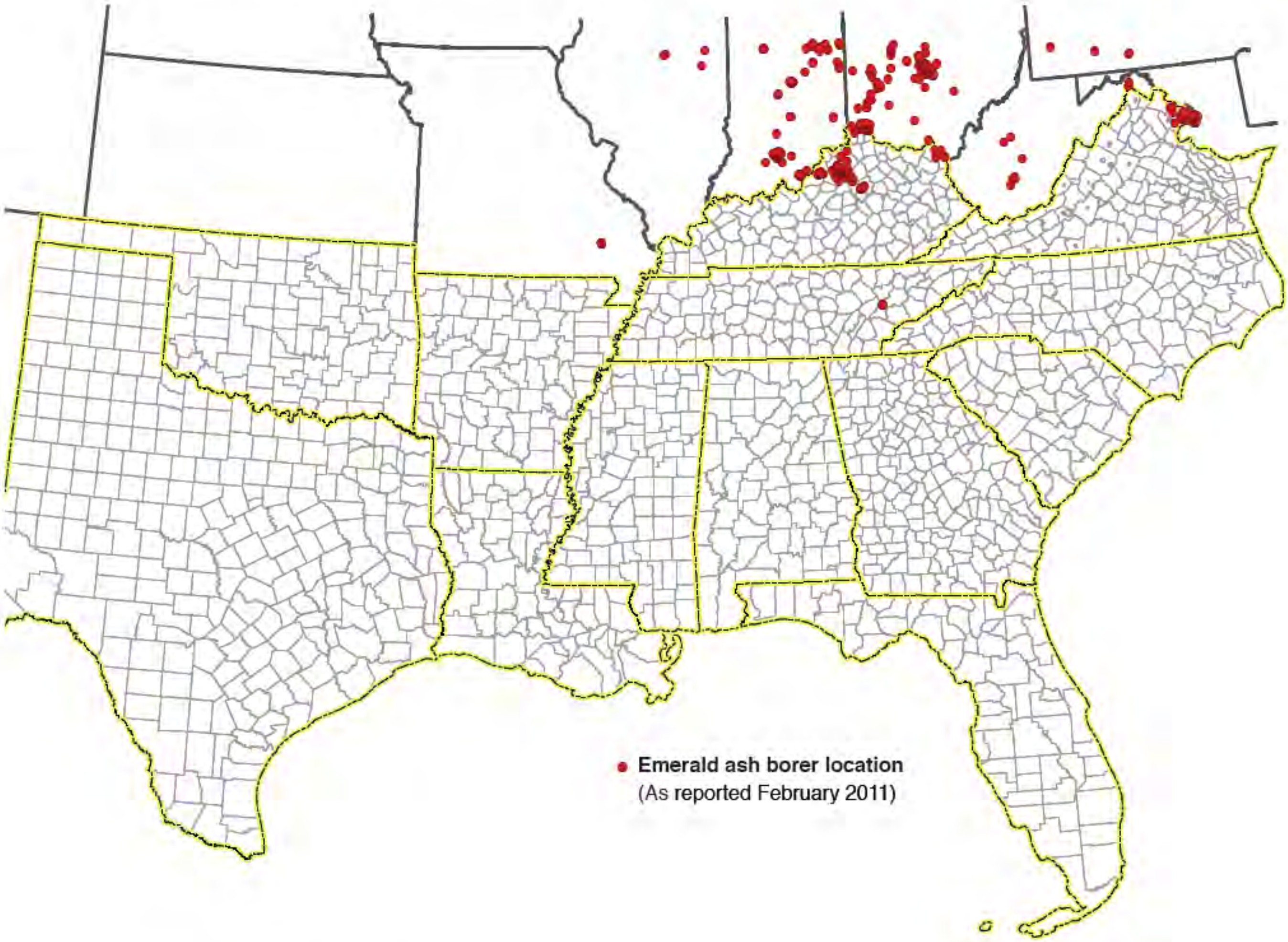


Figure 16.2—Emerald ash borer locations in the United States and Canada as reported February 2011 (adapted from USDA Animal and Plant Health Inspection Service 2011). Note: This map is undergoing rapid change due to the ongoing expansion of the range of this disease. The most current map can be found at: http://www.aphis.usda.gov/plant_health/plant_pest_info/emerald_ash_b/downloads/multistateeab.pdf

Inspection Service 2003). Ash wood is used for a number of applications including tool handles, baseball bats, furniture, cabinetry and paper. As a result of wide-scale loss of American elms to Dutch elm disease in the 1970s and 1980s, ash has often become the tree of choice for landscaping in new residential areas and commercial plantings. Ashes are now among the most common tree species along streets, and in parks and yards. Annually, the nursery industry produces an estimated 2 million ash trees, valued at approximately $140 million. Ecologically, the 16 species of ash fill a number of niches, from riparian areas to upland forests.

In all likelihood the emerald ash borer will infest and kill many, if not most, of the ash trees in the South over the next 50 years. Generally, ash is not a dominant component of southern forests, but it is almost always common and in some areas (such as the bottomland hardwood forests of the Mississippi delta) ash makes up a considerable portion of hardwood harvests. Green ash is a small but significant component of most riparian forests in the South. The largest impact is likely to be in urban areas, where ash is a common street and yard tree in many communities.

In its native range in Asia, the emerald ash borer does not cause serious damage to ash trees. As a consequence, very little was known about its biology (life cycle, flight capabilities, host preferences, and natural enemies) and control. Also unknown were methods to detect the presence of the borer and the trees they had infested. One of the greatest challenges for managers is this limited ability to detect infestations early enough to effectively control them and prevent their spread.

There are a number of effective chemical control options available to protect individual trees from infestation (Herms and others 2009). Unfortunately, available time, funding, equipment, and expertise limit the number of trees that can be protected to urban/suburban settings and a very small number of high value trees in forested settings. With the emerald ash borer destroying every ash in its path, one practical option may be to delineate and protect small pockets of exceptional ash resource as "ash conservation areas."

Several larval and egg parasitoids are being investigated for use as biological control agents (USDA Animal and Plant Health Inspection Service and others 2010). Although results are preliminary, it is reasonable to expect that biological control agents would mitigate populations but would not control or completely stop the spread and impacts of this insect invader.

The effects of changes in climate—such as increases in temperature, precipitation, and carbon dioxide— on emerald ash borer are uncertain. Warmer temperatures would likely result in more rapid life cycle completion resulting in increased population growth and impacts. However, the extreme heat of southern summers could actually inhibit activity and reduce the amount of ash mortality. The range of ash trees in the South is expected to shrink as the climate warms; between climate stress and the emerald ash borer infestations, the South is likely to lose millions of ash trees in the next 50 years.

Forest tent caterpillar—Forest tent caterpillar, *Malacosoma disstria*, occurs throughout most of the United States and Canada, where it defoliates a variety of hardwoods (Batzer and Morris 1978, Drooz 1985, Fitzgerald 1995, USDA Forest Service 1985b). In the South, it heavily defoliates water tupelo (*Nyssa aquatica*), sweetgum (*Liquidambar styraciflua*), blackgum (*N. sylvatica*), and various oak species (*Quercus* spp.). The most persistent and extreme outbreaks in the South occur on host trees in bottomlands, forested wetlands, and riparian areas. When populations reach epidemic levels, the caterpillars often spread to urban and suburban areas where they defoliate shade trees and ornamental plants.

Outbreaks occur in several Southern States, where more than 500,000 acres can be defoliated in a single season; defoliation does not cause significant amounts of tree mortality and therefore control practices are rarely cost effective. However, significant loss of tree growth is often an outcome, and repeated, heavy defoliation of stands may cause significant dieback. If needed, control techniques are available and have proven effective but depend on the availability of both funding and technical expertise.

Tent caterpillar impacts occur mainly in the bottomland hardwood-cypress forest types (mapped as oak-gum-cypress and elm-ash-cottonwood), but they occasionally occur in upland northern hardwood forest types (mapped as maple-beech-birch, oak-hickory, and oak-pine).

Changes in temperature and precipitation are unlikely to increase defoliation by forest tent caterpillars. If climate change significantly stresses the forest types most vulnerable to tent caterpillar defoliation, the additive effect of multiple stressors could mean hastened or increased tree mortality.

Gypsy moth—Gypsy moth, *Lymantria dispar,* is native to Europe and Asia. In 1869, Leopold Trouvelot introduced the European strain of the gypsy moth. Since then, it has spread across the landscape of the eastern United States, defoliating vast acreages of forest (USDA Animal and Plant Health Inspection Service 2010b). The insect was found in northeastern Virginia in the early 1980s. At its current rate of spread, specialists predict that a significant portion of the South will be infested in the next 50 years.

The impact of repeated gypsy moth defoliation on the health of oak forests is significant (Campbell and Sloan 1977). Repeated severe defoliation of oaks weakens trees to such an extent that they may be attacked and killed by secondary pest organisms, such as the two-lined chestnut borer (*Agrilus bilineatus*) and Armillaria root rot (caused by *Armillaria mellea*). Extended drought intensifies the death rate.

Gypsy moth caterpillars feed on a wide range of trees and shrubs (Liebhold and others 1995, Zhu 1994) but prefer oaks. Species are attacked preferentially without respect to forest type. Highly favored species include sweetgum, northern red oak (*Quercus rubra*), and American basswood (*Tilia americana*). Species of limited suitability include pines, maples (*Acer* spp.), ash (*Fraxinus* spp.), American beech (*Fagus grandifolia*), and cherry (*Prunus serotina*). Species that are not favored or are avoided include blackgum, yellow-poplar (*Liriodendron tulipifera*), black locust (*Robinia pseudoacacia*), baldcypress (*Taxodium distichum*), magnolia (*Magnolia grandiflora*), and tupelo (*Nyssa sylvatica*). As gypsy moth moves south and west, it will encounter lower concentrations of oak and cove hardwoods, and forest susceptibility will decrease in many but not all areas. However, with its wide host range it should still persist.

The most important disease agents affecting gypsy moths are the gypsy moth nucleopolyhedrosis virus (LdMNPV) and the gypsy moth fungus, *Entomophaga maimaiga* (Andreadis and Weseloh 1990, Hajek and others 1990).

The Slow the Spread Program decreases the gypsy moths' rate of spread from approximately 25 miles a year to 7 to 10 miles per year (Sharov and others 2002). If the program continues, we can expect the gypsy moth to move 350 to 500 miles farther into the South over the next 50 years, compared to total infestation within 25 to 30 years without the program.

Gypsy moths can also be artificially spread by human activities; continued vigilance to detect and eradicate the resulting small infestations help to prevent the moth's rapid spread into all areas of the South. In addition, methods exist to suppress areas of high populations in infested areas and to eradicate "satellite" infestations in advance of the moth's moving front; these methods include aerial applications of Bt (*Bacillus thuringiensis*) or dimilin (insecticides), or pheromone flakes (to disrupt mating).

Temperature changes alone are unlikely to have a dramatic effect on gypsy moth movement or impacts. The range of gypsy moth infestation is expected to expand regardless of changes in climate, and at a rate faster than can be attributed to any potential climate change-caused host range expansion. If warmer temperatures cause the oak-hickory forest type to displace boreal forests at higher elevations in the South, gypsy moth impacts will likely increase in these areas.

However, one hypothesis is that gypsy moth spread and damage will decrease as temperatures warm, thereby reducing the extent of southward spread. Gypsy moths need a cold snap to synchronize hatches (avoids different life stages from occurring at the same time) and thus improve mating efficiency.[2] If this hypothesis is correct, as the moth moves farther south and as the temperatures warm, winters would not be cold enough or the necessary cold snap would come too late in the year to synchronize the spring hatch.

A drier climate would likely increase gypsy moth impacts because it would stress host trees and discourage build-up of the moth's fungal predator, which thrives during wetter springs.

Because the gypsy moth is still spreading into the South, barring unforeseen circumstances we can say with certainty that its impacts will increase over the next 50 years. How severe and widespread the impacts will be, however, is dependent on many factors including: the continuation of active programs to slow the spread, suppress and eradicate gypsy moth; the amount and health of hardwood forests the moth encounters in the future; and potential unknown temperature and moisture effects on the moth, its hosts, and its natural enemies.

Hardwood borers—Insect borers are important pests of hardwood trees throughout the South. They tunnel in the bark, trunks, terminals, and roots, causing a variety of defects in wood, stem deformity, reduction of seed production, and tree decline.

Some of the major damaging borers in the South (Solomon 1995) are the carpenterworm (*Prionoxystus robiniae*), red oak borer (*Enaphalodes rufulus*), white oak borer (*Goes tigrinus*), redheaded ash borer (*Neoclytus acuminatus*), poplar borer (*Saperda calcarata*), oak timberworm (*Arrhenodes minutus*), Columbian timber beetle (*Corthylus columbianus*), and ambrosia beetle (*Xyleborus celsus*). Borers that are endemic to an area do not normally cause dieback and mortality, but in abnormally large numbers they contribute to tree decline and stand degradation. Excessive numbers of growth defects caused by borers affect between 25 and 88 percent of all hardwood logs (Ward and Mistretta 2002).

In the early 2000s, prolonged droughts compromised the vigor of oaks in northern Arkansas, leading to a massive red oak borer outbreak. Although they were not the primary cause of the oak mortality in that area, the borers soon became the most destructive agent in the decline complex. More than 340,000 acres of oak and mixed-oak-pine forest were severely impacted, with an estimated loss of 500 million board feet (more than $29 million) of oak.

Temperature change by itself is unlikely to have much effect on hardwood borer populations. As secondary insect pests, these borers are expected to have increased impact as populations of hardwood age and decline, especially during periods of drought stress. Hardwood borer activity and damage is likely to increase throughout the South over the next 50 years if current predictions of future climate change prove accurate.

Soapberry borer—Soapberry borer, *Agrilus prionurus*, a native of Mexico, was first confirmed in eastern Travis County, Texas, in 2003. It infests and kills western soapberry (*Sapindus saponaria* var. *drummondii*), its only known host. Reports by landowners and arborists indicate that the insect had probably been infesting soapberry trees for several years prior to being identified. Infested trees were observed in Travis and McLennan counties as early as 1998. By January 2009, infestations had been reported in 18 Texas counties, including areas near Fort Worth, Dallas, Waco, College Station, Austin, Houston, and Corpus Christi. By December 2010, the number of counties had increased to 43 (Billings 2011).[3] To date no infestations have been observed in adjacent States, although infestations in Roberts County in the Texas panhandle and

[2]John Ghent, USDA Forest Service, Forest Health Protection, 200 W.T. Weaver Blvd., Asheville, NC 28804, 828-257-4328, jghent@fs.fed.us. Personal communication: May 11, 2010.

[3]R. Billings, Texas Forest Service, Forest Health unit, 200 Technology Way, Suite 1281, College Station, TX 77845-3424, 979-458-6650, rbillings@tfs.tamu.edu. Personal communication: March 8, 2011.

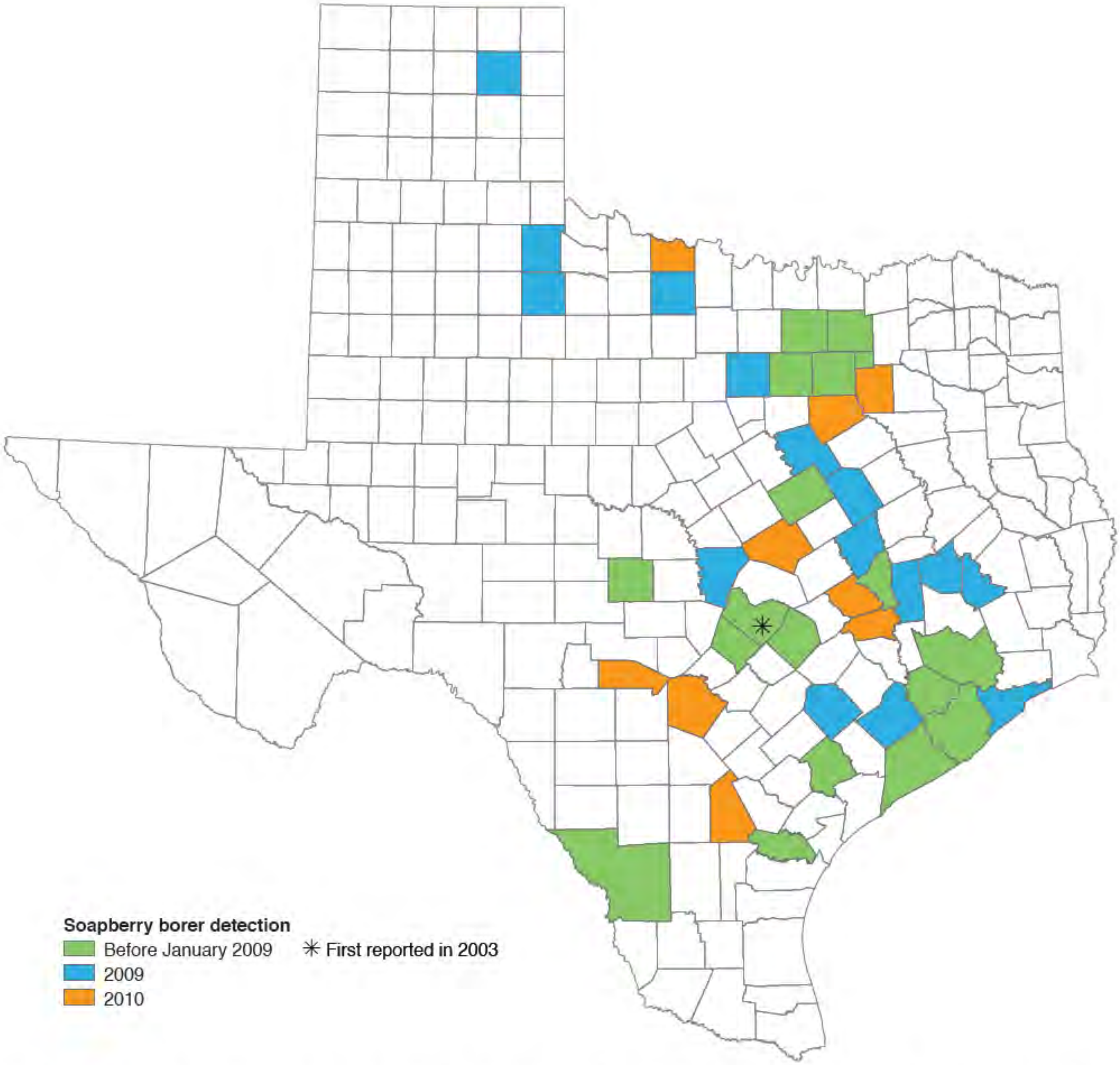


Figure 16.3—Counties where soapberry borer has been found in Texas through July 2011; courtesy of the Texas Forest Service, Texas A&M University System (adapted from http://www.isatexas.com/images/pdf_files/insect_pests/Soapberry_Borer_Found_in_33_counties_in_Texas.pdf). Note: This map is undergoing rapid change due to the ongoing expansion of the range of this insect pest.

Wichita County on the Texas-Oklahoma border suggest that the insect may already be in Oklahoma (fig. 16.3).

As soapberry borer populations expand rapidly in Texas, this wood-boring beetle is killing all soapberry trees larger than 2 inches d.b.h. Methods of prevention and control are being investigated. Among the most promising is injection of a systemic insecticide (emamectin benzoate, registered for the control of insects on conifers and hardwoods, including the prevention of emerald ash borer) into uninfested soapberry trees or those in early stages of attack. Test-injection trees are still being monitored, but early results look promising.

Regardless of climate change, it is likely that within 50 years the insect will threaten western soapberry populations throughout the tree's entire range, which extends from northern Mexico to Missouri, and west to Arizona.

Diseases of Softwoods

Annosum root disease—Annosum root disease (ARD), caused by the fungus *Heterobasidion annosum* (recently proposed to be renamed *H. irregulare* (Otrosina and Garboletto 2010), produces significant losses of conifers across the South. On sandy, well-drained sites, this disease causes growth loss and mortality. It is most often associated with thinning of loblolly, longleaf, shortleaf, slash, and white pine plantations. The fungus commonly infects fresh stumps and then grows through root grafts (roots that come into physical contact and then grow together, sharing water and nutrients) and infects residual trees on the site. Slash and loblolly pines are the most commonly planted species in the South and are both very susceptible to ARD (Robbins 1984, Stambaugh 1989).

A survey in the South documented: 44 to 60 percent occurrence of this root disease; and 2 to 3 percent mortality in planted pine. Radial and height growth are significantly less for diseased pines (Applegate 1971, Froelich and others 1977, Morris 1970).

The primary risk factors associated with ARD are the amount of host type available, the soil type and condition, and the timing and degree of management activity. Risk decreases as clay content in the surface layer of soil increases, a condition that enables risk mapping (Ward and Mistretta 2002). In the South, risk of ARD is high or moderately high on an estimated 163.5 million acres, not all currently forested (Hoffard and others 1995).

The range of ARD already extends throughout southern forests and into the boreal forests of the North, making spread unlikely. Indeed, its range could decrease with efforts by many land management agencies to restore the less susceptible longleaf pine to its previous range while concurrently potential drought/temperature related dieback in the southernmost part of the loblolly/slash pine range further decrease its range. Increased temperatures, reduced rainfall, and increased host growth (from more carbon dioxide in the atmosphere) would all produce some increases in disease activity resulting from increased host susceptibility, but would not significantly increase fungus virulence. It is improbable that climate warming/drying would affect pine susceptibility on well-drained, sandy sites and forested old farm fields since on these sites potentially affected pines are already highly susceptible to the disease.

Management for disease prevention using borax as a stump treatment in uninfected stands should continue to be effective. Depending on the rate of temperature increase, insolation (thermal treatment of the stumps by the sun) may be effective in preventing infection via stumps further north than the 35th parallel, which is the currently accepted northern limit of its effectiveness.

Loss of area by host species favored by *H. annosum* should lead to a slight overall loss of the negative impact of this disease over the next 50 years.

Brown spot needle disease—Brown spot needle disease, caused by the fungus *Scirrhia acicola,* is considered the most damaging disease of longleaf pine. It primarily affects seedlings by delaying the onset of height growth and causing loss of potential wood production and mortality (if infection is severe). Brown spot is somewhat a disease of opportunity: the grasses that compete with longleaf seedlings also maintain a humid microclimate that contributes significantly both to infection of the seedling and to the general success of the disease.

This disease occurs from Virginia to Texas, primarily on the Coastal Plain. It is more severe in certain geographic areas (Ward and Mistretta 2002). Use of controlled fires to remove competing grasses and eliminate dampness is highly effective for controlling the disease and encouraging early growth of seedlings, provided steps are taken to avoid subsequent colonization by competing non-natives such as cogongrass.

At present, longleaf pine occupies only about 5 million acres of its former 60 million acre range. Recent restoration efforts have led to the production of healthier seedlings for planting and planting success has improved on sites where longleaf was once the dominant species (Cordell and others 1989, Kais 1989). Over the next 50 years, the emphasis on longleaf pine restoration should have a greater impact on this disease than climate warming. Longleaf pine is well adapted to summer temperatures in the South and it is unclear that increases even as high as 1 ^{o}C would have significant impact on the southern extent of the longleaf pine range. Higher temperatures might slightly favor increase in growth and longer summer heat spells might trigger early onset of height growth from the grass stage to the candle stage, ending the potential for brown-spot damage sooner. Reductions in rainfall, dew, and fog should favor the longleaf pine over the fungal pest. No shift in aggressiveness of infection or virulence of the pathogen is foreseen.

We anticipate a significant increase in the incidence of brown spot disease. This expectation is based more on increased out-planting of longleaf pine seedlings than on climate influences. Thus, although climate change is not expected to significantly change the disease profile (its virulence or host spectrum), human intervention to increase the quantity of host trees could result in increased incidence.

Fusiform rust—Fusiform rust, caused by the fungus *Cronartium fusiforme* f. sp. *fusiforme*, occurs primarily on slash and loblolly pines. It is considered the most destructive disease of southern pines, causing the production of cigar-shaped galls that are generally fatal if formed on the main stem of the host (Anderson and others 1980, Czabator 1971).

Extensive planting of susceptible slash and loblolly pines since the 1930s has resulted in an epidemic of fusiform rust, which now extends throughout its available host range in the South; infected trees being found throughout the southern pine region (Ward and Mistretta 2002). Losses are most serious on Coastal Plain sites from Louisiana to southeastern South Carolina. Several variables including weather, amount of inoculum, abundance of oaks (the alternate host), and susceptibility of the individual pine species govern incidence of the disease. Effective strategies are available for managing fusiform rust impact in plantations and forests including avoidance of over-fertilizing seedlings in the nursery, silvicultural manipulation of young stands to favor healthy saplings, and favoring the deployment of genetically screened resistant seedlings in areas of historic high rust incidence.

Increase in disease range in this region under the influence of a warmer, drier climate change scenario is not a concern since the disease is already distributed host-range wide within the region. However, increased temperature and carbon dioxide in the atmosphere could cause the pathogen to become more virulent on its current host base. Although there is some disagreement on the effect of projected warmer, drier climate regimes on the geographic ranges for the pine hosts, it is anticipated that any losses of pine in coastal areas would be matched by gains in the Piedmont and in the lower reaches of the Appalachian Mountains.

Although research on rust fungi is inconclusive and primarily based on cereal grains and other field crops, results suggest that there would be greater incidence of fusiform rust simply as a function of healthier fungus and host trees (Chakraborty and others 1998). We also anticipate that loblolly pine at least will be planted in areas north of its current range; and that the rust, which infects juvenile tissue, will rapidly follow into these newly planted areas.

Over the next 50 years given the general availability of oak alternate hosts for the fungus and the only slight predicted migration of pine from coastal areas upward into the Appalachian Mountains, we expect that the pathogen will successfully fully colonize the extended range of its hosts. The potential effect of outplanting rust resistant seedlings in conjunction with potential geographic range and climate shifts is uncertain at the present time. If the resistance is maintained in the face of changing conditions, a reduction of the impact of this disease would be expected to occur.

Littleleaf disease—Littleleaf disease is the most serious pest of shortleaf pines in the South. It is caused by a complex of factors including a nonnative fungus (P*hytophthora cinnamomi*), low soil nitrogen, eroded soils, poor internal soil drainage, and a plow pan—a compacted layer of soil that has become less porous than the soil above or below, generally the result of tilling or other farming operations (Campbell and Copeland 1954). Often, native nematodes (microscopic roundworms) and native species of *Pythium* (also a fungus) are associated with the disease. Infected trees have reduced growth rates and commonly die within 12 years of symptom onset.

P. cinnamomi is distributed throughout (and well beyond) the range currently occupied by shortleaf and loblolly pine in the South. Shortleaf pine is the most seriously damaged softwood host, with loblolly pine affected to a lesser extent; American chestnut was its primary hardwood host. Littleleaf disease has also been reported on Virginia, pitch, slash, and longleaf pines. Affected pine stands are found on the Piedmont from Virginia to Mississippi. The disease has its greatest impact in Alabama, Georgia, and South Carolina (Ward and Mistretta 2002, fig. 17.10), with additional scattered pockets occurring in eastern Tennessee and southeastern Kentucky. Note that, although the fungus' range exceeds the range of its pine hosts, littleleaf disease is further restricted in within that larger range generally by site conditions.

The fungus has a mobile spore and needs water to spread from and infected host to uninfected potential hosts; however, the disease thrives under dry conditions that stress the host. Control strategies are available but most—such as sanitation thinning and salvaging dead materials—rely on treatment after infection when damage is imminent or already occurring.

Because of its specific site requirements, spread into uninfected southern forests is not expected. Further, rehabilitating sites by breaking up of the plow pans that favor this disease should result in better water relations and a reduction in infections. An increase in atmospheric carbon dioxide would result in increased growth of the host and greater disease expression in affected trees. Losses to this disease should continue at the same rate on affected sites. However, its range should contract if increased temperatures cause its hosts to migrate north, and its impact should decrease over time as sites are rehabilitated.

Loblolly pine decline—Reports of sparse, yellowing crowns, and low annual wood production in the pines of central-to-northern Alabama date back to the late 1960s (Brown and McDowell 1968, Brown and others 1969). Since the early 1990s, localized incidents of declining pines have been occurring throughout Alabama and into southwestern Georgia, with additional symptoms including root mortality and discoloration of many of the surviving rootlets (Hess and others 2003). Recent literature suggests the presence of fungi—including *Leptographium serpens, L. terebrantis,* and *L. lundbergii*–in the roots of affected trees (Eckhardt and others 2004b); but whether they are primary pathogens or simply taking advantage of already significantly weakened trees is still uncertain. A bark beetle, *Hylastes* sp., has been found in the root systems of many declining pines, and is suspected of vectoring the fungus from infected to uninfected trees (Eckhardt and others 2004a). Information is lacking on whether they select weakened trees to attack or are indiscriminate in their attacks (which would suggest that healthy trees may be able to overcome successful inoculation).

The symptoms of the decline primarily occur in loblolly pines older than 40 years, first becoming apparent in trees in the 40 to 50 year age class. Mortality can occur beginning as little as two to three years after first symptom expression. Little is known about the potential range and severity beyond that from field surveys in central northern Alabama (Hess and others 2005) and Fort Benning, Georgia (Menard and others 2006). Nevertheless, there is strong speculation that both abiotic and biotic factors are involved in predisposing affected stands to decline. These factors include climate, wildfire, and human disturbances such as previous agriculture. Coincidently, many upland sites in northern and central Alabama were originally converted from subsistence farming to loblolly pine plantation because of loblolly's out-planting success rate and its rapid growth. One theory is that many of these sites are simply unable to sustain such rapid growth over the long-term.

Despite the uncertainties about the causes and progression of this disease complex, management strategies are in place that can be implemented with the expectation of improving resistance of future stands on affected sites. These strategies start with applying a risk rating model that uses digital elevation maps and mapped shape files for the sites in question combined with data on landform and root health of the trees in the stand. If the model predicts hazard to loblolly pine, the recommended alternative species is longleaf pine. For existing loblolly pine stands on high hazard sites, the recommendation is to thin them between ages 20 and 40 (Hess and others 2003). A previous recommendation, to allow a high- risk site to revert back to native hardwoods (Loomis 1976, Miller 1979), is still a viable (but seldom adopted) management option.

Tree decline is likely to increase in a warmer and drier climate, regardless of inputs from disease and insect vectors. This response to changing climate is a major factor in the northward movement projected for the southern pines. Increasing incidence of decline should eventually diminish as new adapted ecosystems form in the region, but this is not expected to occur within the next 50 years.

Diseases of Hardwoods

Beech bark disease—Beech bark disease is caused by a complex of two or more agents working in concert. The beech scale, *Cryptococcus fagisuga*, attacks the bark of American beech, creating infection courts which are subsequently colonized by the fungus *Nectria coccinea* var. *faginata.* This fungus causes cankers that grow together and girdle host trees.

While the beech scale is now a common pest of the American beech, it is nonnative, having been introduced through the Canadian Province of Nova Scotia in the late 1800s. There is speculation that the fungus is also an introduced species. Discussion on that point is somewhat pointless since a native fungus, *N. galligena,* is also capable of inciting cankers and killing hosts after entering through scale-damaged bark. The scale is considered the pivotal introduction that allowed the invasive spread of this disease complex (Houston and O'Brien 1983, Southern Appalachian Man and the Biosphere 1996).

This disease complex, first identified in southern forests in the early 90s, continues to spread along a broad front and is expected to occupy the range of its host (Ward and Mistretta 2002). In the early phase of its cycle, more than half of the American beech trees 10 inches d.b.h. or larger are killed. Openings created by death or removal of the beech result in dense stands of root-sprouts, which produce stands dominated by beech but lacking any of its normal associates. In the second phase of the cycle, revegetated beech stands are attacked less severely, resulting in cankered survivors rather than in extensive mortality. Trees infected in this phase are rarely girdled, but they are generally severely deformed.

Since this disease complex affects only American beech, there is a direct relationship between the amount of beech in a stand and the intensity of the disease. Houston (1997) reports that stand age and density, tree size, and species composition affect disease severity, especially in forests affected for the first time.

Beech bark disease is enabled by an insect vector, so the projection of future condition is complicated beyond that of a simple pathogen or insect driven pest system. Vector mediation corresponds to availability of spores and host susceptibility, and is expected to maintain synchronicity sufficient to cause a slight increase in infection. Temperature intolerance of the host should reduce the host's geographic range in the face of climate change. Increases in carbon dioxide should increase host growth allowing a slight increase in disease virulence.

Ultimately, however, the reduction in available host trees should result in an overall decrease of significance of beech bark disease in southern forests despite the probability that individual trees will experience a slight increase in disease severity.

Butternut canker—Butternut is being killed throughout its range in North America by a fungus, *Sirococcus clavigignenti-juglandacearum*, which causes multiple cankers on the main stem and branches of host trees. Butternut canker has been found in 55 counties in the South extending north from northern Alabama along the Appalachian Mountains into North Carolina, Tennessee, Virginia, and Kentucky, with scattered occurrences throughout Kentucky and Tennessee (Ward and Mistretta 2002). Butternut numbers have been dramatically reduced and the species is now listed as a species of Special Concern in Kentucky and as Threatened in Tennessee (USDA Natural Resources Conservation Service 2011). In both states the species is listed as G4/S3. G4 indicates a plant which is "…apparently secure globally, though it may be quite rare in parts of its range…" while S3 indicates "…rare and uncommon in the state…" (USDA Natural Resources Conservation Service 2008, 2009).

Detailed examination of cankers indicates that butternut canker has been present in the United States since the early 1960s. Its origin is unknown but its rapid spread throughout the butternut range, its highly aggressive nature on infected trees, the scarcity of resistant trees, the lack of genetic diversity in the fungus, and the age of the oldest cankers (40 years) support the theory that it is a recent introduction. Data from forest inventories show a dramatic decrease in the number of live butternut trees in the United States (77 percent loss in North Carolina and Virginia).

Because butternut makes up less than 0.5 percent of the trees in the South, the overall current impact of its loss to the forested ecosystem in the South is considered by some to be minor. However, as butternut trees die, they are replaced by other already present species, contributing to a reduction of biodiversity.

Climate change would likely raise temperatures at the higher elevations of the Appalachians and the Cumberland Plateau. This coupled with drier conditions would significantly reduce the range of butternut at its southern edge. Although the higher temperatures and predicted increases in atmospheric carbon dioxide could increase the host trees' growth, drier conditions resulting from reduced precipitation would act against this increase. Overall we expect to see more cankering and mortality occurring on fewer butternut trees in the South.

Chestnut blight—Introduction of the chestnut blight fungus, *Cryphonectria parasitica*, from Asia, probably in the middle-to-late 1890s, led to a permanent change in forest ecosystems. The American chestnut (*Castanea dentata*) was essentially lost, not only as a valuable timber species but also as the most important producer of hard mast for wildlife. Oaks and other species filled the voids in forest stands left by the death of chestnut (Hepting 1974, Oak and others 1998). The fungus continues to survive on infected sprouts from old chestnut rootstock, various oaks, and some other hardwoods (Boyce 1961).

No control was found to stop the rapid devastation caused by this blight, and there is little chance that the pathogen will disappear or that the American chestnut will naturally recover its preeminent position in eastern forests. Researchers into hypovirulence have discovered a disease that weakens the blight fungus, resulting in less damage to the infected tree (Anagnostakis 1978). Field-testing is underway on a genetically engineered virus that causes a hypovirulent reaction and has the potential to efficiently spread hypovirulence throughout the fungal population.

Attempts to cross American chestnuts with oriental varieties and then backcross to the American parent appear to offer a viable method of maintaining resistant chestnut in forests (Schlarbaum 1988). Selectively breeding chestnuts as described has produced chestnut hybrid clones that are undergoing field evaluation by the American Chestnut Foundation. If the seedlings overcome both the blight and another disease (caused by *Phytophthora cinnamomi*) that was devastating chestnuts at the time chestnut blight was introduced, a serious effort can be made to reintroduce chestnut into the American forests. It is too early yet to predict the outcome of this effort. However, even if the hybrids are resistant to the disease, large areas of forest land cannot be restored to chestnut in the next 50 years because the seedlings that would be needed for that effort are not expected to be available in large enough quantities. Further, if climate change is considered, the impacts on chestnut deployed in the restoration effort would probably be similar to those predicted for oaks suffering from oak decline.

Dogwood anthracnose—Dogwood anthracnose is caused by an introduced fungus, *Discula destructiva.* It was first reported in the United States on flowering dogwood, *Cornus florida*, in 1978 and on western flowering dogwood, *C. nuttallii*, in 1979. For the past three decades, flowering dogwoods have been declining at a rate that threatens important cultural aspects of southern society. In some areas, they have been all but eliminated from the forest ecosystem above 3,000 feet (Ward and Mistretta 2002).

The eastern flowering dogwood is a small tree valued both as a sign of spring for rural communities and forest visitors, and as an important source of soft mast for over 100 different species of wildlife that feed on its berries (Kasper 2000). It is typically an understory tree found growing with other hardwoods such as oak and hickory. Severe infection is restricted to fully shaded understory trees at higher elevations (above 3,000 feet) and to those on shaded sites with a northern exposure. The hazard of severe infection and mortality is greatest in shaded, moist, and cool areas.

The range of this disease stretches southward into South Carolina and Alabama and westward into central Tennessee and scattered western Kentucky counties (Ward and Mistretta 2002) with activity concentrated in the Appalachian Mountains. The southernmost limit of the dogwood anthracnose range relative to available host trees suggests that this disease is temperature limited in the South. Whether this limitation functions at the time of spore propagation or dissemination and host infection, or whether it acts directly to limit disease success is unclear.

Any projected increase in the incidence or virulence of dogwood anthracnose based on increased host and fungal growth resulting from higher carbon dioxide levels in the atmosphere should be eclipsed by the temperature increases and possible rainfall reductions projected to occur under climate change. Increased temperature and aridity encroaching at higher-than-current elevations in the Appalachian Mountains should diminish the importance of this disease in the region, especially if it has reached a temperature barrier farther south. A recolonization of some areas currently denuded of dogwood by this disease might be possible.

Dutch elm disease—The Dutch elm disease pathogen is vectored by one of two bark beetles and can be caused by either of two closely related species of fungi: *Ophiostoma ulmi* (formerly called *Ceratocystis ulmi*); and *Ophiostoma novo-ulmi*, which is more aggressive in causing disease (Brasier 1991). These fungi were first introduced to the United States on diseased elm logs from Europe prior to 1930. It is unknown when the more aggressive species became established; however it was possibly present as early as the 1940s to 1950s, and most likely caused much of the devastating elm mortality through the 1970s. The less aggressive species is becoming increasingly rare in nature, and the aggressive species is thought to be the primary cause of current mortality. Although some local resurgence has been observed, there is no evidence that the pathogen has further changed. Localized resurgence is more likely the result of decreased monitoring and sanitation vigilance, a buildup in populations of the insect vectors, or high densities of susceptible host trees in the wild (French and others 1980, Haugen 2007, Hubbes 1999).

Native species of North American elms vary in their susceptibility to Dutch elm disease. American elm (*Ulmus americana*) is generally highly susceptible To the disease while winged elm (*U. alata*), September elm (*U. serotina*), slippery elm (*U. rubra*), rock elm (*U. thomasii*), and cedar elm (*U. crassifolia*) range from susceptible to somewhat resistant. No native elms are immune, but some individuals or cultivars have a greater resistance or a higher tolerance to infection (and therefore may recover or at least survive). Many European and Asiatic elms are less susceptible than American elm (Haugen 2007).

In addition to genetic factors present in some cultivars and species, physical factors affect tree susceptibility. These factors include season of the year, climatic conditions (such as drought), and vitality of the tree. Water conducting elements are most susceptible to infection because they are produced in the spring, making susceptibility highest from first leafing to midsummer and lowest during drought conditions. Vigorously growing trees are generally more susceptible than slower growing trees (D'Arcy 2005).

Roots of the same or closely related tree species growing in close proximity often cross each other in the soil and eventually fuse (become grafted). The fungus can move from infected trees to adjacent trees through these grafted roots. Infections that occur through root grafts can spread very rapidly throughout the tree, because the fungus is carried upward in the sap. Root graft spread is a significant cause of tree death in urban areas where elms are closely spaced (French and others 1980, Haugen 2007).

Current management options in urban, suburban, and other high value settings include sanitizing to reduce insect vectors, applying insecticides to kill insect vectors, disrupting root grafts; injecting trees with fungicide, eradicating the fungus from newly infected trees (pruning), and planting resistant or tolerant trees (French and others 1980, Haugen and Stennes 1999, Newhouse and others 2007, Scheffer and others 2008).

Although the most effective action is prompt removal of stressed, dead, and dying elms, this intensity of treatment is often not feasible (Haugen 2007).

Despite the presence of several elm species (American elm, winged elm, and slippery elm, at least) very little Dutch elm disease can be found in areas below northern North Carolina, Tennessee, and Arkansas. It appears that either the beetles or the fungi involved in transmitting/causing the disease are temperature limited. Barring significant changes in its pathogen/vector combination, increasing temperature and migration of the host slightly to the north is expected to diminish the disease's overall impact in the South.

Laurel wilt—Laurel wilt is an insect-vectored disease that is currently decimating the redbay (*Persea borbonia*) population of the southern Coastal Plain. This disease was first identified near Port Wentworth, Georgia, in 2003 and has subsequently spread north, south, and inland (west) from that location (fig. 16.4). It is caused by an introduced and only recently classified fungus, *Raffaelea lauricola*, (Harrington and others 2008) that is vectored from host to host by an ambrosia beetle (*Xyleborus glabratus*, also an introduced species). The beetle carries the fungus in pouches located near its mandibles. When the beetle bores into the sapwood the fungus inoculates the xylem. Once inoculated, the host rapidly develops a vascular wilt; its leaves die generally downward from the top, and the wood beneath the bark becomes discolored from streaking (Fraedrich and others 2008). Infected hosts display rapid dieback (wilted leaves and discolored sapwood) and may or may not exhibit extrusion of frass (the fine powdery sawdust and excrement that insects pass as waste after digesting plant material) from the insect's entry holes.

Several additional hosts have been identified for this vectored disease including swampbay (*Persea palustris*), sassafras (*Sassafras albidum*), avocado (*Persea americana*), camphor (*Cinnamomum camphorate*), pondberry (*Lindera melissifolia*), and pondspice (*Litsea aestivalis*). Redbay, however, is the favored host for the ambrosia beetle and to the present the severest damage has been limited to redbay (Hanula and others 2008).

At the present time there is no effective control known for this disease for forest and woodland use. While preliminary results using propiconazole (a fungicide) show promise for preventing the disease in treated trees, the necessity of retreating them and the cost of treatment suggests that in the future use may be limited to the protection only of high value trees (Mayfield 2008). Research into chemical treatment, centered on control of the vector, is ongoing but has yet to identify a chemical effective for this purpose. Management recommendations emphasize early sanitation (removal) of killed material but with the strong concurrent recommendation that the dead materials not be moved offsite, or if moved offsite then not out of the known infested/infected area. Further, it is recommended that whenever possible material that has been cut down should be chipped or buried rather than left intact (Mayfield 2008).

Based on the current rate of spread (estimated to be about 20 miles per year), the known distribution of redbay, and regional climate projections, Koch and Smith (2008b) have extrapolated probable spread of this disease through 2040 (fig. 16.5). According to their projection, the disease complex will have reached its northern extent (host based) by 2020, and will reach the western extent of its host range in eastern Texas by 2040. The basis of their projections is the combination of redbay's natural range and climatic barriers that affect the vector and fungus, which will likely stall further progress of the disease in the South. Their caveat is that projections are limited to the redbay host.

Unanswered at this point in time is whether this fungus/vector complex could become established in other parts of the country on other lauraceous hosts (such as the California laurel) should fungus-carrying beetles be introduced into potential new host ranges. Further, potential for affecting the spread of and possibly controlling some of the loss through implementation of the Recovery Plan for Laurel Wilt on Redbay and Other Forest Species (Mayfield and others 2009) is as yet an unknown factor in the management of this disease.

Unfortunately, in 2009, laurel wilt was detected in the Sand Hill Crane National Wildlife Reserve in southern Mississippi—a location that was not predicted by Koch and Smith (2008b) for infection until about 2017—apparently through human introduction. Regardless whether this is a new introduction or movement from the east coast infected area, it has reduced by 8 years the disease's expected arrival in Texas.

Of concern is whether the disease might expand its host range under the influence of climate change or through a modification of the fungus/vector complex that would allow a new insect vector to become involved. If either occurs, there is strong potential for currently unpredicted involvement of new hosts and unpredicted spread; newness of this complex in the South leads to extreme uncertainty when attempting to project future behavior.

Given the rapid and severe damage done to the infected hosts coupled with predicted shifts in coastal vegetation resulting from projected temperature increases and possibly decreasing precipitation, the potential of this disease to spread beyond its projected range is highly uncertain.

Oak decline—Because of the history of woods grazing, widespread wildfire, and exploitive logging for wood

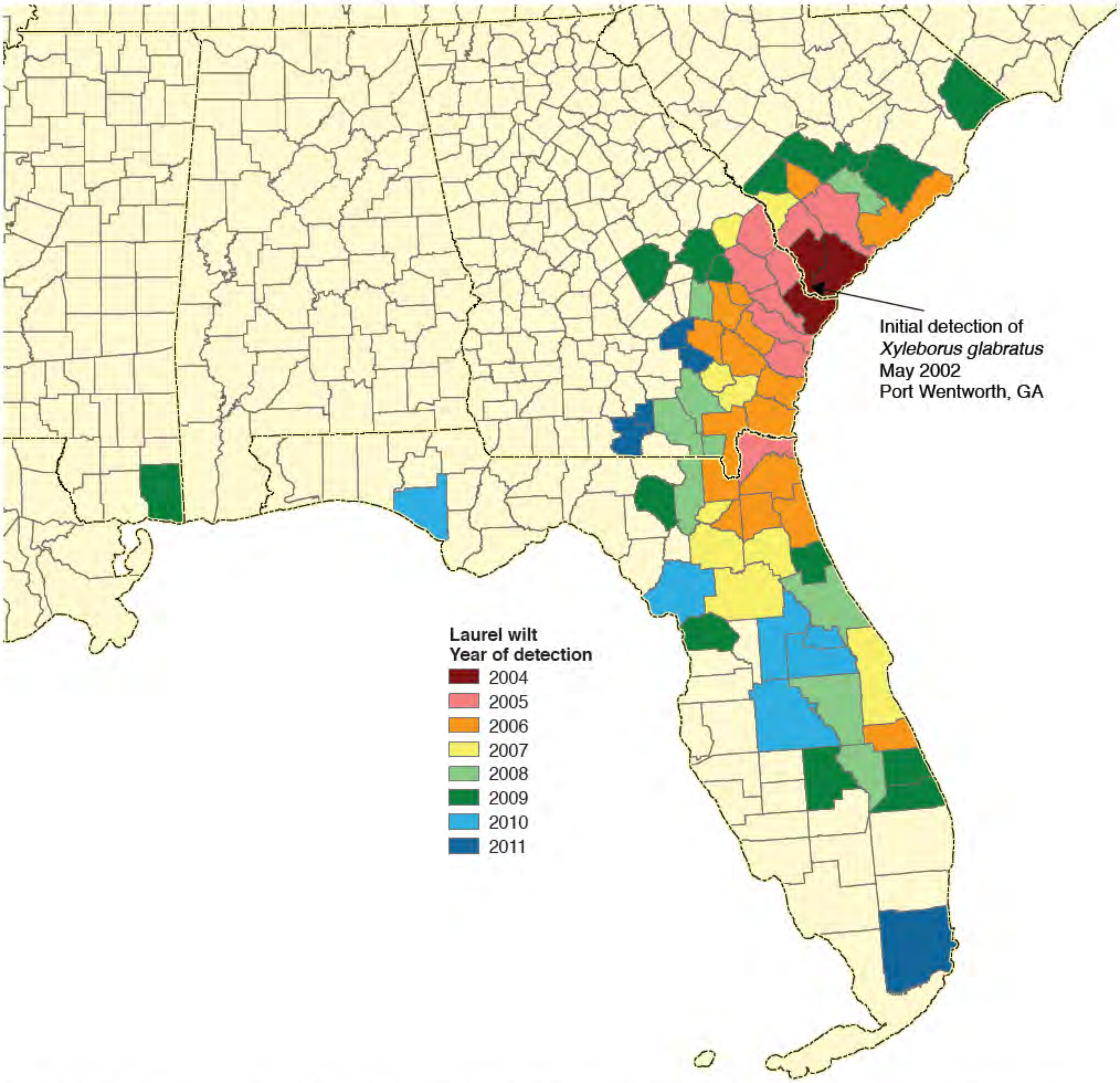


Figure 16.4—Distribution of counties with laurel wilt disease by year of initial detection and as confirmed through laboratory analysis of host samples collected in the counties affected; updated September 12, 2011 (adapted from Reid and others 2011). Note: This map is undergoing rapid change due to the ongoing expansion of the range of this disease. The most current map can be found at: http://www.fs.fed.us/r8/foresthealth/laurelwilt/dist_map.shtml.

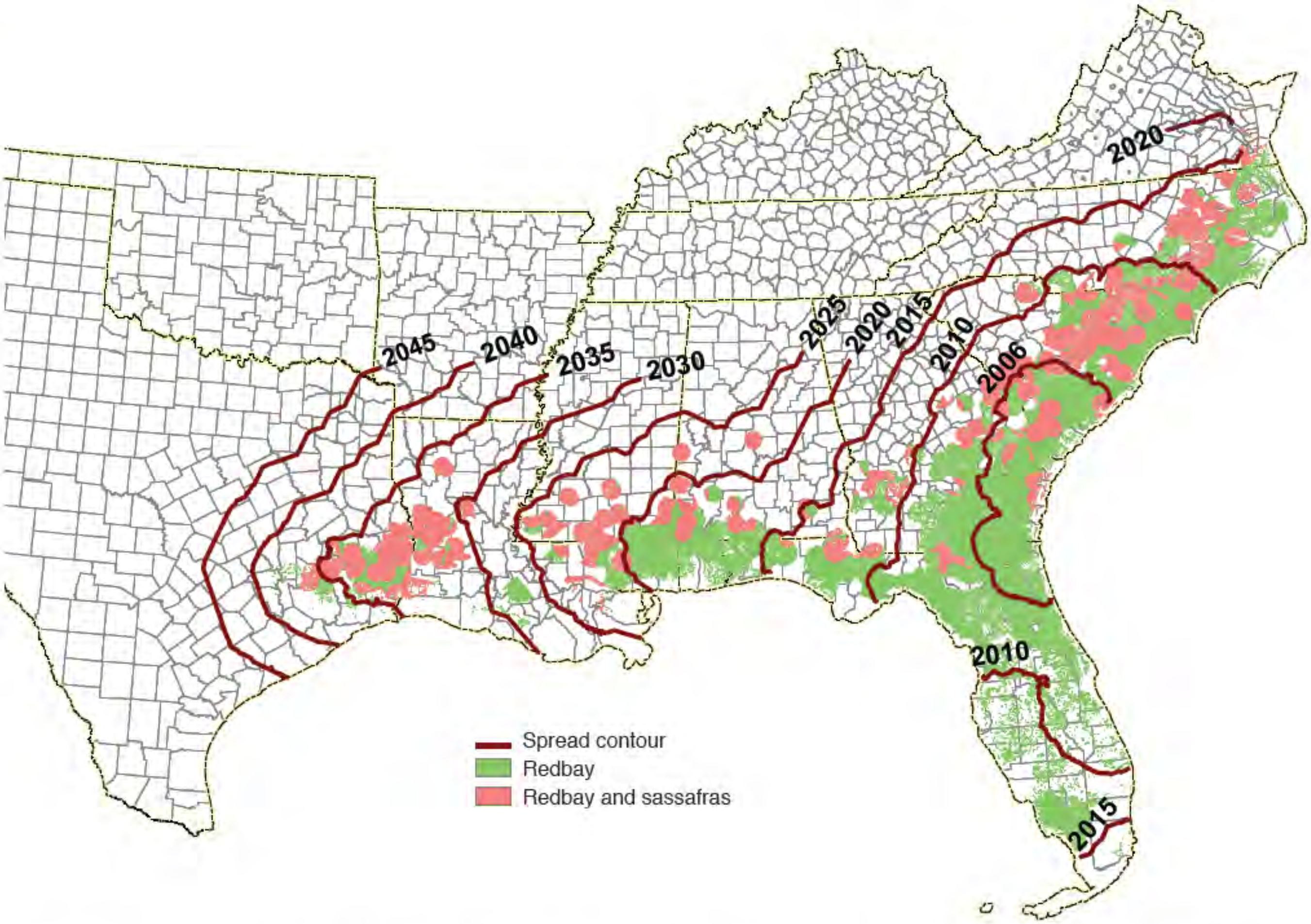


Figure 16.5—Probable spread of laurel wilt disease from 2006 to 2045, based on the current rate of spread and known distribution of the redbay host. (Source: Koch and Smith 2008b)

products, and the loss of American chestnut to chestnut blight, oaks probably represent a larger component of the southern forest ecosystem today than at any time in the past (Millers and others 1990).

Decline of oaks in upland hardwood and mixed oak-pine forests is a complex involving environmental stressors (often drought), root diseases, insect pests of opportunity such as the two-lined chestnut borer (*Agrilus bilineatus*), introduced pests such as the Japanese beetle (*Popillia japonica*) and Asiatic oak weevil (*Cyrtepistomus castaneus*), and physiological maturity of the trees (Staley 1965, Wargo 1977, Wargo and others 1983). Bottomland oak forests are also subject to oak decline but at a lower incidence. Stress agents of bottomland hardwoods also include seasonal, sometimes prolonged flooding.

Decline progression is measured in decades rather than months or years. Introduction of the gypsy moth into northern parts of the region has worsened oak decline because oaks are preferred hosts, and spring defoliation contributes to the chain of events that increase susceptibility. Although decline development may take decades from inception to the appearance of visible symptoms, susceptible trees die within a few years after dieback exceeds a third of the crown volume. Not all affected trees reach this point. Species in the red oak group (particularly black and scarlet oaks) are most susceptible. Hickories are the only non-oak species group commonly observed with symptoms in decline areas (Starkey and others 1989).

Forest workers have reported oak decline occurrences since the mid-1800s (Balch 1927, Beal 1926) and in every decade since the 1950s (Millers and others 1990). A severe drought in the 1950s may have led to the current cohort of trees being highly susceptible to oak decline (Dwyer and others 1995, Tainter and others 1990). Also, within about 60 years after the loss of American chestnuts in the Southern Appalachians, the oaks that replaced them began to decline and dieback, due in part to growth stress from sites better adapted to chestnuts. Significant oak decline episodes continue to occur in the region (primarily in Arkansas and Virginia) where predisposing conditions, inciting events, and contributing factors are coincident (Gysel 1957, Oak and others 1988, Starkey and others 2000).

With increased temperature and (possibly) less rainfall being predicted, oak decline is expected to increase, possibly significantly. Decline resulting from the stresses imposed should be contributory to elimination of oak in some drier areas, and it is uncertain what community of plants would replace the oak on these sites.

Oak wilt—Oak wilt is a vascular wilt disease of oaks that is found only in North America. The causal fungus, *Ceratocystis fagacearum*, was first identified in Wisconsin in 1942. Scientists believed the disease to be native to North America and to have been present long before its discovery (MacDonald 1995, Tainter and Baker 1996). Recently, strong speculation has been voiced that the fungus is actually a nonnative introduction, possibly from South America where it occurs without causing disease (Juzwick and others 2008). Oak wilt occurs in 21 Central and Eastern States (Rexrode and Brown 1983); 9 of the 13 Southern States are known to harbor the disease, but severe mortality is limited to a recent outbreak in central Texas (Ward and Mistretta 2002).

Oak wilt causes affected trees to wilt and usually to die. All species of oak are susceptible, but species in the red oak group—northern red (*Quercus rubra*), scarlet (*Q. coccinea*), and black (*Q. velutina*) oak—are most readily killed. Oaks in the white oak group—white (*Q. alba*), post (*Q. stellata*), and chestnut (*Q. prinus*) oaks—are infected but mortality occurs much less frequently and more slowly. Live oaks (*Q. virginiana*) die at a rate generally intermediate between red and white oaks.

Sap-feeding beetles can carry fungal spores to nearby healthy trees, the fungus can colonize neighboring uninfected trees by growing through root grafts, and human mediated transmission is also possible (moving infected firewood with intact bark allows fruiting of the fungus in areas currently not infected).

It is unclear whether the north-to-south progress of the disease was halted by a temperature barrier that limits migration of the fungus. The existence of such a barrier could mean that the Texas outbreak is the result of a relatively recent adaptation of the fungus to a higher temperature regime or an adaptation to the hosts (live oak) attacked in that area. Regardless of what caused the recent surge in oak wilt activity in Texas, its rapid spread raises the practical question of whether the fungus can now spread throughout the uninfected areas from Louisiana to Georgia and Florida. We anticipate that this question may be answered within the next 10 to 20 years as the disease appears to be spreading (or being spread by humans) at a fairly rapid rate.

Increasing soil temperature might provide a further barrier to spread, if indeed temperature has been a barrier. Predicting the direct effects of temperature and atmospheric carbon dioxide on this disease will require an understanding of the pathogen-host mechanisms at play: whether damage to the root system is sufficient to cause symptoms and death, or whether the fungus must grow from the root system (where most of the transmission is occurring) into and throughout the vascular system aboveground to cause the same effect.

Little can be said with any degree of certainty about possible insect transmission of this disease. Consistent but inefficient transmission by sap-feeding beetles (Nitidulids and Scolytids) is an accepted mode of spread. Shothole borers have also been suggested, but these, and other possible insects, are less accepted. Longer periods of activity of these insects, resulting from the lengthening of summers (already being observed), could greatly increase transmission. However, this increase could only occur if fruiting mats of the fungus (which, in Texas, is associated with cooler and moister fall, winter and spring conditions; not the anticipated conditions) were present during the time in which the insects are active. Unless increased temperature triggers more mat formation than has been historically reported in Central Texas (unlikely), it is not expected that additional insects would become significant carriers of the fungus to uninfected trees. Possible loss of some coastal forest to savanna should have only a slight impact: simply reducing the number of hosts lessens disease incidence.

Management of this disease has proven to be expensive and is generally reserved for high value (aesthetically desirable) trees. Given the apparent adaptation of the fungus to warmer temperatures and relatively dry conditions, and the limitations of control tactics available, there is a high probability of significant oak loss in previously unaffected areas along the Gulf of Mexico and in Georgia within 50 years. However, if the apparent adaptation to warmer and drier conditions proves inadequate for continued disease spread, we would expect an overall slight lessening of the impact of oak wilt in the South.

Sudden oak death—First reported in California in 1995, sudden oak death (SOD) is now a well-established pest with a fairly limited range in California and Oregon. However, despite this relatively limited current range, it is believed that if introduced into the eastern oak forest the consequences could be dire.

Literature relating to this disease is extensive, but has recently been reviewed (Kliejunas 2010) and much of what follows has been extracted from or cross checked with that review to limit the number of citations included here. This publication, which includes a 58 page bibliography of relevant literature, is available on the internet at http://www.fs.fed.us/psw/publications/documents/psw_gtr234/.

Sudden oak death is caused by *Phytophthora ramorum,* a fungus, which causes several nonspecific symptoms depending on the host and host part affected. Symptoms include stem or bole cankers, twig blight (dieback), and leaf blight. Individual plant species can display more than one or only one symptom type (see http://rapra.csl.gov.uk/background/hosts.cfm for links to images of symptoms on a variety of hosts).

Cankers appear in the phloem (tissues that carry sugars away from the leaves of a tree) which may be discolored a bright red, and spread until they reach the xylem (tissues that carry water and minerals up from the root; wood fiber). Cankers are sunken, "bleed" sap, and are generally restricted to the lower portion of the tree trunk. The amount of bleeding is variable even on a single tree and may be related to environmentally available water and the age of the canker. Decline symptoms (loss of leaves) and crown death first appear at the top of the tree and spread rapidly down through the crown often resulting in tree death (Garbelotto and others 2001).

The list of hosts currently reported for this pest is extensive. As of 2010 the list includes 45 proven regulated hosts plus another 82 associated hosts regulated in the nursery trade (USDA Animal and Plant Health Inspection Service 2010a). Hosts with stem or branch cankering include California tanoak (*Lithocarpus densiflora*), coast live oak (*Quercus agrifolia*), California black oak (*Quercus kelloggii*), and Shreve's oak (*Quercus parvula* var. *shrevei*). In addition, field and greenhouse inoculation experiments (Rizzo and others 2002) confirm that the fungus can cause a variety of leaf and branch symptoms, but generally not stem cankering, on rhododendron and azalea (*Rhododendron* spp.), madrone (*Arbutus menziesii*), huckleberry (*Vacinium ovatum*), manzanita (*Arctostaphylos* sp.), California bay laurel (*Umbellularia californica*), buckeye (*Aesculus californica*), bigleaf maple (*Acer macrophyllum*), toyon (*Heteromeles arbutifolia*), California coffeeberry (*Rhamnus californica*), honeysuckle (*Lonicera hispidula*), and a long list of other plants.

Although few of these species occur in eastern forests, several of them can be found in significant numbers. Early results by Rizzo and others (2002) show that northern red oak and pin oak (*Q. palustirs*) are susceptible to infection. In California greenhouse tests, seedlings of both eastern oak species developed lesions almost twice as long as those formed on the oak seedlings from Pacific coastal areas and roughly equal to those formed on tanoak (considered the most susceptible species in California). These results suggest that, all conditions being equal, these species should be highly susceptible to sudden oak death.

Kliejunas (2003) rated the risk posed by this disease as very high, but cautions that the degree of uncertainty related to future disease risk is also high based on lack of knowledge about the host range. Noting the absence of control measures, his risk assessment predicts rapid spread by wind, water, and human transport of infected plants; and suggests the potential for severe economic and ecologic losses, reductions in biodiversity, and indirect impacts on sensitive or critical habitat for at-risk plant and animal communities.

Based on past history with invasive species, it is easy to project that it is not a matter of "if," but "when," sudden oak death will gain a foothold in eastern oak forests (see alternative hypothesis below as "Note"). If the disease reaches southern forests, the role that climate would play is far from certain. Also uncertain, lacking basic epidemiological research, is the potential effects on eastern species; these could range from insignificant to potentially catastrophic (rivaling the effects of chestnut blight).

Sudden oak death appears to have the potential to devastate the eastern oak population, even absent climate change considerations (Kliejunas 2010, chapter 4). Increased temperatures and atmospheric carbon dioxide could be expected to increase growth of both the pathogen and its host, at least in the short term. That effect would be somewhat counteracted by reductions in precipitation and increased ozone in conjunction with the warmer temperatures. Nevertheless, once acclimated to the eastern forest, the disease would probably spread even faster than it has in California.

Using the distribution of known or likely hosts, climate conditions adequate for the survival and propagation of the pathogen, and probable pathways of introduction of the disease outside of its current range Koch and Smith (2008a; fig. 16.6) project a potential range for this disease. Very similar potential range is indicated by DEFRA, Fowler and others, and Margary and others. Kelly and others and Venette and Cohen propose somewhat different potential ranges but both include significant Southern forest areas (Kliejunas 2010, chapter 4).

Climate-induced losses of native oaks at their southern margins (Iverson and others 1999) would reduce the potential incidence of disease, but only slightly, and would not slow the progress of the disease in other parts of its potential range. Sturrock and others (2011) state that, based on CLIMEX projections, changing climate will decrease substantially the area in the Eastern United States favorable or very favorable for *P. ramorum*.

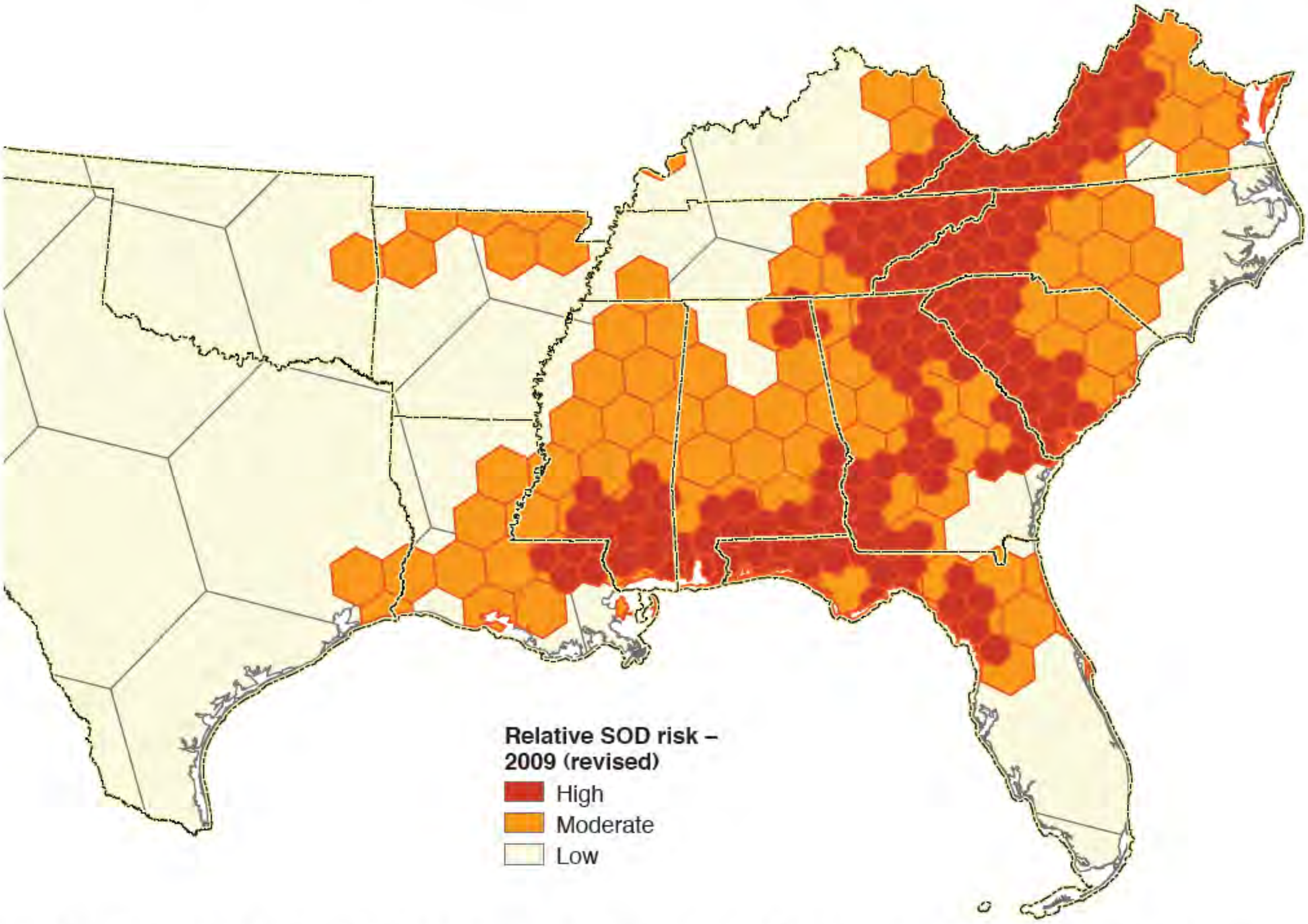


Figure 16.6—Potential range for sudden oak death in the contiguous United States based on the distribution of known or likely hosts, climate conditions adequate for the survival and propagation of the pathogen, and probable pathways of introduction of the disease outside of its current range. (Source: Koch and Smith 2008a).

During technical review of this paper, one reviewer (2011) noted that to the present this disease has only been found in the woods in a very narrow geographic range in coastal California and Oregon; generally extending no more than 50 miles inland. It has yet to be confirmed as being established in other than West Coast forests despite the pathogen having been identified from diseased nursery plants shipped from California to many northern, eastern and southern nurseries. In addition, the fungus has been found in the East in water in the nurseries and in a limited number of cases in waters in ditches or outflow conduits outside those nurseries. The inference from these statements opposes the previously suggested scenario of explosive colonization of a susceptible population by a non-native pest. The risk maps presented by Kliejunas (2010, chapter 4) from a variety of sources and using a range of predictive models show clearly the narrow, basically coastal range (present and predicted) for this disease in California and Oregon but also show a significantly larger area at risk in the eastern and southern forests.

Based on this conflicting information the future of sudden oak death is unclear at the present. However, what is clear is that if it is introduced into the East its invasive spread will override climate change concerns during the next 50 years.

Thousand cankers disease—Thousand cankers disease of is caused by a fungus *(Geosmithia morbida*) (Kolarik and Freeland 2010) and vectored from infected to healthy trees by the walnut twig beetle, *Pityophthorus juglandis* (Seybold and others 2010). The beetle is native to Arizona, New Mexico, on Arizona and California (also probably Texas). First identified on Arizona walnut, *Juglans major*, the fungus is also associated with cankering and dieback of *J. californica* and *J. hindsii* (Kolarik and Freeland 2010). The fungus infects and subsequently kills black walnut, *Juglans nigra*, a species that is highly valued for furniture, paneling, and walnuts.

Thousand cankers disease was recently discovered and confirmed in urban/suburban settings in 4 Tennessee counties (with suspect trees occurring in similar settings in an additional 10 counties); as yet no woodland or forest surveys have been conducted. Although the Tennessee infections were the first reported east of the Great Plains, they may have been occurring since the 1990s. The full extent of this infection is as yet to be determined.

Symptoms of the disease include a foliage wilt in which the leaves progress rapidly from green through yellow and then to brown. Wilting progresses from the top of the crown downward as branches die. In the West, the dieback and ultimate death of infected trees takes about three years. Symptoms at first (and certainly when observed at a distance) resemble those caused by drought. Closer inspection of dead branches reveals many beetle entry holes through the bark and many (often small) cankers just under the bark. As cankers increase in number and each grows bigger until the areas of dead tissue coalesce and girdle the branch. In the later stages of dieback the beetles may attack the bole of the tree accelerating its death (Seybold and others 2010).

Control measures for thousand cankers disease have been proposed but not yet evaluated. Because the current range of the fungal pest is generally hotter and drier than Tennessee's climate, the disease is highly unlikely to encounter temperature barriers that would limit its spread into southern forests. And predicted a warming climate is likely to have little effect; the pathogen and vector originated in a hot dry area of the Southwest but both have moved into the cooler, moister climate of central Tennessee. Finding no barriers to spread, thousand cankers disease could occupy the entire range of black walnut within 50 years, similar to the projected spread of laurel wilt.

Additional Concerns

Although we can make relatively uncertain predictions about the future of known pests, predicting currently endemic organisms that may become pests or organisms from other locations that may invade the South is virtually impossible. Lovett and others (2006) predict that forest pests will be the primary source of changes in eastern forests but cautioned against speculation on specific changes or specific pest introductions.

An important consideration is human caused change in the forest land base driven by increasing and shifting populations and economic conditions. As shown in chapter 5, all of the Cornerstone Futures forecast that total forest acreage will decline over the next 50 years, only planted pine is expected to expand, the oak-hickory type is expected to remain relatively stable, but the three other forest types considered are expected to decline. Additionally, total forest biomass is expected to increase at first but then decline somewhat.

A generalized implication of these potential shifts is relatively straightforward. Because pest activity appears to be basically a linear response to availability, less biomass would indicate less (in absolute terms) loss of biomass to pests. However, planted softwoods would be expected to show an increase in absolute loss proportional to the increase in planted acreage.

The possible effects of fragmentation, parcelization, and urbanization on pest impacts and management are so complex (and largely unknown) that it is not prudent or feasible to attempt to identify specific interactions. Generally, parcelization (greater number of landowners on smaller units of land) may complicate pest prevention and/or suppression by making it more difficult to attain effective management on significant acreages due to the greater number of landowners involved. On the other hand, fragmentation and urbanization would interrupt or decrease the amount and continuity of host species, thereby potentially decreasing the spread and impacts of pests.

We expect continuing introduction (through international and domestic commerce and tourism) of nonnative insects and diseases which could become pests of forest trees, despite imposition of inspections and quarantines. Which organisms might be introduced, and then which of these might become pest species is the source of significant speculation, but is relatively unpredictable.

DISCUSSION AND CONCLUSIONS

Future Considerations for Pest-Host Relationships

Planned adaptation (Spittlehouse and Stewart 2003) should reduce vulnerability for commercial tree species at selected sites. However, many forest species will have to adapt autonomously and society will have to adjust to the result (Winnett 1998). Forest pest distribution changes caused by climate change are likely closely tied to shifts in host distribution (Sturrock 2007).

Some ecosystems are expected to be new: new communities of tree and plant species with different suites of insects and pathogens. If forests do remain on a particular site, similar functional types of insects and pathogens are likely to remain, although they may be include different species than at present (Beukema and others 2007). Pathogens expanding their ranges and contacting 'new' hosts and vectors may mean that new pathosystems probably will emerge. Interactions between pathogens may change (Sturrock 2007).

Climate change may amplify the impact and aggressiveness of pathogens or alter the balance between pathogens and their natural enemies; it may also change the status of weak/opportunistic pathogens such that they are able to infect and damage stressed tree hosts (Sturrock 2007).

Tree decline is likely to increase in a warmer and drier climate, regardless of inputs from diseases and insects. The effect of warmer and drier climate is to stress trees used to a cooler and moister regime. This stress alone should cause an increase in the incidence of declining trees, but compounded by the presence of opportunistic insects and pathogens, there is a strong possibility that this increase in declining trees could be significant. Increasing incidence of decline should eventually diminish as new adapted ecosystems form in the region, but this is not expected to occur within the next 50 years.

Almost every study and review of climate change effects on forests has a common caveat—the complexity of the ecosystems and pest systems, about which relatively little is known (Sturrock 2007). The difficulty in predicting the future of plant disease is highlighted by Woods and others (2005), who report on an endemic needle blight fungus (*Mycosphaerella pini*) that previously had only minimal impact on native forest trees in British Columbia. However, recently, in apparent response to a local increase in summer precipitation, this disease has been causing extensive mortality of lodgepole pines. While admitting that establishing causality of the increased virulence of this endemic pathogen is fraught with risk of misinterpretation of the evidence, they indicate the link to precipitation (while dismissing warmer temperatures) appears to be far greater than "circumstantial." No prior indication of this shift to virulence appears in the literature—the event was unprecedented, unpredicted, and possibly unpredictable. In partial confirmation, Sturrock (2007) notes that wetter springs in some regions may result in increased foliage diseases without venturing to predict subsequent possible host/pest scenarios.

Endemic root rot fungi (*Inonotus schweinitzeii*, *I. tomentosus*, or *Ganoderma* spp.), which currently cause limited damage, or insects such as engraver beetles or species of wood borers could become important management concerns or could fade into obscurity from a management standpoint. The fungi that cause littleleaf disease, sudden oak death (Brasier and Scott 1994), and other infections are predicted to increase their activity in temperate zones in the Northern and Southern Hemispheres as they migrate away from the tropics. Under changing climatic conditions these fungi are expected to cause more damage to existing urban and forest tree hosts in the South and to expand the number of species they can infect. Expected to be especially prevalent and damaging are those, like the littleleaf disease fungus, that can grow in temperatures higher than 28 ^{o}C (Broadmeadow 2005).

Increased drought stress on hosts may mean increased mortality from root pathogens. Pathogenic *Armillaria* spp. fungi may be assisted by the impairment of host tolerance caused by climate change-induced stress: this may enable less pathogenic fungi to become more successful on stressed trees (Sturrock 2007). Incidence of oak and beech decline, highly complex disorders, is likely to increase if the predicted frequency and severity of summer drought stress prove accurate (Broadmeadow 2005).

A changing climate with increased temperatures, increased evapotranspiration, and extreme weather events would increase the frequency and severity of stress factors, which may lead to more frequent forest declines (Sturrock 2007). Pathogen evolution could be accelerated by mutation resulting from increased sunlight or increased reproduction rates (shorter life cycles under higher temperatures) that could lead to host resistance being overcome more rapidly (Coakley and Scherm 1996).

Based on these occurrences and trends, the following basic patterns have emerged on which we have built our projections of future impacts of pests:

- The current emphasis on longleaf pine restoration, coupled with increasing temperature and decreasing rainfall should result in a measurable shift in the population distribution of southern yellow pine types, both spatially and numerically.
- Boreal forest species are expected to have reduced ranges in the South due to the combined effects of increased temperature and decreased available water.
- Pests associated with southern host species are expected to migrate with their hosts with few exceptions. The exceptions are those pests that already occur throughout the South and extend into the northern part of the United States.
- Although long-term projections suggest that coastal savannah will replace forests in many coastal and coastal-plain locations, the progress of this change within the next 50 years is not expected to be severe.
- Most root rotting diseases are expected to respond aggressively to the combination of warmer soil temperature and reduced precipitation. This combination of heat and drought is expected to result in an increase in dieback and decline among many tree species, often providing further stress that could act as a precursor to successful invasion/colonization by root rotting fungi. Newly stressed trees also may become the focus of insect attack.
- Trees suffering long-term stress may prove to be more resistant to secondary pest attack because of lower physiological activity and reduced availability of resources needed by pest organisms.

- Tree diseases which affect primarily stem and branch tissue are subject directly to the potential effects of warmer temperatures and a drier environment. At first, warmer temperatures and increased carbon dioxide in the atmosphere are expected to have a stimulatory effect on both host and pathogen. However, the anticipated lower availability of water should generally function more against the host plant than the fungi infecting it, favoring an increase in disease. This assumes that the temperature increase does not exceed the thermal death point of the fungus or its spores.
- Foliage attacking fungi are subject to significant pressure from light and the microclimate in the host's leaves. Although significant loss of spore viability is common on the upper surface of leaves, any change in the amount of sunlight will normally alter the survival rate; more sunlight results in lower spore survival and less successful infection and vice versa. The microclimate of the underside of leaves is also critical to the success of foliar pathogens. Lower atmospheric moisture resulting from less rainfall, fog, and dew (with a secondary effect of reduced secretion of liquids) is expected to reduce the effectiveness of colonization by leaf-infecting fungi.
- Longer and warmer summertime temperatures are expected to increase pathogen and insect activity. Insect populations may show simple increases in number due to the availability of additional host material on which to browse, or may be able to produce an additional generation each year.

Managing Pests Under Changing Conditions

Many land-management decisions made today are based on the assumption that the climate will remain relatively stable throughout a forest's life—an assumption that may have worked well in the past but is being challenged by climate change. Even without a clear view of the future climate and forest, it is possible to develop adaptive strategies now. Adaptation in forest management requires a planned response well in advance of the impacts of climate change (Spittlehouse and Stewart 2003). This is especially important when the rotation periods are long (Lemmen and Warren 2004).

Changes in climate, especially if they lead to greater variability among and within regions, tend to add extra uncertainty to decision making (Garrett and others 2006). Burton and others (2002) appear to contest the conclusion of Spittlehouse and Stewart (2003) cited above with their conclusion that development of adaptation measures for some time in the future, under an uncertain climate, in an unknown socioeconomic context is bound to be highly speculative. Not so; reconciling the apparent contradiction here is the necessity that best professional judgment rather than proven science be brought to bear on planning for an uncertain, but generally predicted future.

Adaptive strategies include resilience options and response options. Mitigation options include options to sequester carbon and reduce overall greenhouse gas emissions (Millar and others 2007). Coping strategies for one disturbance type are often appropriate management responses to other disturbance types. Before disturbance occurs forests can be managed to reduce vulnerability or to enhance recovery. Trees can be planted that are less susceptible to disturbance. Species that promote disturbance can be removed (Dale and others 2001). Millar and others (2007) propose the following generalized strategies:

- **Improve resistance in hosts:** From high-value plantations near to harvest to high-priority endangered species with limited available habitat, maintaining the status quo for a short time may be the only or the best option. Resistance practices seek to improve forest defenses against direct and indirect effects of rapid environmental changes by reducing the undesirable or extreme effects of fires, insects, and diseases. Because they may require intensive intervention, these options are best applied only in the short-term.
- **Promote resilience to change:** Resilient forests are those that not only accommodate gradual changes related to climate but also tend to return toward a prior condition after disturbance, either naturally or with management assistance. Promoting resilience is the most commonly suggested adaptive option discussed in a climate change context. This process may also become intensive as changes in climate accumulate over time.
- **Enable forests to respond to change:** These adaptation options intentionally accommodate change rather than resist it. Treatments implemented would mimic, assist, or enable ongoing natural adaptive processes such as species dispersal and migration, population mortality and colonization, community composition and dominance within communities, and disturbance regimes. Some potential practices include: (1) Increase redundancy and buffers, manage for asynchrony, realign significantly disrupted conditions, and use establishment phase to reset succession; (2) Establish "neo-native" forests, experiment with refugia, and promote connected landscapes; (3) Develop indicators as a prerequisite for any kind of decisionmaking and surveillance networks to assess spatial and temporal evolution of diseases and improve epidemiological models; (4) Take an anticipatory and preventive approach based on risk analysis when addressing disease management in forest ecosystems (even more so than for crops), avoid total reliance on one or two control strategies (as Hain [2006] recommended when discussing the unsatisfactory results of balsam woolly adelgid control efforts), and anticipate surprises and threshold effects.
- Disease management options could be altered (Coakley and others 1999) or imposed. For example, although it is known that movement of firewood, nursery stock, and even family trailers and boats is responsible for the transport of many

species, there is no cohesive strategy for addressing this problem (Moser and others 2009). Other actions proposed for managing insects and diseases include:

- Avoid dissemination of pests into climatically favorable zones where they could find naïve host populations by practicing strict hygiene measures, based on the most probable dissemination pathways of organisms (in seeds, wood, and plants).
- Reduce vulnerability to future disturbance by managing tree density, species composition, forest structure, and location and timing of activities (Dale and others 2001).
- Increase light, water, and nutrient availability to the uninfected/uninfested trees and decrease susceptibility to pest attack by practicing precommercial thinning, sanitation removal, or selective removal of suppressed, damaged, or poor quality individuals (Gottshalk 1995, Papadopol 2000, Wargo and Harrington 1991).
- Underplant with other species or genotypes in forests where the current composition is unacceptable as a source of regeneration (Spittlehouse and Stewart 2003).
- Shorten rotations to reduce the period of stand vulnerability to insect or disease attack, and replant to speed the establishment of better-adapted forest types (Gottshalk 1995; Parker and others 2000).
- Use pesticides in situations where silvicultural or other means of pest management are ineffective (Parker and others 2000); however, because morphological or physiological changes in the host resulting from increased carbon dioxide uptake could affect uptake, translocation, and metabolism of systemic fungicides (Coakley and others 1999), incorporate integrated pest management practices.
- Expand and improve existing monitoring efforts to include an expected increase in the number of new, introduced plant diseases (Sturrock 2007).
- Assist in the migration of forests, by introducing carefully selected tree species (including using biotechnology techniques in some situations) in regions beyond their current ranges, being mindful of the potential for unforeseen consequences.

With respect to nonnative invasive species management, Moser and others (2009) recommend five priorities: (1) promoting education and awareness, (2) expanding early detection and active management and intensifying enforcement of quarantines, (3) building the capacity to increase understanding of and treatments for NNIS control, (4) strengthening the basic forest health curriculum, and, (5) encouraging cross agency collaboration and investment.

Although the process of planning and acting to prepare for a future most probably affected by climate change is fraught with uncertainty, not planning and acting will likely result in greater economic and social disruption. Success can only be achieved if those in environmentally sensitive management roles are well informed and exercise their best judgment.

The single consistent theme throughout the literature on pest impacts and climate change is that minimizing ecological change (and disruption) requires maximum possible biodiversity, either through a system of protected refugia or by direct adaptive management for specific characteristics.

Differing perceptions of risk and adaptation may lead to increased tension among various groups. Conflicting priorities and mandates could also lead to future problems (Lemmen and Warren 2004). In these situations, care must be taken to adopt a decisionmaking process that identifies and evaluates all issues and employs the best ecological science.

KNOWLEDGE AND INFORMATION GAPS

As should be clear from the above discussion of current knowledge and from our projections of the future activity of known pests, huge uncertainty dominates the subject of pest management and climate change, with significant gaps existing in baseline knowledge making any generalized quantitative modeling of future conditions impossible. Although some specific pest behaviors have been projected, most of them are qualitative. Lacking generalized and often specific baseline data leaves modeling (quantitative projection) a desired tool whose time has yet to come. Currently unavailable data that would contribute to a generalized projection of potential future pest activity in forests (Beukema and others 2007; Chakraborty and Datta 2003; Hain 2006; Lemmen and Warren 2004; Logan and others 2003; Mamlstrom and Raffa 2000; Rogers and others 1994; Scherm 2004; and, Seem 2004) include:

Information on host biology and response to pests: the role of changing secondary metabolites (primarily phenols or phenol-like) under changing environmental conditions; the functional components of respiration (construction, maintenance, and ion uptake) as well as carbon costs due to root exudation; the role of water in tree health; the genotypic variability and plasticity of hosts; water balance threshold as it affects direct mortality of host plants, the effects of climate change on host defensive mechanisms (physiological, morphological, or other); the impact of climate change on biodiversity and the role of biodiversity in ecosystem functions and pest management/prevention; and, projections of host migration and availability under the influence of climate change.

Information on forest pests: current distributions and ranges of pests; influence of mycorrhizae on plant health under climate change; direct and indirect effects of carbon dioxide, ozone, and UV-B on roots and root-surface microfloras under natural conditions; knowledge of insects and pathogens from outside the area such as Mexican bark beetles and various Asian insects; mechanisms by which changes in carbon dioxide and precipitation alter pest survival, growth, susceptibility and interactions

Information to add clarity and specificity on pest/host interactions: dispersal structure and distance and interconnectedness of temperature, phenology and pest population growth rate; phenological relationships among trees and pests; role of climate on insects and pathogens in relation to available water; baseline data on pests of natural populations that identify the separate of multiple climate variables and problems they cause (including forecasts of epiphytotics or epizootics, and evaluations the role of evolution); pest/predator interactions and responses, relationships among climate, pests, and their parasites; minimum and maximum temperature preferences of pests and pest/host interactions and response to temperature extremes; protocol for identifying the "drivers" that transform new insects and diseases into pests; disturbance regimes and their interactive impacts; and, synergies among fire, insects, and pathogens.

Models and modeling protocols needed: models that incorporate local meteorological data; improved spatially-explicit climate predictions at finer scales (average daily patterns and projected variations from the average); effects of down-scaling or up-scaling data from various models and appropriate linking tools for increasing the accuracy of these predictive processes to be more accurate predictors; functional group rather than single-species models; and, predictive models that incorporate data on disturbances and disturbance impacts.

Management information needed: a new protocol for addressing the research needs of invasive forest pests that involves all stakeholders in a coordinated partnership; and management action plans developed in the face of no-analog vegetation systems and climate change.

ACKNOWLEDGMENTS

Our appreciation is extended to Christopher Asaro, Virginia Department of Forestry; Matthew P. Ayres, Biological Sciences Department, Dartmouth College; Fred P. Hain, Department of Entomology and Frank Koch, Department of Forestry and Environmental Resources, North Carolina State University; Edward L. Barnard, Florida Division of Forestry; Ronald F. Billings and Donald M. Grosman, Texas Forest Service; Scott Cameron and James Johnson, Georgia Forestry Commission; Stephen R. Clarke, John A. Ghent, William E. Jones, Bruce D. Moltzan, Derek Puckett, James D. Smith, Dale A. Starkey, and Borys M. Tkacz, Forest Health Protection, Susan J. Frankel, Pacific Southwest Research Station, and Kier Klepzig, Albert E. 'Bud' Mayfield, III, Daniel Miller, William J. Otrosina, and A. Daniel Wilson, Southern Research Station, U.S. Department of Agriculture, Forest Service.

LITERATURE CITED

Anagnostakis, S.L. 1978. The American chestnut: new hope for a fallen giant. Bull. 777. New Haven, CT: Connecticut Agricultural Experiment Station. 9 p.

Anderson, R.L.; Powers, H.; Snow, G. 1980. How to identify fusiform rust and what to do about it. For. Bull. SA–FB/P24. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State and Private Forestry, Forest Insect and Disease Management. 12 p.

Andreadis, T.G.; Weseloh, R.M. 1990. Discovery of Entomophaga maimaiga in North American gypsy moth, *Lymantria dispar*. Proceedings of the National Academy of Science (U.S.). 87: 2461–2465.

Antipin, J.; Dilley, D. 2004. Chicago vs. the Asian longhorned beetle: a portrait of success. Misc. Publ. MP-1593. Washington, DC: U.S. Department of Agriculture Forest Service. 51 p.

Applegate, H.W. 1971. Annosus root rot mortality in once-thinned loblolly pine plantations in Tennessee. Plant Disease Reporter. 55: 625–627.

Asaro, C.; Fettig, C.J.; McCravy, K.W. [and others]. 2003. The Nantucket pine tip moth: a literature review with management implications. Journal of Entomological Science. 38: 1–40.

Balch, R.E. 1927. Dying oaks in the Southern Appalachians. Forest Worker. 3(7): 13.

Batzer, H.O.; Morris, R.C. 1978. Forest tent caterpillar. Forest Insect and Disease Leaflet 9. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p.

Beal, J.A. 1926. Frost kills oak. Journal of Forestry. 24: 949–950.

Bentz, S.E.; Riedel, L.G.H.; Pooler, M.R.; Townsend, A.M. 2002. Hybridization and self-compatibility in controlled pollinations of eastern North American and Asian hemlock (*Tsuga*) species. Journal of Arboriculture. 28: 200-205.

Berisford, C.W. 1988. The Nantucket pine tip moth. In: Berryman, A.A., ed. Dynamics of forest insect populations: patterns, causes, and implications. New York: Plenum Publishing Corp.: 141–161.

Beukema, S.J.; Robinson, D.C.E.; Greig, L.A. 2007. Forests, insects and pathogens and climate change: workshop report. Prineville, OR: The Western Wildlands Environmental Threat Assessment Center. 20 p. http://www.fs.fed.us/wwetac/workshops/Forest%20Pests%20and%20Climate%20Report.pdf. [Date accessed: November 22, 2010].

Billings, R.F. 1980. Direct control. In: Thatcher, R.C.; Searcy, J.L.; Coster, J.E.; Hertel G.D., eds. The southern pine beetle. Tech. Bull. 1631. Washington, DC: U.S. Department of Agriculture Forest Service, Expanded Southern Pine Beetle Research and Applications Program: 178-192.

Billings, R.F.; Kibbe, C.A. 1978. Seasonal changes between southern pine beetle brood development and loblolly pine foliage color in eastern Texas. Southwestern Entomologist. 3: 89–95.

Billings, R.F.; Upton, W.W. 2010. A methodology for assessing annual risk of southern pine beetle outbreaks across the southern region using pheromone traps. In: Pye, J.M.; Rauscher, H.M.; Sands, Y.; [and others], tech. eds. Advances in threat assessment and their application to forest and rangeland management. Gen. Tech. Rep. PNW-GTR-802. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest and Southern Research Stations: 73-85. Vol. 1.

Boyce, J.S. 1961. Chestnut blight. In: Forest pathology. 3rd ed. New York: McGraw-Hill Book Co.: 285–292.

Brasier, C.M. 1991. *Ophiostoma novo-ulmi* sp. nov., causative agent of current Dutch elm disease pandemics. Mycopathologia. 115: 151-161.

Brasier, C.M.; Scott, J.K. 1994. European oak declines and global warming: a theoretical assessment with special reference to the activity of Phytophthora cinnamomi. Bulletin OEPP. 24(1): 221–232.

Broadmeadow, M.; Ray, D. 2005. Climate change and British woodland. Inf. Note 69. Edinburgh, United Kingdom: Forestry Commission. www.forestresearch.gov.uk/pdf/fcin069.pdf/$FILE/fcin069.pdf. [Date accessed: November 22, 2010].

Brown, H.D.; McDowell, W.E. 1968. Status of loblolly pine die-off on the Oakmulgee District, Talladega National Forest, Alabama-1968. Rep. 69–2–28. Pineville, LA: U.S. Department of Agriculture Forest Service, Forest Insect and Disease Management. 22 p.

Brown, H.D.; Peacher, P.H.; Wallace, H.W. 1969. Status of loblolly pine die-off on the Oakmulgee District, Talladega National Forest, Alabama-1968. Rep. 70–2–3. Pineville, LA: U.S. Department of Agriculture Forest Service, Forest Insect and Disease Management. 7 p.

Burton, I.; Huq, S.; Lim, B. [and others]. 2002. From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate Policy. 2: 145–159.

Cameron, R.S.; Billings, R.F. 1988. Southern pine beetle: factors associated with spot occurrence and spread in young plantations. Southern Journal of Applied Forestry. 12: 208-214.

Campbell, R.W.; Sloan, R.J. 1977. Forest stand responses to defoliation by gypsy moth. Forest Science Monograph 19. Forest Science. 23(Suppl.): 1–35.

Campbell, W.A.; Copeland, O.L., Jr. 1954. Littleleaf disease of shortleaf and loblolly pines. Circ. 940. Washington, DC: U.S. Department of Agriculture. 41 p.

Chakraborty, S.; Datta, S. 2003. How will plant pathogens adapt to host plant resistance at elevated CO_2 under a changing climate? New Phytologist. 159: 733–742.

Chakraborty, S.; Murray, G.M.; Magarey, P.A. [and others]. 1998. Potential impact of climate change on plant diseases of economic significance to Australia. Australasian Plant Pathology. 27: 15–35.

Cherret, J.M. 1986. History of the leaf-cutting ant problem. In: Lofgren, C.S.; Vander Meer, R.K., eds. Fire ants and leaf-cutting-ants biology and management. Boulder, CO: Westview Press: 10–17.

Coakley, S.M.; Scherm, H. 1996. Plant disease in a changing global environment. Aspects of Applied Biology. 45: 227–238.

Coakley, S.M.; Scherm, H.; Chakraborty, S. 1999. Climate change and plant disease management. Annual Review of Phytopathology. 37: 399–426.

Conner, M.D.; Wilkinson, R.C. 1983. Ips bark beetles in the South. Forest Insect and Disease Leaflet 129. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p.

Cordell, C.E.; Anderson, R.L.; Kais, A.G. 1989. How to identify and control brown-spot disease on longleaf pine. Atlanta, GA: U.S. Department of Agriculture Forest Service, Southern Region. 10 p.

Coulson, R.N.; Flamm, R.O.; Pulley, P.E. [and others]. 1986. Response of the southern pine bark beetle guild to host disturbance. Environmental Entomology. 15: 859–868.

Cowles, R.S.; Montgomery, M.E.; Cheah, C.A.S.J. 2006. Activity and residues of imidacloprid applied to soil and tree trunks to control hemlock woolly adelgid (Hemiptera: Adelgidae) in forests. Journal of Economic Entomology. 99: 1258–1267.

Czabator, F.J. 1971. Fusiform rust of southern pines—a critical review. Res. Pap. SO–65. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 39 p.

Dale, V.H.; Joyce, L.A.; McNulty, S. [and others]. 2001. Climate change and forest disturbances. BioScience. 51: 723–734. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone2.pdf. [Date accessed: November 22, 2010].

D'Arcy, C.J. 2005. Dutch elm disease. Saint Paul, MN: American Phytopathological Society. http://www.apsnet.org/edcenter/intropp/lessons/fungi/ascomycetes/Pages/DutchElm.aspx. [Date accessed: November 29, 2012].

Dilling, C.; Lambdin, P.; Grant, J. [and others]. 2010. Spatial and temporal distribution of imidacloprid in eastern hemlock in the Southern Appalachians. Journal of Economic Entomology. 103: 368–373.

Doggett, C.A.; Grady, C.R.; Green, H.J. [and others]. 1977. Seedling debarking weevils in North Carolina. For. Note 31. Raleigh, NC: North Carolina Forest Service, Department of Natural and Economic Resources. 15 p.

Drooz, A.T. 1985. Forest tent caterpillar. In: Insects of eastern forests. Misc. Publ. 1426. Washington, DC: U.S. Department of Agriculture Forest Service: 204-205.

Dull, C.W.; Ward, J.D.; Brown, H.D. [and others]. 1988. Evaluation of spruce and fir mortality in the Southern Appalachian Mountains. Rep. R8–PR 13. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State and Private Forestry, Forest Pest Management. 92 p.

Dwyer, J.P.; Cutter, B.E.; Wetteroff, J.J. 1995. A dendrochronological study of black and scarlet oak decline in the Missouri Ozarks. Forest Ecology and Management. 75: 69–75.

Eckhardt, L.G.; Goyer, R.A.; Klepzig, K.D. [and others]. 2004a. Interaction of *Hylastes* species (Gleeptera: Scolytidae) with *Leptographium* associated with loblolly pine decline. Journal of Economic Entomology. 97: 468–474.

Echhardt, L.G.; Jones, J.P.; Klepzig, K.D. 2004b. Pathogenicity of *Leptographium* species associated with loblolly pine decline. Plant Disease. 88: 1174-1178.

Emerald Ash Borer Information Network. 2010. Emerald ash borer information network. Lansing, MI: Michigan State University. http://www.emeraldashborer.info/index.cfm. [Date accessed: June 10, 2011].

Fitzgerald, T.D. 1995. The tent caterpillars. Cornell Series in Arthropod Biology. Ithaca, NY: Cornell University Press. 303 p.

Fraedrich, S.W.; Harrington, T.C.; Rabaglia, R.J. [and others]. 2008. A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the Southeastern United States. Plant Disease. 92: 215–224.

French, D.W.; Ascerno, M.E.; Stienstra, W.C. 1980. The Dutch elm disease. Publ Ag-BU-0518. St. Paul, MN: Minnesota Extension Service, University of Minnesota. 10 p.

Friedenberg, N.A.; Sarkar, S.; Kouchoukos, N. [and others]. 2008. Temperature extremes, density dependence, and southern pine beetle (Coleoptera: Curculionidae) population dynamics in east Texas. Environmental Entomology. 37: 650–659.

Froelich, R.C.; Cowling, E.B.; Collicott, L.C. [and others]. 1977. *Fomes annosus* reduces height and diameter growth of planted slash pine. Forest Science. 23: 299–306.

Gan, J. 2004. Risk and damage of southern pine beetle outbreaks under global climate change. Forest Ecology and Management. 191: 61–71.

Garbelotto, M.; Svihra, P.; Rizzo, D. 2001. Sudden oak death syndrome fells 3 oak species. California Agriculture. 55(1): 9–19.

Garrett, K.A.; Dendy, S.P.; Frank, E.E. [and others]. 2006. Climate change effects on plant disease: genomes to ecosystems. Annual Review of Phytopathology. 44: 489–509.

Gottschalk, K.W. 1995. Using silviculture to improve health in northeastern conifer and eastern hardwood forests. In: Eskew, L.G., ed. Forest health through silviculture. Gen. Tech Rep. RM–267. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Experiment Station: 219–226. http://www.fs.fed.us/rm/pubs_rm/rm_gtr267/rm_gtr267_219_226.pdf. [Date accessed: November 22, 2010].

Grassano, S.; Costa, S. 2008. Optimizing fungal production for hemlock woolly adelgid suppression [Abstract]. In: Onken, B.; Reardon, R. Fourth symposium on hemlock woolly adelgid in the Eastern United States. Publ. FHTET–2008–01. Morgantown, WV: U.S. Department of Agriculture Forest Service, Forest Health Technology Enterprise Team: 111. http://na.fs.fed.us/fhp/hwa/pubs/proceedings/2008_proceedings/fhtet_2008.pdf. [Date accessed: November 22, 2010].

Gysel, L.W. 1957. Acorn production on good, medium, and poor sites in southern Michigan. Journal of Forestry. 55: 570–574.

Hain, F. 2006. New threats to forest health require quick comprehensive research response. Journal of Forestry. 104(4): 182–186.

Hajek, A.E.; Humber, R.A.; Elkinton, J.S. [and others]. 1990. Allozyme and RFLP analyses confirm *Entomophaga maimaiga* responsible for 1989 epizootics in North American gypsy moth populations. Proceedings of the National Academy of Science (U.S.A.). 87: 6979–6982.

Hanula, J.L.; Mayfield, A.E., III; Fraedrich, S.W. [and others]. 2008. Biology and host associations of redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae), exotic vector of laurel wilt killing redbay trees in the Southeastern United States. Journal of Economic Entomology. 101: 1276–1286.

Harrington, T.C.; Fraedrich, S.W.; Aghayeva, D.N. 2008. *Raffaella lauricola*, a new ambrosia beetle symbiont and pathogen on the Lauraceae. Mycotaxon. 104: 399–404.

Haugen, D.A.; Hoebbeke, E.R. 2005. Sirex woodwasp–*Sirex noctilio* F. (Hymenoptera: Siricidae). Pest alert. Newtown Square, PA: U.S. Department of Agriculture Forest Service, State and Private Forestry, Northeastern Area. 3 p.

Haugen, L. 2007. How to identify and manage Dutch elm disease. Newtown Square, PA: U.S. Department of Agriculture Forest Service, State and Private Forestry, Northeastern Area. 16 p. http://na.fs.fed.us/pubs/detail.cfm?id=918. [Date accessed: November 22, 2010].

Haugen, L.; Stennes, M. 1999. Fungicide injection to control Dutch elm disease: understanding the options. Plant Diagnosticians Quarterly. 20(2): 29-38.

Hepting, G.H. 1974. Death of the American chestnut. Journal of Forest History. 18: 60–67.

Herms, D.A.; McCullough, D.G.; Smitley, D.R. [and others]. 2009. Insecticide options for protecting ash trees from emerald ash borer. North Central IPM Center Bull. (unnumbered). Lansing, MI: North Central IPM Center. 12 p. http://www.emeraldashborer.info/files/Multistate_EAB_Insecticide_Fact_Sheet.pdf. [Date accessed: November 22, 2010].

Hess, N.J.; Eckhardt, L.G.; Menard, R.D. [and others]. 2005. Assessment of loblolly pine decline on the Oakmulgee Ranger District, Talledega National Forest, Alabama. Revised. Rep. 2005–02–04. Pineville, LA: U.S. Department of Agriculture Forest Service, Forest Pest Management. 36 p.

Hess, N.J.; Walkinshaw, C.H.; Otrosina, W.J. 2003. The role of histology in defining fine root mortality of loblolly decline stands. Prot. Rep. R8 PR–53. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, Forest Health Protection. 12 p.

Hoffard, W.H.; Marx, D.H.; Brown, H.D. 1995. The health of southern forests. Prot. Rep. R8PR27. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 36 p.

Hollingsworth, R.G.; Hain, F.P. 1991. Balsam woolly adelgid (Homoptera:Adelgidae) and spruce-fir decline in the southern Appalachians: assessing pest relevance in a damaged ecosystem. Florida Entomologist. 74: 179-187.

Houston, D.R. 1997. Beech bark disease. In: Britton, K.O., ed. Exotic pests of eastern forests: Proceedings of a conference. Nashville, TN: Tennessee Exotic Plant Pest Council: 29–41.

Houston, D.R.; O'Brien, J.T. 1983. Beech bark disease. Forest Insect and Disease Leaflet 75. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p.

Hubbes, M. 1999. The American elm and Dutch elm disease. Forestry Chronicle. 75: 265-273.

Iverson, L.R.; Prasad, A.M.; Hale, B.J. [and others]. 1999. Potential future distributions of common trees of the Eastern United States. Gen. Tech. Rep. NE–265. Delaware, OH: U.S. Department of Agriculture Forest Service, Northeastern Research Station. 245 p. http://www.nrs.fs.fed.us/atlas/tree/. [Date accessed: June 11, 2010].

Jetton, R.M.; Dvorak, W.S.; Whittier, W.A. 2008. Ecological and genetic factors that define the natural distribution of Carolina hemlock in the Southeastern United States and their role in ex situ conservation. Forest Ecology and Management. 255: 3212-3221.

Jetton, R.M.; Whittier, W.A.; Dvorak, W.S.; Rhea, J.R. 2010. Status of gene conservation for eastern and Carolina hemlock in the Eastern United States. In: Onken, B.; Reardon, R., comps: Proceedings of the 5th Symposium on Hemlock Woolly Adelgid in the Eastern United States. Publication no. FHTET-2010-07. Morgantown, WV: U.S. Department of Agriculture Forest Service, Forest Health Technology Enterprise Team: 93-99.

Juzwik, J.; Harrington, T.C.; MacDonald, W.L.; Appel, D.N. 2008. The origin of *Ceratocystis fagacearum*, the oak wilt fungus. Annual Review of Phytopathology. 46: 13-26.

Kais, A.G. 1989. Brown spot needle blight. In: Cordell, C.E.; Anderson, R.L.; Hoffard, W.H. [and others], tech. coords. Forest nursery pests. Agric. Handb. 680. Washington, DC: U.S. Department of Agriculture Forest Service: 26–28.

Kasper, C.A. 2000. Flowering dogwood (*Cornus florida*). Windstar Wildlife Institute. Accessed at: http://www.windstar.org/features/clearinghouse/a_flowerin.htm

Kliejunas, J. 2003. A pest risk assessment of *Phytophthora ramorum* in North America. Vallejo, CA: U.S. Department of Agriculture Forest Service, State and Private Forestry. 11 p. http://www.suddenoakdeath.org/pdf/RevisedPRA.8.03.pdf. [Date accessed: November 22, 2010].

Kliejunas, J.T. 2010. Sudden oak death and *Phytophthora ramorum*: a summary of the literature: 2010 edition. Gen. Tech. Rep. PSW-GTR-234. Albany, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station. 181 p.

Koch, F.H.; Smith, W.D. 2008a. Mapping sudden oak death risk nationally using host, climate and pathways data. In: Frankel, S.J.; Kliejunas, J.T.; Palmieri, K.M., tech. coords. 2008. Proceedings of the sudden oak death third science symposium. Albany, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Forest Experiment Station: 279-287. http://www.fs.fed.us/psw/publications/documents/psw_gtr214/. [Date accessed: June 11, 2010].

Koch, F.H.; Smith, W.D. 2008b. Spatio-temporal analysis of *Xyleborus glabratus* (Coleoptera: Circulionidae: Scolytinae) invasion in Eastern U.S. forests. Environmental Entomology. 37: 442–452.

Kolarik, M.; Freeland, E. 2011. *Geosmithia morbida* sp. nov., a new phytopathogenic species living in symbiosis with the walnut twig beetle (*Pityophthorus juglandis*) on Juglans in USA. Mycologia. 103(2): 325-332.

Kovacs, K.F.; Haight, R.G.; McCullough, D.G. [and others]. 2009. Cost of potential emerald ash borer damage in U.S. communities, 2009-2019. Ecological Economics. 69: 569–578.

Kruse, J.J. 2000. *Archips goyerana* n. sp. (Lepidoptera: Tortricidae), an important pest of baldcypress (Taxodiaceae) in Louisiana and Mississippi. Proceedings of the Entomological Society of Washington. 102: 741–746.

Lemmen, D.S.; Warren, F.J., eds. 2004. Climate change impacts and adaptation: a Canadian perspective. Ottawa, Ontario: Natural Resources Canada. 174 p.

Liebhold, A.M.; Gottschalk, K.W.; Muzika, R. [and others]. 1995. Suitability of North American tree species to gypsy moth: a summary of field and laboratory tests. Gen. Tech. Rep. NE–211. Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 34 p.

Logan, J.A.; Régnière, J.; Powell, J.A. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment. 1: 130–137.

Loomis, R.C. 1976. Loblolly pine die-off, Oakmulgee R.D. Eval. Memo. Pineville, LA: U.S. Department of Agriculture Forest Service, Forest Insect and Disease Management. 2 p.

Lovett, G.M.; Canham, C.D.; Arthur, M.A. [and others]. 2006. Forest ecosystem responses to exotic pests and pathogens in Eastern North America. BioScience. 56(5): 395–403.

MacDonald, W.L. 1995. Oak wilt: an historical perspective. In: Appel, D.N.; Billings, R.F., eds. Oak wilt perspectives: Proceedings of the national oak wilt symposium. College Station, TX: Texas Forest Service, Texas Agricultural Experiment Station: 7–13.

Mamlstrom, C.M.; Raffa, K.F. 2000. Biotic disturbance agents in the boreal forests: considerations for vegetation change models. Global Change Biology. 6: 35–48.

Mausel, D.L.; Salom, S.M.; Kok, L.T. [and others]. 2010. Establishment of the hemlock woolly adelgid predator, *Laricobius nigrinus* (Coleoptera: Derodontidae), in the Eastern United States. Environmental Entomology. 39: 440–448.

Mayfield, A.E., III. 2008. Laurel wilt. Forest and Shade Tree Pests, Leaflet 13. Tallahassee, FL: Florida Department of Agriculture and Consumer Services, Division of Forestry. 2 p.

Mayfield, A.; Barnard, E.; Bates, C. [and others]. 2009. Recovery plan for laurel wilt on redbay and other forest species. Caused by *Raffaelea lauricola*, vector *Xyleborus glabratus*. National Plant Disease Recovery System, a cooperative project of The American Phytopathological Society and The United States Department of Agriculture. 27 p. http://www.ars.usda.gov/SP2UserFiles/Place/00000000/opmp/ForestLaurelWilt100107.pdf. [Date accessed: November 29, 2012].

McClure, M.S. 1987. Biology and control of hemlock woolly adelgid. Bull. 851. New Haven, CT: Connecticut Agricultural Experiment Station. 9 p.

Menard, R.D.; Eckhardt, L.G.; Hess, N.J. 2006. Assessment of loblolly pine decline on Fort Benning Military Reservation. Rep. 2006–02–01. Pineville, LA: U.S. Department of Agriculture Forest Service, Southern Region, Forest Health Protection. 21 p.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forest of the future: managing in the faces of uncertainty. Ecological Applications. 17(8): 2145–2151.

Miller, R.E. 1979. Loblolly pine die-off status report. Rep. 79–2–4. Pineville, LA: U.S. Department of Agriculture Forest Service, Forest Insect and Disease Management. 3 p.

Millers, I.; Shriner, D.S.; Risso, D. 1990. History of hardwood decline in the Eastern United States. Gen. Tech. Rep. NE–126. Durham, NH: U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry, Forest Health Protection. 75 p.

Montgomery, M.E.; Bentz, S.E.; Olsen, R.T. 2009. Evaluation of hemlock (*Tsuga*) species and hybrids for resistance to *Adelges tsugae* (Hemiptera: Adelgidae) using artificial infestation. Journal of Economic Entomology. 1021(3): 1247-1254.

Morris, C.L. 1970. Volume losses from *Fomes annosus* in loblolly pine in Virginia. Journal of Forestry. 68: 283–294.

Moser, J.C. 1984. Town ant. In: Proceedings of the 10th anniversary of the east Texas forest entomology seminar. Misc. Publ. MP–1553. College Station, TX: Texas Agricultural Experiment Station: 47–52.

Moser, W.K.; Barnard E.L.; Billings, R.F. [and others]. 2009. Impacts of nonnative invasive species on U.S. forests and recommendations for policy and management. Journal of Forestry. 107: 320–327.

Newhouse, A.E.; Schrodt, F.; Liang, H. [and others]. 2007. Transgenic American elm shows reduced Dutch elm disease symptoms and normal mycorrhizal colonization. Plant Cell Reporter. 26: 977-987.

Nicholas, N.S.; Zedaker, S.M. 1990. Forest decline and regeneration success of the Great Smoky Mountains spruce-fir. [Abstract]. In: Smith, E.R., ed. Proceedings: the first annual southern man and the biosphere conference. Rep. TVA/LR/NRM–90/8. Norris, TN: Tennessee Valley Authority. [Number of pages unknown].

Nord, J.C.; Ragenovich, I.; Doggett, C.A. 1984. Pales weevil. Forest Insect and Disease Leaflet 104. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p.

Nowak, J. [N.d.]. Southern pine beetle hazard maps. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region. http://www.fs.fed.us/foresthealth/technology/nidrm_spb.shtml. [Date accessed: November 19, 2010].

Oak, S.W.; Starkey, D.A.; Dabney, J.M. 1988. Oak decline alters habitat in southern upland forests. In: Proceedings of the annual conference of the Southeastern Association of Fish and Wildlife Management Agencies. 42: 491–501.

Oliveira, E.B.; Penteado, S.R.C.; Lede, E.T. 1998. Forest management for the prevention and control of *Sirex noctilio* in *Pinus taeda*. In: Lede, E.T., ed. Training in the control of *Sirex noctilio* by the use of natural enemies: Proceeding of a conference. Morgantown, WV: U.S. Department of Agriculture. 104 p.

Otrosina, W.L.; Garbelotto, M. 2010. *Heterobasidion occidentale* sp. nov. and *Heterobasidion irregulare* nom. nov.: a disposition of North American *Heterobasidion* species. Fungal Biology. 114(1): 16-25.

Paine, T.D.; Birch, M.C.; Svihra, P. 1981. Niche breadth and resource partitioning by four sympatric species of bark beetles (Coleoptera: Scolytidae). Oecologia. 48: 1–6.

Papadopol, C.S. 2000. Impacts of climate warming on forests in Ontario: options for adaptation and mitigation. Forestry Chronicle. 76: 139–149.

Paradis, A.; Elkinton, J.; Hayhoe, K. [and others]. 2008. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in Eastern North America. In: Mitigation and adaptation strategies for global change. Dordrecht, Netherlands: Springer. 13: 541–555.

Parker, W.C.; Colombo, S.J.; Cherry, M.I. [and others]. 2000. Third millennium forestry: what climate change might mean to forests and forest management in Ontario. Forestry Chronicle. 76: 445–463.

Pooler, M.R.; Riedel, L.G.H.; Bentz, S.E.; Townsend, A.M. 2002. Molecular markers used to verify interspecific hybridization between hemlock (*Tsuga*) species. Journal of the American Society for Horticultural Science. 127: 623-627.

Reid, L.; Eickwort, J.; Johnson, J.; Riggins, J.J. 2011. Distribution of counties with laurel wilt disease by year of initial detection. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. http://www.fs.fed.us/r8/foresthealth/laurelwilt/dist_map.shtml. [Date accessed: March 9, 2011].

Rexrode, C.O.; Brown, H.D. 1983. Oak wilt. Forest Insect and Disease Leaflet 29. Washington, DC: U.S. Department of Agriculture Forest Service. 6 p.

Rhea, J.R.; Watson, J.K. 1994. Forest health evaluation of the hemlock woolly adelgid, *Adelges tsugae*, infestations in Shenandoah National Park (SMP), Virginia, 1993. Rep. 94–1–22. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State and Private Forestry, Forest Health Protection. 10 p.

Rivera Rojas, M.; Locatelli, B.; Billings, R. 2010. Cambio climático y eventos epidémicos del gorgojo descortezador del pino *Dendroctonus frontalis* en Honduras (Climate change and outbreaks of the southern pine beetle, *Dendroctonus frontalis*, in Honduras). Forest Systems. 19: 70–76.

Rizzo, D.M.; Garbelotto, M.; Davidson, J.M. [and others]. 2002. *Phytophthora ramorum* and sudden oak death in California: I. Host relationships. In: Verner, J., tech. ed. Proceedings of a symposium on the Kings River sustainable forest ecosystem project: progress and current status. Gen. Tech. Rep. PSW–GTR–183. Albany, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station: 733–740.

Robbins, K. 1984. Annosus root rot in eastern conifers. Forest Insect and Disease Leaflet 76. Washington, DC: U.S. Department of Agriculture Forest Service. 6 p.

Rogers, H.H.; Runion, G.B.; Krupa, S.V. 1994. Plant responses to atmospheric CO_2 enrichment with emphasis on roots and the rhizosphere. Environmental Pollution. 83: 155–189.

Scheffer, R.J.; Voeten, J.G.W.; Guries, R.P. 2008. Biological control of Ductch elm disease. Plant Disease. 92: 192-200.

Scherm, H. 2004. Climate change: can we predict the impacts on plant pathology and pest management? Canadian Journal of Plant Pathology. 26: 267–273.

Schlarbaum, S.E. 1988. Returning the American chestnut to the forests of North America. Katuah Journal. 21(Fall): 6, 7, 23.

Seem, R.C. 2004. Forecasting plant disease in a changing climate: a question of scale. Canadian Journal Plant Pathology. 26: 274–283.

Seybold, S.; Haugen, D.; O'Brien, J. [and others]. 2010. Thousand cankers disease. Pest Alert NA–PR–02–10. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry. 2 p. http://na.fs.fed.us/pubs/palerts/cankers_disease/thousand_cankers_disease_screen_res.pdf. [Date accessed: January 10, 2011].

Sharov, A.; Leonard, D.; Liebold, A.M. [and others]. 2002. "Slow the spread": a national program to contain the gypsy moth. Journal of Forestry. 100: 30–35.

Smith, E.L.; Storer, A.J.; Roosien, B.K. 2009. Emerald ash borer infestation rates in Michigan, Ohio, and Indiana. [Abstract]. In: McManus, K.A.; Gottschalk, K.W., eds. Proceedings. 20th U.S. Department of Agriculture interagency research forum on invasive species. Gen. Tech. Rep. NRS–P–51. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 96.

Smith, R.H.; Lee, R.E., III. 1972. Black turpentine beetle. Forest Pest Leaflet 12. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p.

Snover-Clift, K.L. 2009. Dutch elm disease: Ophiostoma novo-ulmi. Factsheet. Ithica, NY: Cornell University, Plant Diagnostic Clinic. 4 p. http://plantclinic.cornell.edu/factsheets/dutchelmdisease.pdf. [Date accessed: March 11, 2011].

Solomon, J.D. 1995. Guide to insect borers of North American broadleaf trees and shrubs. Agric. Handb. 706. Washington, DC: U.S. Department of Agriculture Forest Service. 706 p.

Southern Appalachian Man and the Biosphere. 1996. The effects to Southern Appalachian Assessment forest ecosystems from native and exotic pests. In: The Southern Appalachian assessment terrestrial technical report. Rep. 5 of 5. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region: 103-122.

Spittlehouse, D.L.; Stewart, R.B. 2003. Adaptation to climate change in forest management. BC Journal of Ecosystems and Management. 4(1): 1–11. http://www.forrex.org/publications/jem/ISS21/vol4_no1_art1.pdf. [Date accessed: November 22, 2010].

Staeben, J.C.; Clarke, S.; Ghandi, K.J.K. 2010. Black turpentine beetle. Forest Insect and Disease Leaflet 12. Portland, OR: U.S. Department of Agriculture Forest Service. 8 p.

Staley, J.M. 1965. Decline and mortality of red and scarlet oaks. Forest Science. 11: 2–17.

Stambaugh, W.J. 1989. Annosus root disease in Europe and the Southeastern United States: occurrence, research, and historical perspective. In: Otrosina, W.J.; Scharpf, R.F., tech. coords. Proceedings of the symposium on research and management of annosus root disease (*Heterobasidion annosum*) in Western North America. Gen. Tech. Rep. PSW–116. Berkeley, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Forest and Range Experiment Station: 3–9.

Starkey, D.A.; Mangini, A.; Oliveria, F. [and others]. 2000. Forest health evaluation of oak mortality and decline on the Ozark National Forest, 1999. Rep. 2000–02–02. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State and Private Forestry, Forest Health Protection. 31 p.

Starkey, D.A.; Oak, S.W.; Ryan, G. [and others]. 1989. Evaluation of oak decline areas in the South. Prot. Rep. R8 PR–17. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State and Private Forestry, Forest Pest Management. 43 p.

Sturrock, R.N. 2007. Climate change effects on forest diseases: an overview. In: Jackson, M.B., comp. Proceedings of the 54th annual western international forest disease work conference. Missoula, MT: U.S. Department of Agriculture Forest Service: 51–55.

Sturrock, R.N.; Frankel, S.J.; Brown, A.V. [and others]. 2011. Climate change and forest diseases. Plant Pathology. 60: 133-149.

Tainter, F.H.; Baker, F.A. 1996. Oak wilt. In: Principles of forest pathology. New York: John Wiley: 671-682.

Tainter, F.H.; Retzlaff, W.A.; Starkey, D.A.; Oak, S.W. 1990. Decline of radial growth in red oaks is associated with short-term changes in climate. European Journal of Forest Pathology. 20: 95–105.

Texas Forest Service. 1982. Texas forest pest report 1980–1981. Publ. 127. College Station, TX: Texas Forest Service. 39 p.

Thatcher, R.C. 1960a. Bark beetles affecting southern pines: a review of current knowledge. Occas. Pap. 180. Washington, DC: U.S. Department of Agriculture Forest Service. 25 p.

Thatcher, R.C. 1960b. Influence of the pitch-eating weevil on pine regeneration in east Texas. Forest Science. 6: 354–361.

Thatcher, R.C.; Barry, P.J. 1982. Southern pine beetle. Forest Insect and Disease Leaflet 49. Washington, DC: U.S. Department of Agriculture Forest Service. 6 p.

Thatcher, R.C.; Conner, M.D. 1985. Identification and biology of southern pine bark beetles. Agric. Handb. 634. Washington, DC: U.S. Department of Agriculture Forest Service; Cooperative State Research Service, Expanded Southern Pine Beetle Research and Applications Program. 14 p.

Thatcher, R.C.; Coster, J.E.; Hertel, G. [and others], eds. 1980. The southern pine beetle. Tech. Bull. 1631. Washington, DC: U.S. Department of Agriculture Forest Service, Science and Education Administration, Expanded Southern Pine Beetle Research and Applications Program. 266 p.

Tran, J.K.; Ylioja, T.; Billings, R. [and others]. 2007. Impact of minimum winter temperatures on the population dynamics of *Dendroctonus frontalis* (Coleoptera: Scolytinae). Ecological Applications. 17: 882–899.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2003. Emerald ash borer; quarantine and regulations: interim rule and request for comment. Federal Register. 68: 59,082–59,091.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2006. Emerald ash borer; quarantined areas: affirmation of interim rules as final rule. Federal Register. 70: 249–263.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2010a. APHIS list of regulated hosts and plants proven or associated with *Phytophthora ramorum*. http://www.aphis.usda.gov/plant_health/plant_pest_info/pram/downloads/pdf_files/usdaprlist.pdf. [Date accessed: March 4, 2011].

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2010b. European gypsy moth (*Lymantria dispar*) North America quarantine. Washington, DC: U.S. Department of Agriculture, Animal and Plant Health Inspection Service. http://www.aphis.usda.gov/plant_health/plant_pest_info/gypsy_moth/downloads/gypmoth.pdf. [Date accessed: November 19, 2010].

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 2011. Cooperative emerald ash borer project: EAB locations in Illinois, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Virginia, Wisconsin, West Virginia and Canada: February 1, 2011. http://www.emeraldashborer.info/files/MultiState_EABpos.pdf. [Date accessed: March 1, 2011].

U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Agricultural Research Service, Forest Service; Cooperating State Departments of Agriculture. 2010. Emerald ash borer, *Agrilus planipennis* (Fairmaire), biological control release guidelines, ver. 1. Riverdale, MD: U.S. Department of Agriculture, Animal & Plant Health Inspection Service. 63 p.

U.S. Department of Agriculture Forest Service. 1985a. Black turpentine beetle and Ips beetles. In: Insects of eastern forests. Misc. Publ. 1426. Washington, DC: U.S. Department of Agriculture Forest Service: 346–347, 358–361.

U.S. Department of Agriculture Forest Service. 1985b. Forest tent caterpillar. In: Insects of eastern forests. Misc. Publ. 1426. Washington, DC: U.S. Department of Agriculture Forest Service: 204-205.

U.S. Department of Agriculture Forest Service. 2010. Hemlock woolly adelgid [home page]. Newtown Square, PA.: U.S. Department of Agriculture Forest Service, Northeastern Area. http://www.na.fs.fed.us/fhp/eab/. [Date accessed: March 1, 2011].

U.S. Department of Agriculture Forest Service, and USDA Animal and Plant Health Inspection Service. 2008. Asian longhorned beetle: a new introduction. Pest Alert NA–PR–01–99GEN. Newtown Square, PA: U.S. Department of Agriculture Forest Service; Animal and Plant Health Inspection Service. 2 p. http://www.na.fs.fed.us/pubs/palerts/alb/alb_pa.pdf. [Date accessed: November 22, 2010].

U.S. Department of Agriculture Natural Resources Conservation Service. 2008. Tennessee Natural Heritage Program rare plant list 2008. Nashville, TN: Tennessee Division of Environment and Conservation, Division of Natural Resources. 46 p. http://www.state.tn.us/environment/na/pdf/plant_list.pdf. [Date accessed: February 18, 2011].

U.S. Department of Agriculture Natural Resources Conservation Service. 2009. County report of endangered, threatened and special concern plants, animals, and natural communities of Kentucky. Frankfort, KY: Kentucky Nature Preserves Commission. 136 p. http://plants.usda.gov/java/threat?statelist=states&stateSelect=US21. [Date accessed: February 18, 2011].

U.S. Department of Agriculture Natural Resources Conservation Service. 2011. Threatened and endangered: protected plants for scientific name = Juglans cinerea. http://plants.usda.gov/java/threat?txtparm=Juglans+cinerea&category=sciname&familycategory=DI&duration=PR&growthhabit=TR&wetland=all&statefed=statelist&stateSelect=US01&stateSelect=US05&stateSelect=US12&stateSelect=US13&stateSelect=US21&stateSelect=US22&stateSelect=US28&stateSelect=US37&stateSelect=US40&stateSelect=US45&stateSelect=US48&stateSelect=US51&stateSelect=US72&sort=sciname&submit.x=84&submit.y=13. [Date accessed: February 18, 2011].

Vilela, E.F. 1986. Status of leaf-cutting ant control in forest plantations in Brazil. In: Lofgren, C.S.; Vander Meer, R.K., eds. Fire ants and leaf-cutting ants: biology and management. Boulder, CO: Westview Press: 399-408.

Ward, J.D.; Mistretta, P.A. 2002. Impact of pests on forest health. In: Wear, D.N.; Greis, J.G. Southern forest resource assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 403-428. Chapter 17.

Wargo, P.M. 1977. *Armillaria mellea* and *Agrilus bilineatus* and mortality of defoliated oak trees. Forest Science. 23: 485–492.

Wargo, P.M.; Harrington, T.C. 1991. Host stress and susceptibility to armillaria. Agric. Handb. 691. In: Shaw, C.G., III; Kile, G., eds. Armillaria root disease. Washington, DC: U.S. Department of Agriculture: 88–101.

Wargo, P.M.; Houston, D.R.; LaMadeleine, L.A. 1983. Oak decline. Forest Insect and Disease Leaflet 165. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p.

Winnett, S.M. 1998. Potential effects of climate change on U.S. forests: a review. Climate Research. 11: 39–49. http://www.int-res.com/articles/cr/11/c011p039.pdf. [Date accessed: November 22, 2010].

Woods, A.J.; Coates, K.D.; Hamann, A. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate change? BioScience. 55: 761–769.

Zhu, Z. 1994. Forest density mapping in the lower 48 States: a regression procedure. Res. Pap. SO–280. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 11 p.

APPENDIX C. Climate Change and Its Impacts on Forests

INTRODUCTION

This appendix contains a generalized summary of the relevant literature related to climate change, vegetation change (species and geographic range changes), and pest activity scenario classification as reflected in the current literature.

Information for this appendix was derived from published science literature, along with a selection of literature about the biology and ecology of forest pests. Additional information about forest pests and their control is readily available from State and Federal forestry agencies or online (two good starting points are http://na.fs.fed.us/pubs/index.shtm and http://www.fs.fed.us/r8/foresthealth/).

Many scientists believe that climate change in the form of global warming has occurred over the last century and will continue to occur into the immediate future (Intergovernmental Panel on Climate Change 2007, Kleijunas and others 2009, Malcolm and Pitelka 2000, McNulty and Aber 2001, National Assessment Synthesis Team 2000). The primary factors of climate noted as driving observed ecological effects are temperature and available water. In addition atmospheric gasses (carbon dioxide and air pollutants such as nitrogen oxides and sulfur dioxide) in excess of their 'normal' ranges are often identified as additional drivers of the change being observed. Climate change is also linked, at least in part, to human activity (Malcolm and Pitelka 2000, Sturrock 2007, Winnett 1998). These changes are expected to impact crops and their pests individually, as well as impacting the interactions between crops and pests (Runion 2003).

Reporting the results of a workshop attempting to understand the potential interactions among forests, insects, diseases, and climate change, Beukema and others (2007) report that:

Participants agreed that things will change. Most vegetation communities will not simply migrate from one location to another. Instead, many communities will be completely new, with new combinations of trees, understory plants, insects, and diseases. At the same time it is important to bear in mind that we are not going to completely lose all forests and all vegetation. New plant communities will organize themselves and will replace plants that are unable to adapt to new climates. New communities could include current tree species, other tree species (e.g., hardwoods or strongly dispersing species from warmer areas) or could become dominated by grass and shrub species.

MODELING CLIMATE CHANGE

Available Models

Major efforts are underway to create and use models that can project potential scenarios describing both the impacts of climate change on ecological conditions and the subsequent responses resulting from and possibly then influencing those conditions. Modeling can contribute to our projections of future conditions "…but requires sound knowledge of the causal factors determining spatial distribution, survival, reproduction, dispersal, and infliction of damage" (Goudriaan and Zadocks 1995).

Selection of broad-scale model types (such as general circulation models, process-based models, and empirical models) depends on the specific questions being analyzed and the available relevant data. The application of general circulation models is limited; the finest scale used for global climate simulation is far too coarse for meaningful ecological applications (Logan and others 2003). At a smaller scale, gap models, biogeography models, and biogeochemistry models are among those being used to refine probable broad-scale model projections to reflect conditions at a more local scale (Winnett 1998).

Current model projections of future conditions that will affect forest composition and productivity vary over a wide range of plausible scenarios (Logan and others 2003, National Assessment Synthesis Team 2000, Scherm 2000).

Scherm (2000) supports Millstein's (1994) contention that uncertainties in model input can compromise the credibility of the output because of error perpetuation or propagation. These scientists are not alone in their concern. Others add the concern that data selection can also significantly influence model output. The use of a crisp data set versus a "fuzzy number" set will have additional major impacts on outputs (Coakley and others 1999).

Scherm and Coakley (2003) have identified three continuing problems with the application of models for predicting climate change effects:

- Model inputs have a high degree of uncertainty.
- Nonlinear relationships and thresholds in the relationship between climatic variables and epidemiological responses complicate efforts to collect sufficient data for clear predictive understanding.
- Modeling often ignores the potential for adaptation by plants and the insects and diseases that attack them.

Physical Impacts of Climate Change

Temperature—Increase in average temperature is consistently shown in results from a variety of models as being of concern. The Intergovernmental Panel on Climate Change (2007) stated that the data supporting an ongoing warming of the climate are unequivocal, pointing to observations of increases in global air and ocean temperatures, widespread melting of snow and ice, and rising sea levels. The panel found a linear trend in average temperature which had increased by 0.74 ºC (0.56 to 0.92 ºC) from 1906 to 2005, higher than the earlier reported increase of 0.6 ºC (0.4 to 0.8 ºC) for 1901 to 2000 (Intergovernmental Panel on Climate Change 2001); that land areas have warmed faster than oceans; and that temperature increases appear to be larger in northern latitudes.

Overall, climate change is predicted to lead to increasing temperature. Mean global surface air temperatures are predicted to increase from 1.4 to 5.8 ºC by the end of the century. Both night-day and winter-summer average temperature ranges are likely to shrink as minimum temperatures increase more than maximum ones, and continental and high-latitude areas will tend to warm more than coastal and lower-latitude areas (Burdon and others 2006, Harvell and others 2002). The magnitude of these changes is expected to vary both temporally and spatially (McNulty and Boggs 2010).

Water regime—Water is reported to be of great significance, second only to temperature, when projecting potential effects of climate change. Overabundance of water, lack of it, and seasonality of its availability all have significant impacts on the forest processes that govern the overall health of individual organisms. Projections of overall responses to rainfall pattern vary greatly. Generalizations found in the literature include the following:

- In the South, intense precipitation events have increased over the past 100 years (National Assessment Synthesis Team 2000).
- Rising sea levels have already had significant impacts on coastal areas, and these impacts will likely increase (National Assessment Synthesis Team 2000).

Malcolm and Pitelka (2000) summarized the effects of water as follows: future regional-scale precipitation changes remain particularly difficult to predict, and changes in the frequency and severity of storms and other extreme weather events are uncertain (Wigley 1999). Overall these changes will appear as a shift of climatic zones towards the poles; warmer temperatures will reach further north in the United States. This last observation introduces a critical concern when discussing climate change. Ecological factors do not function in isolation, they interact and influence each other. This is a fact easily forgotten when reading the literature, much of which discusses single factor effects at a variety of scales.

Carbon dioxide and trace gases—Carbon dioxide is routinely cited as a primary cause of global warming. The consensus within the scientific community (Coakley 1988) is that the increase in carbon dioxide and shifting percentage of trace gases (ozone, chlorofluorocarbons, nitrogen oxides, sulfur oxides, and methane) will combine to bring about continuing global warming. Although this is generally agreed to be an accurate projection of future condition, the spatial relationships involved are extremely uncertain, as are predictions of where the effect will be significant.

Light—Solar radiation is the source of energy for most terrestrial processes, and anything that alters the amount of radiation reaching the earth's surface may alter climate. Fluctuations in solar output, volcanic eruptions, and other natural perturbations influence solar input to the earth's energy engine, as do changes in land use and industry. The quality of light and the duration of photoperiod have been shown to affect plants in a variety of ways. Yet except to note that greenhouse gasses can affect the quality of light, little is said in the literature about possible future shifts in light quality. Photoperiod is seldom discussed as changing for a given area. Effects of photoperiod only appear to be noted as significant within the context of other factors that influence plant migrations as described below.

Wind—In the early 1950s, Hepting (1963) found that wind, not temperature or rainfall, was the primary driver of climate change in Great Britain. More recently, Lemmen and Warren (2004), also discussing climate change in Great Britain, suggest that a warmer climate may be more conducive to extreme wind events and that these may in turn have consequences for other forest disturbances. Yarwood (1959) suggested that wind has significant impacts, both directly or indirectly, on plants and the pests that attack them. Unfortunately, with the exception of discussions in the context of storm events, wind is little discussed in the literature, and we found no projections of future wind events in the South.

Soil—Soil chemical properties do not appear to be directly affected by climate change, their only contribution to climate change being a complex of secondary effects. However, it is generally recognized that as air temperature increases so does soil temperature. Soil warming in conjunction with drought is a major concern because it predisposes roots and rootlets to mortality, whether or not root rotting fungi are involved. Localized and often short-term shifts in the albedo are predicted if soil warming results in the failure of vegetative cover, but predictions are not spatially explicit either as to size or location.

Rates of soil mineralization, acidification, nitrification, and carbon sequestration are all processes that are clearly influenced by climate change, but generally these effects are more affected by (and subsequently influence) the local biota.

Mixed edaphic effect projections—A variety of projections have been made for compounded edaphic factors; four are briefly noted below:

- Increased frequency of extreme weather events (Scherm 2003)
- Increased frequency and intensity of drought occurring under warmer temperatures (Breshears and others 2005)
- More frequent winter waterlogging resulting from increased winter rainfall (Broadmeadow and Ray 2005)
- Increased duration of sunshine resulting from changes in temperature and humidity which in turn lead to reduced summer cloud cover (Broadmeadow and Ray 2005)

IMPACTS ON PESTS AND INDIVIDUAL HOST PLANTS

Climate is the single most important factor determining the distribution of major vegetation types and individual species (Malcolm and Pitelka 2000).

Extrapolating the physical effects of climate change to the potential biological/ecological effects that they engender is often problematic. The simple description is that as the climate warms, southern forests will migrate northward and upward (assuming that higher elevation sites become available), and will displace a portion of the temperate mixed hardwood forest. The temperate mixed hardwood forest in its turn will migrate, displacing part of the northern boreal forest. Although this presents an easy to understand generalization, it masks an extremely complex reality.

Forests are not expected to migrate as cohesive units. Although driven by a set of individual physical parameters, migration will more likely respond directly at the species and individual plant level, not at the association, ecosystem, or other ecological level of organization. Different species (and different individuals even within a species) will react in potentially very different ways to the various stimuli generated by climate change. The responses of ecosystems can only be predicted by understanding the behavior of their convergent properties and the unique characteristics and responses of individual species (Malcolm and Pitelka 2000).

On the positive side, increasingly sophisticated computer models have been developed that incorporate more fundamental ecological mechanisms. However, even these newer models cannot yet predict with accuracy what happens as the climate is changing (Malcolm and Pitelka 2000).

Nevertheless, we have some clear reports of observed responses to climate change. An average 1°C increase in average temperature is reported to increase plant growth and lengthen the growing season. Budbreak of quaking aspen (*Populus tremuloides*) is reported to be 26 days earlier than a century ago in Alberta, Canada; and budbreak of white spruce (*Picea glauca*) is earlier in Ontario (Lemmen and Warren 2004). Ground-based monitoring efforts in Europe documented an 11-day increase in growing season length over a 34-year period (Malcolm and Pitelka 2000). Because temperature can affect ecosystems in many different ways and because there are multiple pathways for feedback and interaction, evaluating or predicting the effects of temperature increases is not simple. Not surprisingly, published results have been mixed (Malcolm and Pitelka 2000).

The size of plant organs at multiple scales may increase as a response to elevated levels of carbon dioxide. Increased area per leaf, leaf thickness, number of leaves, leaf area per plant, and diameter of stems and branches have all been observed under increased carbon dioxide. Enhanced photosynthesis, increased water use efficiency, and reduced damage from ozone are also reported as responses to increased carbon dioxide (Garrett and others 2006).

Disease and Insect Risks, Absent Climate Change

The second periodic National Insect and Disease Risk Map, completed in 2006, presents a strategic assessment of potential tree mortality resulting from major insects and diseases. This is the definitive source at the present time for projected insect- and disease-caused mortality for the years 2006 to 2021 (shorter term than the 50 year window of the Southern Forest Futures Project). The risk map is compiled using nearly 190 separate models in a geographic information system (GIS) framework. It assigns risk to individual 1 square kilometer pixels based on forest type, host species basal area, and numerous other factors commonly associated with host species and damage agents. Climate change is not specifically factored into the models, but the map provides an excellent short-term projection of pest activity from which to extrapolate.

A composite map (fig. C.1) displays the summary of risk from all damage agents. The risk shown is the expectation that 25 percent or more of the standing live volume of trees ≥1 inch diameter at breast height (d.b.h.) will be lost over the next 15 years (http://www.fs.fed.us/foresthealth/technology/pdfs/RiskMap_agents_hillshade_8x11.pdf).

Forest health specialists from the U.S. Department of Agriculture Forest Service Southern Region (http://www.fs.fed.us/foresthealth/technology/nidrm.shtml) have developed a Web site that provides separate large-scale risk maps for each Southern State (with county border overlays) color-coded by the degree of risk in each pixel. These maps, labeled by damaging agent—such as gypsy moth (*Lymantria dispar*) or southern pine beetle (*Dendroctonus frontalis*)—show the risk associated with the most serious individual pest problems for each State (http://www.fs.fed.us/r8/foresthealth/programs/riskmap/maps/statemaps.shtml).

Disease and Insect Activity in a Changing Climate

A variety of statements within this section are written specifically about diseases, insects, or specific host species, based on the content of the initial work being cited. Most, if not all, apply to the broader spectrum of pest species or host species and should be interpreted within that context.

Yang and Scherm (1997) showed climate change to be a driving force in the long-term dynamics of plant disease; results can range from the emergence of new threats from minor diseases to the expansion of diseases into areas where they were not previously a concern (Lonsdale and Gibbs 1994). We are, however, working in an area where reported examples of climate change unambiguously causing a shift in pest/disease patterns is very limited (Goudriaan and

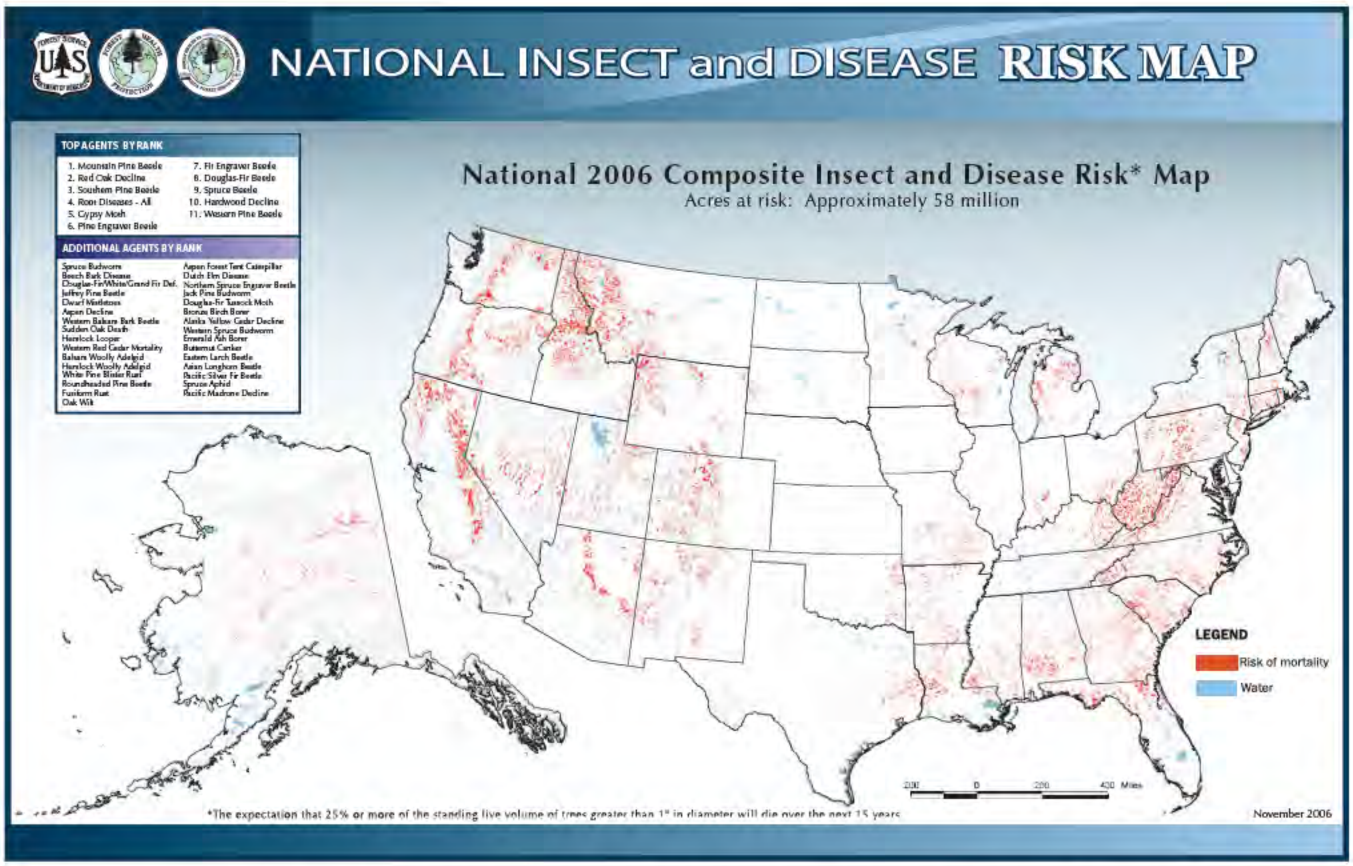


Figure C.1—Composite 2006 regional insect and disease risk map. Adapted from the National Insect and Disease risk map: National 2006. The composite national map is available at: http://www.fs.fed.us/foresthealth/technology/pdfs/RiskMap_agents_hillshade_8x11_.pdf

Zadocks 1995). Although the number of recent attributions of pathosystem shifts resulting from climate change is increasing, field research is plagued by the long-term nature of climate change, which is much more complicated than the shifts in weather that have been more commonly studied in the past (Coakley 1988).

Host-pest interactions will be affected by climate change in similar ways as other plants and animals. In the most simplistic scenario, pest species migrations will generally follow the migration of their preferred hosts. All of the same ecological elements affecting the hosts in the new environment will impact the pests themselves. Temperature, available water, quality and duration of light, air quality, soil condition, and other factors will affect their physiological and ecological responses. In addition, the condition and possibly altered physiology of the host in its new environment will influence the new host-pest interaction.

Disease evolution is another factor that presents complications when predicting the migration of diseases into new areas; rates are determined by the number of generations of reproduction per time interval, along with the heritability of traits related to fitness under the new climate scenario (Garrett and others 2006).

A few recent publications have focused on the need to consider microclimate factors as being immediately relevant when describing pest-host interactions. This is a little studied area due to the complexity inherent in isolating micro-effects in a macro-scale ecosystem.

Temperature effects on diseases—Gradual warming would probably lead to a general northerly shift in seasonal climatic regimes, which in turn would affect the range of oak (*Quercus* spp.), sometimes adversely and sometimes favorably (Brasier and Scott 1994). New disease complexes may arise and some diseases may cease to be economically important if warming causes a poleward shift of agroclimatic zones and host plants migrate beyond their current ranges. Pathogens would follow the migrating hosts and may infect remnant vegetation of natural plant communities not previously exposed (Coakley and others 1999).

The geographic range of fungal pathogens are to some extent determined by the temperature ranges over which they can grow (Lonsdale and Gibbs 1994). Brasier and Scott (1994) found that the growth and development of many fungi within the host may often be favored by climate warming, and the conditions that prevail when fungi arrive at the host surface are often critical for disease establishment; they also observed that the effects of temperature on the development and population dynamics of many potential oak diseases have been little researched and they identified the difficulties involved. Nevertheless, they predicted that as warming increases in Europe, a root rot disease (caused by *Phytophthora cinnamomi*) will extend its northward range, survive winters better in root systems, show increased spread within the host, have greater infection frequency of new hosts, and cause markedly more rapid host decline and mortality.

Other authors concur with the predictions of Brasier and Scott (1994). Chakraborty and others (1998) point out that changes in temperature will alter host-plant physiology and thus host resistance to pests. Broadmeadow and Ray (2005) add that increased temperatures will result in higher evapotranspiration. And Burdon and others (2006) reiterate that when we turn to the impact of the more unpredictable aspects of global climate change on the pathogens themselves, we will likely see significant changes in host-pathogen interactions over time, which are likely in both directions (increase and decreased activity).

Increased soil temperature has been shown to have negative effects on plant roots. Redmond (1955) reported that in a 55-year old stand, yellow birch (*Betula alleghaniensis*) rootlets with a normal background mortality rate of about 6 percent suffered 19 percent root mortality when average soil temperature increased 1°C and 60 percent root mortality if the temperature average increased 2°C. They also reported a change in microbial population and a change in the development of mycorrhizae, the symbiotic associations between fine feeder roots of plants and root-inhabiting fungi.

Because of their rapid response to small environmental changes, pathogens may provide good early warning of impending climate change. The damage threshold from a disease may also change in a new geographical location (Chakraborty and others 1998).

Temperature effects on insect pests—Higher air temperatures commonly enhance the general activity, population size, and potential for dispersal of insect pests. Higher temperatures could lead to greater overwintering population size, increased length of flight season, and length of daily flight periods (Brasier and Scott 1994). Continued climate change, and particularly warming, would have a dramatic impact on pest insect species. As cold-blooded organisms, they have a life history that hinges on temperature; thermal habitat largely sets the boundaries of their geographic distribution (Logan and others 2003).

Extended periods of warm weather can favor the development of insect pests both directly and indirectly. Warm temperatures can accelerate the development of insect populations by reducing the time needed for life-cycle completion. Indirect effects can be the result of changes in the host plant, or can be produced by decoupling relationships with natural enemies (Mamlstrom and Raffa

2000). In some circumstances, warmer temperatures could actually inhibit insect activity or disrupt the buildup of populations: although warmer winters would increase overwinter survival of some insect pests, reduced snow cover could increase the winter mortality of others (Burdon and others 2006). Enemies of insect pests would also be affected by climate change, but these effects are generally unknown and require more research. If warmer temperatures favor predators and parasitoids, these natural enemies of pests will exhibit greater control of those pest species. Conversely, if warmer temperatures disrupt or decrease predator and parasitoid populations, pest populations will grow more quickly and will persist at higher levels for longer periods of time.

Available water effects—Gilmour (1960) identified two opposite water related conditions that cause significant impacts on trees. Drought conditions have been shown to be the cause of various disorders with or without any associated fungal pathogen. And, saturated soil has been found to cause disorders in many plants. Thus, both extremes in water availability have been shown to negatively affect trees. Saturated soils, although being somewhat deficient in oxygen, appear also to have altered chemistry from similar drier soils. Garrett and others (2006) found that even without the added impetus of climate change the interaction of precipitation and disease is of primary importance for predicting disease severity.

Broadmeadow and Ray (2005) found that increased winter rainfall leads to more frequent winter waterlogging of soil and, in some circumstances, to fine root death extending into the soil surface horizons. This in turn exacerbates the effects of subsequent summer drought. Black and others (2010) associated Swiss needle cast disease (*Phaeocryptopus gäumannii*) with spring and summer needle wetness, as well as wintertime temperatures.

Because most plant parasitic fungi are believed to require free water for spore germination, microclimate of leaf surfaces is an important consideration. The important sources of free water for foliage diseases are rain, fog, condensed water, and guttation water. Yarwood (1959) found little germination when the relative humidity fell below 95 percent and categorized foliage diseases by their requirements for water in the phyllosphere during the infection stage; but, instead of presenting a broad categorization of this effect, focused attention on rust fungi (specifically their urediospore stage).

Lemmen and Warren (2004) emphasize that forest characteristics and age-class structure also affect how forests respond to changes in moisture, noting that mature forests (with well established root systems) are less sensitive to changes in moisture than younger forests and post-disturbance stands—at least in the short run. They add that different species have different drought tolerance, which also must be considered. And Lonsdale and Gibbs (1994) remind us that climate change with its associated change in frequency of summer droughts would alter the stability of associations between tree species and various members of their non-disease fungal associations—resulting in an outbreak of disease in place of coexistence, or in some circumstances mutualism.

Hanson and others (2001) found that the impact of potential changes in drought or precipitation regimes will not only depend on the predicted scenario of change, but also on the type of forest ecosystem and the climate conditions to which it is currently adapted. They conclude by summarizing six reasons why forests would not exhibit catastrophic dieback under the influence of climate change (including drought) and the prediction that the replacement of forests by faster growing trees will be gradual (Loehle 1996).

Generally speaking, any precipitation regime that stresses host trees (whether it is too little or too much moisture) will make them more susceptible to insect attack.

Wind effects—Yarwood (1959) cites wind as being a serious modifier of water relations and suggests that wind commonly prevents the formation of dew, and causes raindrops or dew to evaporate more rapidly than they would in still air. Broadmeadow and Ray (2005) note that an increase in the number of storms may make woodlands more vulnerable to wind damage.

Light effects—Fungi preferentially grow when the sky is cloudy and are therefore active mainly on shaded parts of the plant or in non-irradiated angles of the ecosystem. Pathogenic fungi are additionally protected when growing partly or completely within the host's tissue (Manning and von Tiedemann 1995).

The great significance of light especially in the near ultraviolet band (UV-A) on fungal sporulation has been recognized since the first studies were performed on this phenomenon in the 1960s. Humphrey (1941) reports that exposure to light stimulated sporulation in 62 of 75 species of fungi tested; most required light for the initiation of sporulation. Sporulation was not inhibited in any of the 417 fungal strains tested when exposed to light. However, enhanced UV-B radiation may increase, decrease, or leave unaffected the severity of biotic diseases. A serious comparison of this contradictory information is not possible since, in the underlying studies, the ranges of light qualities, light intensities, and light exposures were too large and too variable as were the experimental designs and time courses applied (Manning and von Tiedemann 1995).

If some parts of the disease life cycle are photoperiod sensitive, populations might need to undergo extensive adaptation to make use of extended seasons in temperate areas (Garrett and others 2006).

UV-B has positive and negative effects on fungal development; its effect on diseases is mainly through altered physiology and morphology (Chakraborty and others 1998).

Air quality effects—As noted above, increased carbon dioxide in the atmosphere is generally cited as being a primary factor in driving physiological changes in plant populations. Working with a pasture legume and a fungus (*Coletotricum gloeosporioides*) at two times ambient carbon dioxide concentration, Runion (2003) reported an increase of virulence of the disease against resistant cultivars of the legume (no change with respect to susceptible cultivars) and a significant increase in fecundity (more pronounced in the aggressive fungal cultivars being tested). Chakraborty and Datta (2003) focused particular concern on whether this increased fecundity at elevated carbon-dioxide levels could rapidly erode the usefulness of disease resistance. Altering the predisposition of the host to disease may be the predominant effect of rising levels of carbon dioxide (Manning and von Tiedemann 1995).

Charkrabotory and others (1998) report an increase of disease severity in response to increased carbon dioxide for 6 of 10 biotrophic fungi and 9 of 15 necrotrophic fungi; and observe that predicting effects for unstudied pathosystems will be challenging, and even more challenging when including the combined effects on diseases and their host plants.

Burdon and others (2006) suggest that the effect of carbon dioxide may be to increase the efficiency of carbon fixation with a resultant increase in growth and improvement in the carbon status of the plant. This increase would lead to morphological change generally expressed as enhanced growth; the combined changes in nutrition and morphology, in turn, could affect the suitability of the plant as host material for a variety of diseases. This having been said, the authors caution that the reported research on the subject is limited and end the discussion with this further caution: "… the predictability of the impact of these factors as on whole communities is even more uncertain with both indirect and direct effects of varying magnitude being likely."

Mirroring this concern Lemmen and Warren (2004) report that although numerous studies have investigated the impacts of elevated carbon dioxide on forest growth and health, the results are neither clear nor conclusive.

Manning and Keane (1988) conclude that "in a theoretical sense, air pollution can increase, decrease or not affect the course of development of a disease epidemic," based on new and existing observations about air pollution and pest behavior including:

- Bacterial diseases are generally inhibited by sulfur dioxide, which limits lesion size and often increases latent periods.
- Fungal diseases have been reported to be enhanced, inhibited, or not affected at all by air pollutants.
- The little that is known about the effects of pollution on root diseases indicates that virus-affected plants are usually less affected by air pollutants than virus-free plants.
- According to James and others (1980a), inoculated stumps of ozone-stressed pines (*Pinus* spp.) were more readily invaded by annosum root disease (caused by *Heterobasidion annosum*).
- According to Skelly and others (1983), ozone stressed eastern white pine (*Pinus strobus*) in the Blue Ridge Mountains of Virginia were more subject to Leptographium root disease (caused by *Verticicladiella procera*).
- According to Mahoney and others (1985), loblolly pine seedlings with ectomycorrhizae (*Pisolithus tinctorius*) were not adversely affected by ozone, sulfur dioxide, or a combination of both.
- According to Keane and Manning (1987), ozone caused significant decreases in ectomycorrhizae of white birch (*Betula pendula*) and white pine seedlings.

Soil environment effects—Carbon dioxide concentration in soil is expected to be far less impacting to diseases than atmospheric carbon dioxide. Soil microflora is routinely exposed to levels 10 to 20 times higher than atmospheric carbon dioxide levels (Coakley and others 1999; Manning and von Tiedemann 1995). Colonization and persistence of mycorrhizae appears to be dependent, in part, on the nutrient status (primarily nitrogen) and carbon dioxide concentration in soil, although observed responses do not show a consistent pattern. Not much more can be said here because the influence of mycorrhizae on plant disease is still not well understood.

Ozone does not penetrate the soil surface and therefore affects roots only indirectly by altering photosynthesis. Damage caused by several tree root disease pathogens became more severe when the host plant was stressed by ozone (Fenn and others 1990; James and others 1980b, 1982; Skelly and others 1983).

O'Neill (1994) presents a detailed review of the potential effects of elevated levels of carbon dioxide on the rhizosphere (the region of soil that is directly influenced by root secretions and associated soil microorganisms), observing that ecosystems are largely constrained by the rates at which soil processes occur. Much more data will be needed to begin the process of generalized modeling of effects on the rhizosphere.

Effects of soil saturation have already been briefly discussed above. Both the amount of water and timing of flooding affect the degree of negative impact on cover plants.

Soil characteristics, nutrient availability, and disturbance regimes may prove to be more important than temperature in controlling future ecosystem dynamics (Lemmen and Warren 2004). Climate and vegetation interact to determine the characteristic soils of an area, and different climatic zones are characterized by different soil types—except where the presence of unusual rock, such as serpentine, results in unique soils (Malcolm and Pitelka 2000).

Effects on Host Biology

Little is known about how environmental effects on tree physiology influence the inducible responses that are relevant to pathogens (signal recognition, generation of phytoalexins and reactive oxygen species, hypersensitive responses, callus growth, and systemic acquired resistance) (Ayres and Lombardero 2000).

Carbon dioxide is a primary input to growth and development of all plant life, providing both a fertilization effect and an increase in the efficiency with which plants use water. The fertilization effect may be affected by the availability of water and other nutrients. It may also diminish after an initial period of adjustment by the plant. Increased carbon dioxide levels may also trigger changes in the chemical composition of vegetation such as affecting the carbon-to-nitrogen ratio in leaves (Winnett 1998). Positive response to carbon dioxide appears to occur under a wide range of nutrient availability (Rogers and others 1994). In addition, Bazzaz and others (1994) stress that the differential responses of species to elevated levels of carbon dioxide indicate potential shifts in the competitive relationships among plants. Partial closure of the guard cells forming stomates has been proposed as the mechanism by which plants slow transpiration (Jones and Mansfield 1970), which in turn may be one mechanism of adaptive resistance to elevated carbon dioxide levels.

Other factors to consider include the following:

- In soils, some fungi can use carbon dioxide as an additional source of carbon, which is incorporated into organic acids and eventually enters the Krebs cycle as an additional energy supply (Manning and von Tiedemann 1995); this increase tends to increase root growth more than aboveground growth (Rogers and others 1994).

- Ozone effects on plant diseases are host mediated.

- The principal mechanism for UV-B effects on plant diseases would be through alteration of host plants (Manning and von Tiedemann 1995).

- Host-pathogen relationships, defense against physical stressors, and the capacity to overcome resource shortages could be impacted by rises in carbon dioxide (Rogers and others 1994).

- During winter dormancy, direct effects of climate on the host are generally less important than those involving a pathogen (Lonsdale and Gibbs 1994).

Combined Effects

Increased summer temperatures and droughtiness would be expected to help shift the distributions of fungi northwards within the range of potential hosts, or at least to increase the geographic range over which they behave as pathogens (Lonsdale and Gibbs 1994).

Fungi appear to be largely tolerant of current ozone levels. However, a strong negative correlation exists between rainfall or relative air humidity and photochemical ozone generation in the atmosphere: on wet days that are appropriate for fungal growth on plant surfaces, ozone levels are usually low. Consequently, biologically harmful concentrations of ozone are unlikely to coincide with germinating spores or actively growing mycelium (Manning and von Tiedemann 1995).

Expected increases in growth from elevated carbon dioxide levels will almost certainly aggravate problems with diseases. However, this effect would likely be offset by growth reductions caused by increased ozone and UV-B (Manning and von Tiedemann 1995). Because carbon dioxide may greatly alter ecosystem structure and function (Bazzaz and Fajer 1992), unmanaged forest ecosystems may be seriously impacted by carbon dioxide acting in combination with drought, compared to intensively managed, monoculture tree farms where species composition has been altered. Overall the interaction of carbon dioxide and temperature is not well understood and the experimental data have been inconsistent (Rogers and others 1994).

At higher temperatures, an increase in the availability of all major nutrients (nitrogen, phosphorus, calcium, magnesium, potassium, and sulfur) can be expected as a result of increased water fluxes through soil and higher organic matter decomposition rates, which would increase the circulation of nutrients in the soil-nutrition system. Also, nutrient circulation would increase because of higher growth rates of forest species at increasing atmospheric carbon dioxide concentration and warmer temperature (Nilson and others 1999).

Stressed trees are more susceptible to insect pests and diseases (Broadmeadow and Ray 2005), enabling some level of assessment by forest pathologists and entomologists. However, firm projections of future pest activity cannot be made and considerable caution should be exercised in extrapolating analysis to a future climate. For some insects and diseases, likely trends cannot be predicted even on the basis of expert judgment (Broadmeadow and Ray 2005).

Climate change will directly influence infection, reproduction, dispersal, and survival among the seasons and other critical stages in the life cycle of a disease (Coakley and Scherm 1996). Observed outcomes include modifications in host resistance, altered stages and rates of disease development, and changes in the physiology of host-pathogen interactions (Scherm 2003).

EFFECTS ON ECOSYSTEMS

Because individual species will respond to climate change differently, ecosystems will not necessarily shift as cohesive units. The most vulnerable species are expected to be those with narrow temperature tolerances, slow growth characteristics, and limiting dispersal mechanisms such as heavy seeds (Lemmen and Warren 2004). How well plant and animal species adapt to or move with changes in their potential habitat is strongly influenced both by their dispersal abilities and by the characteristics and severity of disturbances to these environments. Nonnative and invasive species that disperse rapidly are likely to find opportunities in newly forming communities (Joyce and others 2001). However, if climate change causes a gradual shift of cropping regions, pathogens will follow their hosts (Goudriaan and Zadocks 1995) into less changed new communities.

The pattern of disturbance imposed on a landscape by a particular biotic agent is determined both by the structure and condition of the landscape and by the characteristics of the agent and its responsiveness to environmental conditions (Mamlstrom and Raffa 2000). Factors such as changes in land use or increases in resistant strains of diseases may underlie range expansions (Harvell and others 2002).

Dale and others (2001) point out that many disturbances are cascading. For example, insect infestations and diseases promote forest fires by creating fuels, and the fires in turn promote future infestations and infections by compromising the resistance of surviving trees to insects and diseases. Invasive nonnative species are sometimes able to modify existing disturbances or introduce entirely new ones. Under climate change, these compounded interactions may be unprecedented and unpredictable. They are likely to appear slowly and be difficult to detect because of tree longevity.

Climate change could represent a new form of disturbance to unmanaged ecosystems and thus could provide new opportunities for invasive species to flourish and displace native species. An important feature of many invasive species is their dispersal effectiveness and their high reproductive rates (Malcolm and Pitelka 2000). Changes in phonological synchronicity of hosts and native pests, as well as their relative abundance and physiological condition, may affect the frequency and consequences of outbreaks (Malcolm and others 2006).

EFFECTS ON DISTRIBUTION OF SPECIES

As climate shifts, climatically sensitive species will eventually die out, and only a subset of the potential pool of incoming plants may actually migrate sufficiently quickly to keep up with the shifting climate. Thus, plant communities could become progressively composed of the more adaptable and faster moving species, especially if warming is rapid. This change in plant communities, especially tree communities, is of considerable concern. Expansion of the warm-temperature mixed-evergreen forests of the South would be at the expense of other kinds of forests. In some scenarios, parts of the South become drier and grasslands or savannahs replace the current forest (Malcolm and Pitelka 2000).

The forest area impacted by insects and diseases in the United States is approximately 45 times that impacted by fire, with an economic impact that is almost 5 times larger (Dale and others 2001). If this trend continues, pests and diseases are likely to be the primary cause of species change in eastern forests over the next few decades. Forecasting the trajectory of those changes is nearly impossible because we cannot predict with any certainty which pests or diseases will be established (Lovett and others 2006). Given the complexities of climate change, and biotic responses to it, prediction of the future impact of climate change on emerging infectious diseases is difficult except on a broad scale. Climate change can lead to the emergence of preexisting pathogens as major disease agents or can provide the climatic conditions required for nonnative diseases to flourish (Anderson and others 2004). Because climate change will allow plants and diseases to survive outside their historic ranges, Harvell and others (2002) have projected an increase in the number of invasive diseases.

The following discussion and analysis is excerpted with only very minor changes from Régnière and Bentz (2008) and provides an example for consideration of a pest present and destructive in the western United States which and its potential impact in the East and South under the influence of climate change.

The mountain pine beetle (*Dendroctonus ponderosae*) is a native insect of pine forests in Western North America. Although it has a broad geographical distribution, it has been historically confined in the United States, by the distribution of its pine hosts, and in the northern half of British Columbia, by the geoclimatic barrier of the Rocky Mountains. Since the early to mid-1990s, an outbreak has reached unprecedented levels in terms of acreage and number of pine trees attacked. Lodgepole pine (*Pinus contorta*) is being killed throughout its range, most notably in Colorado and British Columbia. The beetle is also causing very high mortality among whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) at high elevations. Historical records from the past century suggest that these ecosystems have had pulses of infestation and mortality but not at the levels currently being observed. Since 2006, the range of infestation has expanded into the Peace River area of north-central Alberta. Climate change may well be involved in this recent northeastward and upward range expansion. Evidence of similar shifts in insect distributions is ample and mounting throughout the world, much of it convincingly linked to climate change.

The primary concern at this time is the likelihood that the infestation will continue spreading eastward into the pines of the Canadian boreal forest, eventually reaching the eastern provinces and threatening the pines growing on the Atlantic side of the continent and then spreading into the Southern United States. Because of its recent incursion to the edges of the Canadian boreal forest, mountain pine beetle is viewed as a potential invading species in eastern pine ecosystems.

Three well-understood links connect climate and mountain pine beetles and form the basis for the concern that changing climate (temperature and precipitation) has had—and will continue to have—a role in the recent outbreaks and range expansion of this insect.

1. A well-synchronized adult emergence pattern is a prerequisite for successful mass attack of healthy pine trees. Such highly synchronized emergence is most likely to occur where (and when) the insect has a strictly univoltine (one generation per year) life cycle.

2. Cold winter temperature is the major cause of mortality in mountain pine beetles. For more than 20 years, process-based models describing responses to temperature have been under development; they show that a hemivoltine life cycle (one generation every 2 years) entails exposure to two winters, leading to lower population performance.

3. Drought affects the ability of pine trees to defend themselves against insect attack.

Three model components are available to study the impact of weather on mountain pine beetle populations: a phenology model that predicts life stage-specific developmental timing, a cold-tolerance model that predicts probability of larval mortality resulting from cold temperature, and a drought-stress model that predicts fluctuations of tree susceptibility. All three models have been implemented within BioSIM to make landscape-scale predictions of mountain pine beetle performance under climate change scenarios. BioSIM is a generic modelling tool that uses available knowledge about the responses of particular species (usually pests) to key climatic factors to predict their potential geographic range and performance.

The phenology model is very good at predicting the portions of the continent where the insect has a high likelihood of being univoltine. This model predicts the northward and upward shift of infestation. Under a conservative climate change scenario, it also predicts that by the end of the 21st century, the area at risk will shift considerably northward, to a point that the insect may be maladapted over much of its current distributional range. The cold tolerance model suggests that winter survival is very low and will remain so in the foreseeable future throughout the boreal pine forests from Alberta to Ontario. Although drought stress is, and is predicted to be, more common in that same area, there is not a very large change in this risk factor predicted in the near future.

Thus, with our current understanding of the insect's physiology and host plant interactions, the risk of seeing the mountain pine beetle spread across the northern forests of Canada into the eastern pine forests seems rather low. This prediction, of course, is contingent on failure of the insect to adapt (evolve) and change its thermal responses, and on a relatively stable distribution of pines over the time range under consideration.

Describing similar effects for pest insects in climate change scenarios, Logan and others (2003) indicate that there is a historic trend to intensification in all aspects of outbreak behavior, based on assessments of individual species' responses to date; this certainly characterizes modeling work with the mountain pine beetle (*Dendroctonus ponderosae*), gypsy moth, spruce beetle (*Dendroctonus rufipennis*), and spruce budworm (*Choristoneura fumiferana*).

Walther and others (2002) link climate change to changes in a variety of known springtime life-cycle events in European organisms (including earlier annual bird breeding, migrant bird arrival, the appearance of butterflies, choruses and spawning of amphibians, and shoot growth and flowering of plants); these changes in event timing suggest a lengthening of growing season by 8 to 16 days. Anderson and others (2004), citing grey leaf spot (*Pyricularia grisea*) disease of corn (*Zea* spp.), suggest that the ranges of several important crop insects, nonnative plants, and plant diseases have already expanded northward. They also note that autumn life-cycle events (leaf color change and leaf fall) are not as clearly defined in their response to the extension of growing season as springtime events.

Plants have historically responded to climate change by migration and adaptation. Fragmentation and rate of seedling establishment may hinder some plant populations from successful migration to higher latitudes. Persistence of these populations may depend heavily on adaptive evolution, but predicted rates of evolutionary response are much slower than the predicted rate of climate change. Historical climate changes were generally much slower (by one or more orders of magnitude) than those predicted for the future (Etterson and Shaw 2001). This observation leads to concern that historical response patterns to climate change may not prove to be effective as predictors of future change.

Adding to the concerns expressed above is a critical consideration that has not yet been emphasized enough—climate change cannot be viewed in isolation; its effects on ecosystems must be considered in the context of a range of human-caused impacts on ecosystems, such as air pollution, water pollution, habitat destruction and fragmentation, and the nonnative species that thrive and have their most serious effects in ecosystems already disturbed by human activities (Malcolm and Pitelka 2000).

Many unpredictable, unforeseen pest problems may arise as a result of changing temperatures, changing precipitation regimes, or both in combination. Previously minor or infrequent pests may become significant causes of tree mortality. Some current major pests may decline in importance. In addition to new nonnative invasive pests arriving from overseas, the ranges of insects and diseases native to North America may expand or contract dramatically. Because these changes are largely unpredictable yet bound to occur, land managers and scientists in forestry-related disciplines will need to practice early detection and monitoring of "new" problems and follow up with research and creative, adaptive management strategies.

PATHOSYSTEMS

The subtle changes in conditions attributed to climate change can affect plant-disease development. These changes are not easily determined, and, consequently, the ability to forecast how disease changes under altered growth conditions is not simple (Seem 2004).

Less stable relationships tend to occur in the simpler ecosystems that initially exist in planted forests, often involving new combinations of host and pathogen species that have been transported beyond their natural geographic ranges. In such situations, climate change would likely encourage major changes in disease incidence and severity (Lonsdale and Gibbs 1994).

Tree-disease problems cannot be fully understood without a thorough appreciation of the part played by environmental factors, particularly climate, as a precursor to fungal attack. The manifestation of many diseases often merely reflects unfavorable site factors, the presence of the fungus being the result of an unhealthy condition rather than the primary cause of the tree's debility (Gilmour 1960).

During unusual weather events or biologically induced stress periods, the competitive dominant may be the most vulnerable. Its large size has stretched its limits to coordinate uptake, transport, storage, and photosynthesis (Manion and Lachance 1992).

The timing of the stress event is also very important. Early season stress is frequently overcome although later stressors are not so, often simply because of sufficient time remaining in the growing season (Lundquist and Hamelin 2005).

Nonnative insect pests and diseases pose the most serious threat to the forests of eastern North America. The litany of pest and disease introductions is long: chestnut blight (*Cryphonectria parasitica*), Dutch elm disease (*Ophiostoma ulmi*), beech bark disease (*Nectria coccinea* var. *faginata*), balsam woolly adelgid (*Adelges piceae*), hemlock woolly adelgid (*A. tsugae*), dogwood anthracnose (*Discula destructiva*), and gypsy moth (Lovett and others 2006).

According to Lovett and others (2006), ecologists need adequate information in only six categories of knowledge about nonnative pests and their hosts to make rough predictions of the type and magnitude of potential ecosystem impacts. Pest information is needed concerning: (1) mode of action, (2) host specificity—such as species and age class, and (3) virulence. With respect to the host, the information needed is: (4) ecological importance—position or bio-production values in the system, (5) uniqueness, and (6) phytosociology—such as pure versus mixed stands, effectiveness of regeneration.

When climate change has a significant and direct effect on plants, changes in composition may ensue. Given differential responses across plant species, this may lead to relative changes in community composition. When coupled with range extensions or contractions of individual species, the result may be increased or decreased diversity of whole plant communities. Diseases of one host species may thus be brought into intimate contact with new hosts, although the likelihood of spatial movements necessary for this to occur is perhaps low in the immediate future; they may benefit from increasing overlap of obligate alternate host distributions; or they may suffer significant reductions in population size as a consequence of allopatric distributions or incomplete congruence in the distribution of obligate alternate hosts (Burdon and others 2006).

Boland and others (2004) summarize research on the potential impact of climate change on plant diseases and list 143 plant diseases, only 18 of which are forest tree diseases. Despite this they tabulate data for climate change effects with respect to forest pathosystems under these categories: primary inoculum or disease establishment, rate of disease progress, potential duration of epidemic, reasons for effects, and net effect of the disease. Although predicting the effects on the diseases is relatively intuitive to plant pathologists, the authors argue that extending the intuitive knowledge pathosystems or disease mechanisms requires more knowledge about how the host's physiology and thus the host-pathogen interaction will be affected. They also cite a specific need for further knowledge about the effects of elevated carbon dioxide, UV radiation, and ground level ozone, as well as the effects of environmental changes on insect vectors of diseases.

An interesting sidebar to pathosystems activity is reflected in the capacity of fungi to perform their cleanup function (woody and leaf litter decomposition) under the influence of climate change. Yin (1999) makes several points. First, the decay rate of forest woody debris is a key missing link in our quantitative understanding of carbon dynamics and the global carbon budget of forests. And, in the context of global climate change, a 2 °C warming in air temperature in January and July would accelerate stem woody debris decay (in density loss); accelerated decay would decrease in the presence of increased precipitation (and vice-versa); but, the magnitude of increase would be smaller when adjusted for the detrimental effect of elevated carbon dioxide as part of climate change.

For many fungal diseases that rely on biotic vectors for dispersal, the effects of climate change and weather on the development of outbreaks or epidemics have not been studied in detail. In areas where a pathogen already occurs, weather conditions may favor outbreaks of its vectors in certain years, suggesting that climate change could influence long-term prevalence of the disease (Lonsdale and Gibbs 1994). The introduction of new vector species, changes in vector overwintering and oversummering (Garrett and others 2006), and other effects of change on insects may have important effects on pathogen survival, movement, and reproduction (Garrett and others 2006). Pathogens that rely on vectors may see significant shifts in their distribution or intensity if environmental changes affect the behavior or viability of their vector (Burdon and others 2006).

However, in some circumstances, warmer temperatures could actually inhibit insect activity or disrupt the build-up of populations. Enemies of insect pests will also be affected by climate change, but these effects are unknown and require more research. If warmer temperatures positively affect predators and parasitoids, natural enemies will exhibit greater control of pest species. Conversely, if warmer temperatures disrupt or decrease predator and parasitoid populations, pest populations will grow more quickly and will persist at higher levels for longer periods.

LITERATURE CITED

Anderson, P.K.; Cunningham, A.A.; Patel, N.G. [and others]. 2004. Emerging infectious diseases of plants: pathogen, pollution, climate change and agrotechnology drivers. Trends in Ecology and Evolution 19(10): 535–544.

Ayres, M.P.; Lombardero, M.J. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. Science of Total Environment 262: 263–286. (also: http://www.dartmouth.edu/~mpayres/pubs/gepidem. PDF).

Bazzaz, F.A.; Fajer, E.D. 1992. Plant life in a CO_2-rich world. Scientific American 266: 68-74.

Beukema, S.J.; Robinson, D.C.E.; Greig, L.A. 2007. Forests, insects & pathogens and climate change: workshop report. Prineville, OR: The Western Wildlands Environmental Threat Assessment Center. 20 p. (access at: http://www.essa.com/documents/Forests,%20Pests%20and%20Climate%20-%20Workshop%20Report.pdf).

Black, B.A.; Shaw, D.C.; Stone, J.K. 2010. Impacts of Swiss needle cast on overstory Douglas-fir forests of the western Oregon Coast Range. Web published m.s. Corvalis, OR: Oregon State University. 35 p. (access at http://ir.library.oregonstate.edu/jspui/bitstream/1957/15212/1/Black_et_al_FEM_SNC_study_2010%5B1%5D.pdf).

Boland, G.J.; Melzer, M.S.; Hopkin, A. [and others]. 2004. Climate change and plant diseases in Ontario. Canadian Journal of Plant Pathology 26: 335–350.

Brasier, C.M.; Scott, J.K. 1994. European oak declines and global warming: a theoretical assessment with special reference to the activity of *Phytophthora cinnamomi*. Bulletin-OEPP 24(1): 221–232.

Breshears, D.D.; Cobb, N.S.; Rich, P.M. [and others]. 2005. Regional vegetation die-off in response to global-change type drought. Proceedings of the National Academy of Sciences of the United States of America 102: 15144–15148.

Broadmeadow, M.; Ray, D. 2005. Climate change and British woodland. Information Note 69. Edinburgh, United Kingdom: Forestry Commission. (also: http:// www.forestresearch.gov.uk/pdf/fcin069.pdf/$FILE/fcin069.pdf).

Burdon, J.J.; Thrall, P.H.; Ericson, L. 2006. The current and future dynamics of disease in plant communities. Annual Review of Phytopathology 44: 19–39.

Chakraborty, S.; Datta, S. 2003. How will plant pathogens adapt to host plant resistance at elevated CO_2 under a changing climate? New Phytologist 159: 733–742.

Chakraborty, S.; Murray, G.M.; Magarey, P.A. [and others]. 1998. Potential impact of climate change on plant diseases of economic significance to Australia. Australasian Plant Pathology 27: 15–35.

Coakley, S.M. 1988. Variation in climate and prediction of disease in plants, Annual Review of Phytopathology 26: 163-181.

Coakley, S.M.; Scherm, H.; Chakraborty, S. 1999. Climate change and plant disease management. Annual Review of Phytopathology 37: 399–426.

Dale, V.H.; Joyce, L.A.; McNulty, S. [and others]. 2001. Climate change and forest disturbances. BioScience 51: 723–734. (also: http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone2.pdf).

Etterson, J.R.; Shaw, R.G. 2001. Constraint to adaptive evolution in response to global warming. Science 294: 151-154.

Fenn, M.E. Dunn, P.H.; Durall, D.M. 1989. Effects of ozone and sulfur dioxide on phyllosphere fungi from three tree species. Applied Environmental Microbiology 55: 412-418.

Garrett, K.A.; Dendy, S.P.; Frank, E.E. [and others]. 2006. Climate change effects on plant disease: genomes to ecosystems. Annual Review of Phytopathology 44: 489–509.

Gilmour, J.W. 1960. The importance of climatic factors in forest mycology. New Zealand Journal of Forestry 8: 250-260.

Goudriaan, J.; Zadocks, J.C. 1995. Global climate change: modeling the potential responses of agrosystems with special reference to crop protection. Environmental Pollution 87: 215-224.

Hansen, A.J.; Neilson, R.P.; Dale, V.H. [and others]. 2001. Global change in forests: responses of species, communities and biomes. BioScience. 51: 765–779.

Harvell, C.D.; Mitchell, C.E.; Ward, J.R. [and others]. 2002. Climate warming and disease risks for terrestrial and marine biota. Science. 296: 2158–2162.

Hepting, G.H. 1963. Climate and forest diseases. Annual Review of Phytopathology. 1: 31–50.

Humphrey, H. B. 1941. Climate and plant diseases. Yearbook of Agriculture 1941.Washington, DC: U.S. Department of Agriculture: 499-502.

Intergovernmental Panel on Climate Change. 2001. Climate change 2001: synthesis report. A contribution of Working Groups I, II, and III to the third assessment report of the Integovernmental Panel on Climate Change. In: Watson, R.T. and the Core Writing Team, eds. Cambridge University Press, Cambridge, United Kingdom, and New York: 398 pp.

Intergovernmental Panel on Climate Change. 2007. Summary for policymakers. In: Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; Miller, H.L., eds. Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York: Cambridge University Press.20 p. (also: http://www.ipcc.ch/ pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf.).

James, R.L.; Cobb, F.W., Jr.; Miller, P.R. [and others]. 1980a. Effects of oxidant air pollution on susceptibility of pine rots to *Fomes annosus*. Phytopathology 70: 560-563.

James, R.L.; Cobb, F.W., Jr.; Wilcox, W.W. [and others]. 1980b. Effect of photochemical oxidant injury of ponderosa and Jeffrey pines on susceptibility of sapwood and freshly cut stumps to *Fomes annosus*. Phytopathology 70: 704-708.

Jones, R. J.; Mansfield, T. A. 1970. Increases in the diffusion resistances of leaves in a carbon dioxide-enriched atmosphere. Journal of Experimental Botany 21: 951-958.

Joyce, L.; Aber, J.; McNulty, S. [and others]. 2001. Potential consequences of climate variability and change for the forests of the United States. In: National Assessment Synthesis Team, eds. Climate change impacts on the United States: the potential consequences of climate variability and change. Cambridge, United Kingdom: Cambridge University Press: 489–522. (also: http://www.srs.fs.usda.gov/pubs/ja/ja_joyce001.pdf).

Keane, K.D.; Manning, W.J. 1987. Effects of ozone and simulated acid rain and ozone and sulfur dioxide on mycorrhizal formation in paper birch and white pine. In: Perry, R. et al. London, Great Britain: Selper Ltd.: 608-613.

Kleijunas, J.T.; Geils, B.W.; Glaeser, J.M. [and others]. 2009. Review of literature on climate change and forest diseases of western North America. Albany, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station. 54 p.

Lemmen, D.S.; Warren, F.J., eds. 2004. Climate change impacts and adaptation: a Canadian perspective. Ottawa, Ontario: Natural Resources Canada. 174 p.

Logan, J.A.; Régnière, J.; Powell, J.A. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment. 1: 130–137. (also: http://www.usu.edu/beetle/documents/Loganet.al.2003.pdf. [accessed July 13, 2009]).

Loehle, C. 1996. Do simulations project unrealistic dieback? Journal of Forestry 94: 13-15.

Lonsdale, D.; Gibbs, J.N. 1994. Effects of climate change in fungal disease of trees. In: Frankland, J.C.; Magan, N.; Gadd, G.M., eds. Fungi and environment change: symposium of the British Mycological Society. Cambridge, United Kingdom: Cambridge University Press: 1–19.

Lovett, G.M.; Canham, C.D.; Arthur, M.A. [and others]. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. BioScience 56(5): 395–403.

Lundquist, J.E.; Hamelin, R.C., eds. 2005. Forest pathology: from genes to landscapes. St. Paul, MN: American Phytopathological Society, APS Press. 175 p.

Mahoney, M.J.; Chevone, B.I.; Skelly, J.M. [and others]. 1985. Influence of mycorrhizae on the growth of loblolly pine seedlings exposed to ozone and sulfur dioxide. Phytopathology 75: 679-682.

Malcolm, J.R.; Liu, C.; Neilson, R. P.; Hansen, L.; Hannah, L. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conserv. Biol.20: 238-248.

Malcolm, J.R.; Pitelka, L.F. 2000. Ecosystems and global climate change: a review of potential impacts on U.S. terrestrial ecosystems and biodiversity. 47 p. Accessed at: http://www.pewclimate.org/docUploads/env_ecosystems.pdf. (July 13, 2009).

Mamlstrom, C.M.; Raffa, K.F. 2000. Biotic disturbance agents in the boreal forests: considerations for vegetation change models. Global Change Biology 6: 35-48.

Manion, P.D.; Lachance, D.L. 1992. Forest decline concepts: an overview. In: Manion, P.D.; Lachance, D.L., eds. Forest decline concepts. St. Paul, MN: APS Press: 181–190.

Manning, W.J.; Keane, K.D. 1988. Effects of air pollutants on interactions between plants, insects and pathogens. In: Heck, W.W.; Taylor, O.C.; Tingley, D. T., eds. Assessment of crop loss from air pollutants. London, G. B.: Elsevier: 365-386.

Manning, W.J.; von Tiedemann, A. 1995. Climate change: potential effects of increased atmospheric carbon dioxide (CO_2), ozone (O_3), and ultraviolet-B (UV-B) radiation on plant diseases. Environmental Pollution 88: 219–245.

McNulty, S.G.; Aber, J.D. 2001. United States national climate change assessment on forest ecosystems: an introduction. BioScience 51: 720–723. (also: http://www.usgcrp.gov/usgcrp/Library/nationalassessment/forests/bioone1.pdf).

McNulty, S.G.; Boggs, J. L. 2010. A conceptual framework: redefining forest soil's critical acid loads under a changing climate. Environmental Pollution 30: 1-6. (also: doi:10.1016.j.envpol.2009.11.028).

Millstein, J.A. 1994. Propagation of measurement errors in pesticide application computations. International Journal of Pest Management 40: 159-165.

National Assessment Synthesis Team. 2000. Climate change impacts on the United States: the potential consequences of climate variability and change. Washington, DC: U.S. Global Change Research Program. 541 p.

Nilson, A.; Kiviste, A.; Korjus, H. [and others]. 1999. Impact of recent and future climate change on Estonian forestry and adaptation tools. Climate Research. 12: 205–214.

O'Neill. E. G. 1994. Response of soil biota to elevated atmospheric carbon dioxide. Plant and Soil 165: 55-65.

Redmond, D.R. 1955. Studies in forest pathology. XV. Rootlets, mycorrhiza, and soil temperatures in relation to birch dieback. Canadian Journal of Botany 33: 595-627.

Régnière, J.; Bentz, B. 2008. Mountain pine beetle and climate change. In: McManus, K.; Gottschalk, K.W. Proceedings: 19th U.S. Department of Agriculture Interagency Research Forum on Invasive Species, 2008 (Jan. 8-11: Annapolis, MD) Gen. Tech. Rep. NRS-P-36. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 63-64. (Available at: http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs-p-36.pdf).

Rogers, H.H.; Runion, G.B.; Krupa, S.V. 1994. Plant responses to atmospheric CO_2 enrichment with emphasis on roots and the rhizosphere. Environmental Pollution 83: 155-189.

Runion, G.B. 2003. Climate change and plant pathosystems—future disease prevention starts here. New Phytologist 159: 531–538.

Scherm, H. 2000. Simulating uncertainty in climate-pest models with fuzzy numbers. Environmental Pollution 108: 373-379.

Scherm, H. 2003. Plant pathogens in a changing world. Australian Plant Pathology 32: 157-165.

Scherm, H.; Coakley, S.M. 2003 Plant pathogens in a changing world. Australian Plant Pathology 32: 157-165.

Seem, R.C. 2004. Forecasting plant disease in a changing climate: a question of scale. Canadian Journal Plant Pathology 26: 274-283.

Skelly, J.M.; Yang, Y.S.; Chevione, B.I. [and others]. 1983. Ozone concentrations and their influence on forest species in the Blue Ridge Mountains of Virginia. In: Davis, D. D.; Millen, A.A.; Dochinger, L.S., eds. Air pollution and the productivity of forests (Oct. 4-5, 1983: Washington, DC). State College, PA: Pennsylvania State University, Isaac Walton League of America. 344 p.

Sturrock, R.N. 2007. Climate change effects on forest diseases: an overview. In: Jackson, M.B. (compiler). Proceedings of the 54th annual Western International Forest Disease Work Conference (Oct. 2-6, 2006: Smithers, British Columbia, Canada). Missoula, MT: US Department of Agriculture, Forest Service: 51–55.

Walther, G.R.; Post, E.; Convey, P. [and others]. 2002. Ecological responses to recent climate change. Nature. 416: 389–395.

Wigley, T.M.L. 1999. The science of climate change: global and U.S. perspectives. Arlington, VA: Pew Center on Global Climate Change. http://www.pewclimate. org/docUploads/env_science.pdf. (July 13, 2009).

Winnett, S.M. 1998. Potential effects of climate change on U.S. forests: a review. Climate Research 11: 39–49. (also: http://www.int-res.com/articles/cr/11/c011p039.pdf).

Yang, X.B.; Scherm, H. 1997. El Nino and infectious disease. Science. 275: 739.

Yarwood, C.E. 1959. Microclimate and infection. In: Plant Pathol. Probl. And Progr. 1908-1958. Madison WI: Univ. Wisc. Press: 548-556.

Yin, X. 1999. The decay of forest woody debris: numerical modeling and implications based on some 300 data cases from North America. Oecologia. 121: 81–98.

OTHER REFERENCES

Annosum Root Disease

Anderson, R.L.; Mistretta, P.A. 1982. Management strategies for reducing losses caused by fusiform rust, annosus root rot, and littleleaf disease. Agric. Handbk. 597. Washington, DC: U.S. Department of Agriculture, Forest Service. 30 p.

Asian Longhorned Beetle

U. S. Department of Agriculture, Animal and Plant Health Inspection Service. 2010. Plant health: asian longhorned beetle. Washington, DC: U.S. Department of Agriculture, Animal and Plant Health Inspection Service. Web accessed www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/index.shtml

U. S. Department of Agriculture, Forest Service. Forest health protection – Asian longhorned beetle. Portal page. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry, Forest Health Protection. Web accessed at www.na.fs.fed.us/fhp/alb/

Baldcypress Leafroller

http://www.insectimages.org/browse/subthumb.cfm?sub=4300&Start=1&display=30&sort=2

http://www.fs.fed.us/r8/foresthealth/publications/patterns_of_defoliation_in_southeastern_louisiana_swamps.pdf

Balsam Woolly Adelgid

Ragenovich, I.R.; Mitchell, R.G. 2006. Balsam woolly adelgid. Forest Insect & Disease Leaflet 118. Portland, OR: U. S. Department of Agriculture, Forest Service. 12 p. Available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-118.pdf).

Bark Beetle (see below for southern pine beetle)

Ciesla, W.M. 1973. Six-spined engraver beetle. Forest Pest Leaflet 141. Washington, DC: U.S. Department of Agriculture Forest Service. 6 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl141.pdf).

Clarke, S.R.; Evans, R.E.; Billings, R.F. 2000. Influence of pine bark beetles on the west Gulf Coastal Plain. Texas Journal of Science 52(4) Supplement: 105-126.

Beech Bark Disease

Brown Spot Needle Blight

Phelps, W.R.; Kais, A.G.; Nicholls, T.H. 1978. Brown spot needle blight of pines. Forest Insect & Disease Leaflet 44. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-44.pdf).

Butternut Canker

Fleguel, V.R.. 1996. A literature review of butternut and the butternut canker. Inform. Rep. 20. Ontario, Canada: Ministry of Natural Resources, Eastern Ontario Model Forest. 32 p.

Nicholls, T.H. 1979. Butternut canker. In: Proceedings of the symposium on walnut insects and diseases. Gen. Tech. Rep. NC–52. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station: 73–82.

Ostry, M.E.; Mielke, M.E.; Anderson, R.L. 1996. How to identify butternut canker and preserve butternut. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station. 4 p.

Ostry, M.; Mielke, M.; Skilling, D. 1994. Butternut—strategies for managing a threatened tree. Gen. Tech. Rep. NC–165. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station. 7 p.

Dogwood Anthracnose

Anderson, R.L.; Knighten, J.L.; Windham, M. [and others]. 1994. Dogwood anthracnose and its spread in the South. Protect. Rep. R8–PR–26. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State & Private Forestry, Forest Pest Management. 10 p.

Britton, K.O.; Roncadori, R.W.; Hendrix, F.F. 1993. Isolation of *Discula destructiva* and other fungi from seeds of dogwood trees. Plant Disease. 77: 1026–1028.

Daughtrey, M.L.; Hibben, C.R.; Britton, K.O.; Windham, M.T.; Redlin, S.C.1996. Dogwood anthracnose: understanding a disease new to North America. Plant Disease. 80: 349–358.

Daughtrey, M.L.; Hibben, C.R.; Hudler, G.W. 1988. Cause and control of dogwood anthracnose in Northeastern United States. Journal of Arboriculture. 14(6): 159–164.

Windham, M.T.; Graham, E.T.; Witte, W.T. [and others]. 1998. *Cornus florida* "Appalachian Spring": a white flowering dogwood resistant to dogwood anthracnose. Horticultural Science. 33: 1265–1267.

Emerald Ash Borer

Various. 2010. Emerald Ash Borer Information Network. Lansing, MI: Michigan State University. Available at: http://www.emeraldashborer.info.

U. S. Department of Agriculture, Forest Service. Forest health protection – Emerald ash borer. Portal page. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area, State and Private Forestry, Forest Health Protection. Web accessed at http://na.fs.fed.us/fhp/eab/)

Forest Tent Caterpillar

Harper, J.D.; Abrahamson, L.P. 1979. Forest tent caterpillar control with aerially applied formulations of *Bacillus thuringiensis* and dimilin. Journal of Economic Entomology. 72: 74–77.

Fusiform Rust

Anderson, R.L.; Mistretta, P.A. 1982. Management strategies for reducing losses caused by fusiform rust, annosus root rot, and littleleaf disease. Agric. Handbk. 597. Washington, DC: U.S. Department of Agriculture Forest Service. 30 p.

Dinus, R.J.; Schmidt, R.A. 1977. Management of fusiform rust in southern pines. In: Proceedings of a symposium. Gainesville, FL: University of Florida. 163 p.

Matthews, F.R.; Anderson, R.L. 1979. How to save your fusiform rust infected pines by removing cankers. Bull. SA–FB/P7. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region, State and Private Forestry, Forest Insect and Disease Management. 6 p.

Phelps, R.W.; Czabator. 1978. Fusiform rust of southern pines. Forest Insect & Disease Leaflet 26. Washington, DC: U.S. Department of Agriculture Forest Service. 7 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-26.pdf).

Schmidt, R.A. 1998. Fusiform rust disease of southern pines: biology, ecology, and management. Tech. Bull. 903. Gainesville, FL: University of Florida. 14 p.

U.S. Department of Agriculture, Forest Service (USDA FS). 1971. Thinning pine plantations in 1971 and after. Unnumbered Forest Management Bulletin. Atlanta: U.S. Department of Agriculture Forest Service, Southeastern Area, State and Private Forestry, Forest Insect and Disease Management. 6 p.

Gypsy Moth

Elkinton, J.S.; Liebhold, A.M. 1990. Population dynamics of gypsy moth in North America. Annual Review of Entomology. 35: 571–596.

Gottschalk, K. 1993. Silvicultural guidelines for forest stands threatened by the gypsy moth. Gen. Tech. Rep. GTR NE-171.Radnor, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station. 49 p.

McManus, M.; Schneeberger, N.; Reardon, R.; Mason, G. 1989. Gypsy moth. Forest Insect & Disease Leaflet 162. Washington, DC: U.S. Department of Agriculture Forest Service. 14 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-162.pdf).

U.S. Department of Agriculture, Forest Service and Animal and Plant Health Inspection Service (USDA FS and others). 1995. Gypsy moth management in the United States: a cooperative approach. [Unnumbered Rep.]. Washington, DC: U.S. Department of Agriculture Forest Service. Various [total 1092 p.]

Hardwood Borer

Donley, D.E.; Accivatti, R.E. 1980. Red oak borer. Forest Insect & Disease Leaflet 163. Portland, OR: U.S. Department of Agriculture Forest Service. 7 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-163.pdf).

Graham, S.A. 1959. Control of insects through silvicultural practices. Journal of Forestry. 57: 281–283.

Hay, C.J.; Morris, R.C. 1970. Carpenterworm. Forest Pest Leaflet 64. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-64.pdf).

Hemlock Woolly Adelgid

U. S. Department of Agriculture, Forest Service (USDA FS). 2005. Hemlock woolly adelgid. Pest Alert NA-PR-09-05. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Norhteastern Area, State & Private Forestry. 2 p. (Also: : http://na.fs.fed.us/spfo/pubs/pest_al/hemlock/hwa05.htm).

U.S. Department of Agriculture, Forest Service (USDA FS). 2010. Hemlock woolly adelgid [home page]. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area. Various p. [http://na.fs.fed.us/fhp/hwa/].

Littleleaf Disease

Anderson, R.L.; Mistretta, P.A. 1982. Management strategies for reducing losses caused by fusiform rust, annosus root rot, and littleleaf disease. Agric. Handbk. 597. Washington, DC: U.S. Department of Agriculture Forest Service. 30 p.

Mistretta, P. 1984. Littleleaf disease. Forest Insect & Disease Leaflet 20. Washington, DC: U.S. Department of Agriculture Forest Service. 6 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-20.pdf).

Nantucket Pine Tip Moth

Berisford, C.W. 1974. Comparisons of adult emergence periods and generations of the pine tip moths, *Rhyacionia frustrana* and *R. rigidana*. Annals of the Entomological Society of America. 67: 666–668.

Berisford, C.W.; Kulman, H.M. 1967. Infestation rate and damage by the Nantucket pine tip moth in six loblolly pine stand categories. Forest Science. 13: 428–438.

Eikenbary, R.D.; Fox, R.C. 1965. The parasites of the Nantucket pine tip moth in South Carolina. Tech. Bull. 1017. Clemson, SC: South Carolina Agricultural Experiment Station. 9 p.

Eikenbary, R.D.; Fox, R.C. 1968. Arthropod predators of the Nantucket pine tip moth *Rhyacionia frustrana*. Annals of the Entomological Society of America. 61: 1218–1221.

Fettig, C.J.; Berisford, C.W. 1999. Nantucket pine tip moth phenology in eastern North Carolina and Virginia: implications for effective timing of insecticide application. Southern Journal of Applied Forestry. 23: 30–38.

Nowak, J.T.; Berisford, C.W. 2000. Effects of intensive management practices on insect infestation levels and loblolly pine growth. Journal of Economic Entomology. 93: 336–341.

Warren, L.O. 1985. Primary hymenopterans parasites of Nantucket pine tip moth, Rhyacionia frustrana (Comstock). Journal of Entomological Science. 20: 383–389.

Yates, H.O., III; Overgard, N.A.; Koerber, T.W. 1981. Nantucket pine tip moth. Forest Insect & Disease Leaflet 70. Washington, DC: U.S. Department of Agriculture Forest Service. 8 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-70.pdf).

Oak Decline

Oak, S.W.; Courter, A. 2000. Modeling oak decline effects on forest composition and structure change using the forest vegetation simulator [Abstract]. In: Anon. Proceedings of the first joint meeting of the northeast and southwide forest disease workshops. Morgantown, WV: West Virginia University. [Not paged].

Oak, S.W.; Huber, C.M.; Sheffield, R.M. 1991. Incidence and impact of oak decline in western Virginia 1986. Resour. Bull. SE–123. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 16 p.

Oak, S.; Tainter, F.; Williams, J.; Starkey, D. 1996. Oak decline risk rating for the Southeastern United States. Annals des Sciences Forestiere. 53: 721–730.

Oak Wilt

Appel, D.N.; Billings, R.F., eds. 1995. Oak wilt perspectives: Proceedings of the national oak wilt symposium. College Station, TX: Texas Forest Service, Texas Agricultural Experiment Station, Texas Agricultural Extension Service. 217 p.

Pine Reproduction Weevil

Corneil, J.A.; Wilson, L.F. 1980. Pales weevil—rationale for its injury and control. Michigan Christmas Tree Journal. Fall: 16–17.

Grosman, D.M.; Billings, R.F.; McCook, F.A.; Upton, W.W. 1999. Influence of harvest date and silvicultural practices on the abundance and impact of pine reproduction weevils in western gulf pine plantations. In: Haywood, James, D., ed. Proceedings of the tenth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–30. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 565–568.

Speers, C.F. 1974. Pales and pitch-eating weevils: development in relation to time pines are cut in the Southeast. Res. Note SE–207. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 7 p.

Stevens, R.E. 1971. Pine reproduction weevil. Forest Pest Leaflet 15. Washington, DC: U.S. Department of Agriculture Forest Service. 6 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-15.pdf).

Southern Pine Beetle

Clarke, S.R.; Nowak, J.T. 2009. Southern pine beetle. Forest Insect & Disease Leaflet 49. Portland, OR: U.S. Department of Agriculture Forest Service. 8 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-49.pdf).

Price, T.S.; Doggett, C.; Pye, J.M.; Smith, B. 1998. A history of southern pine beetle outbreaks in the Southeastern United States by the southeastern forest insect working group. Macon, GA: Georgia Forestry Commission. 72 p.

Swain, K.M.; Remion, M.C. 1981. Direct control of the southern pine beetle. Agric. Handbk. 575. Washington, DC: U.S. Department of Agriculture. 15 p.

Texas Leaf Cutting Ant

Bennett, W.H. 1958. The Texas leaf-cutting ant. Forest Pest Leaflet 23. Washington, DC: U.S. Department of Agriculture Forest Service. 4 p. (available at http://www.fs.fed.us/r6/nr/fid/fidls/fidl-23.pdf).

[Grosman, D.] n.d. Leaf-cutting ant. Web page. College Station, TX: Texas Forest Service. (Available at: http://txforestservice.tamu.edu/main/popup.aspx?id=1187 (Accessed: Jun. 28, 2010.)

Cherret, J.M. 1986. History of the leaf-cutting ant problem. In: Lofgren, C.S.; Vander Meer, R.K., eds. Fire ants and leaf-cutting-ants biology and management. Boulder, CO: Westview Press: 10–17.

CHAPTER 17.
Fire

John A. Stanturf and Scott L. Goodrick[1]

KEY FINDINGS

- Climate forecasts indicate that the South's spring and fall wildfire seasons will be extended.
- Prescribed fires, currently conducted on roughly a 3 to 5 year rotation across much of the South, would need to become more frequent if conditions become drier.
- Major wildfire events, such as the 2007 Okefenokee wildfires, 2008 Evans Road Fire in eastern North Carolina, and recent west Texas fire seasons, are also likely to occur more often. Such events currently occur once every 50 years; however they could be more frequent in a warmer/drier climate.
- Land use change will have the most immediate effects on fuels and wildland fire management by constraining prescribed burning and increasing suppression complexity and cost.
- Air quality issues will likely increase restrictions on prescribed burning over large areas, not just in the wildland-urban interface.
- Potential health and safety concerns, in addition to air quality restrictions, will add to the regulatory constraints on use of prescribed burning.
- Alternatives to prescribed burning are generally not cost-effective and do not provide the ecological benefits of fire to adapted ecosystems; nor do they provide adequate protection for structures and human communities.
- Restrictions on use of prescribed burning to manage fuels will exacerbate potential climate change effects, particularly in the Coastal Plain and on the western Appalachian Mountains, where models predict an increase in wildfire potential.
- Fuels buildups combined with more intense wildfires under a warmer, drier climate could severely degrade fire-dependent communities that often support one or more threatened, endangered, or sensitive species.
- In addition to increasing the severity of wildfire events, the drier conditions and increased variability in precipitation that are associated with climate change could hamper successful forest regeneration and cause shifts in vegetation types over time.

[1]John A. Stanturf is a Research Ecologist and Scott L. Goodrick is a Project Leader/Supervisory Research Meteorologist at the Center for Forest Disturbance Science, Southern Research Station, U.S. Department of Agriculture Forest Service, Athens, GA 30602.

INTRODUCTION

Fire is an integral part of the southern landscape. The pervasive role of fire predates human activity in the South (Lafon 2010, Stanturf and others 2002), and human society has magnified that role. The South leads the nation in number of wildfires per year, averaging approximately 45,000 wildfires per year from 1997 through 2003 (Gramley 2005). Continued population growth in this region increases the potential threat that wildfires pose to life and property. In addition, forestry and forestry related industry represent a significant portion of the region's economy, making each wildfire a potential loss to a local economy.

Prescribed fire is an important tool used in the South to manage hazardous fuels and provide other ecological and economic benefits (Wade and Lunsford 1989). Each year approximately 8 million acres (3.2 million ha) of land are treated with prescribed fire in the South — more than in all other regions combined (Wade and others 2000). Most of this acreage is burned for hazardous fuel reduction, wildlife management, and range management; although an increasing number of acres are burned for ecosystem restoration and maintenance. Most prescribed burning is carried out in the Coastal Plain and Piedmont; however, its use is increasing in the Southern Appalachians and Ozark/Ouachita Highlands as historic fire regimes are reintroduced into these physiographic regions. Of increasing importance is the use of prescribed burning in landscape restoration, in particular for longleaf pine (*Pinus palustris*; see Brockway and others 2005). In March 2009, the Regional Working Group for America's Longleaf published a "Range-wide conservation plan for longleaf pine" that calls for increasing the extent of longleaf forests from 3.4 million acres to 8 million acres over 15 years (online report available at http://www.americaslongleaf.net/resources/the-conservationplan/Conservation%20Plan.pdf, last accessed on 9 December 2010). Because periodic burning is essential to maintain the longleaf ecosystem, successful restoration will require a significant increase in the area burned annually in the South (Southern Regional Partnership for Planning and Sustainability 2011).

In the United States, the popular notion of wildfires often focuses on the large conflagrations common in the western States. However, wildfires occur more frequently in the Southeast, where rapid vegetation growth and fuel accumulation combine with frequent ignitions from lightning and humans. Wildfires in the Southeast have the potential to develop into large, dangerous conflagrations, as epitomized by the Volusia Fire (111,130 acres) and the Flagler/St. John Fire (94,656 acres) that occurred in Florida in 1998 and more recently the Bugaboo Fire/Big Turn Around/Sweat Farm Road Fires (Okefenokee) Fires of 2007 (over 600,000 acres), which occurred in Georgia and Florida and the 2008 Evans Road Fire in North Carolina (over 41,000 acres). Despite the annual wildfire acreage typically being relatively small compared to the West, a disproportionate number of the structures destroyed nationally by wildfires are located in the Southeast (Monroe 2002). For example, in 2008 the Highway 31 Fire in South Carolina burned 19,000 acres, destroyed or damaged 176 homes and caused economic losses in excess of $50 million.

Wildland fire is an integral component of southern ecosystems across a range of climatic conditions, including recent warming associated with greenhouse gas emissions. Westerling and Swetnam (2003) have linked annual areas burned in the Southwest to similar large-scale patterns favoring unusually dry conditions. Their reconstructed paleo-fire records reveal that the drought-producing, year-to-year variability in the atmospheric circulation patterns of the past are still a driving force in the variability of wildfire season severity. Wildfires continue to exhibit significant variability from one year to the next. For example, the burned area in the United States increased from 1.3 million acres (0.5 million ha) in 1998 to 5.6 million acres (2.3 million ha) the next year (National Interagency Fire Center 2010). This mainly results from the inter-annual variability of atmospheric condition, which is a determinant for wildfires along with fuel properties and topography (Pyne and others 1996).

The close relationship between droughts and wildfires provides a basis for evaluating and predicting wildfire potential. Several studies have linked long-term atmospheric anomalies and wildfire activities in the South (Brenner 1991, Dixon and others 2008, Goodrick and Hanley 2009), using atmospheric teleconnection patterns to predict wildfire season severity and help establish a strong tie between wildfire activity and the global climate system. Using the Keetch-Byram Drought Index to forecast changes in wildfire potential at a global scale, Liu and others (2009) found that wildfire potential in the United States is likely to increase by the end of this century, although the magnitude of this increase varied widely, depending on the climate model and emissions scenario selected for the projection.

The remainder of this chapter examines how wildland fire conditions could evolve over the next 50 years, and how these changing conditions may impact prescribed fire in the South. Our examination of changing wildland fire conditions builds upon the methodology of Liu and others (2009) by using a simple water balance-based wildfire potential index to relate changes in temperature and precipitation patterns across the South to changes in fire potential. We evaluate four possible futures (chapter 2) each of which represent a different combination of general circulation model and greenhouse gas emission scenario (IPCC 2007). For each of these Cornerstone Futures, we examine potential changes in the duration and severity of future wildfire seasons and how these changes may impact prescribed burning.

The issues affecting continued use under current conditions of prescribed burning will be presented, along with a discussion of alternatives and their efficacy. Prescribed burning is used routinely to reduce fuel loads and decrease the risk of catastrophic wildfires, improve forest health, and manage habitat for threatened and endangered species. Increasingly, one of the most effective tools in the manager's kit, fuel reduction by frequent understory burning, is off-limits because of safety and liability risks (Achtemeier and others 1998, Wade and Brenner 1995) or public dislike for the inconvenience of smoke (Macie and Hermansen 2002). The concluding section will describe the effects of potential climate change on prescribed fire practice.

METHODS

To address questions regarding future wildfire potential, we examine the response of a drought index to a set of simulated future conditions. A description of these methods follows. Questions regarding the future of prescribed burning are addressed using a synthesis of the scientific literature linked to these forecasts.

Climate Scenarios

Four climate scenarios are used in evaluating potential changes in wildfire potential over a 50 year period from 2010 and 2060. These four scenarios represent four of the six Cornerstone Futures presented in chapter 2 and represent different combinations of general circulation model and IPCC greenhouse gas emission scenario. Cornerstone A uses the MIROC model developed by the University of Tokyo's Center for Climate System Research (National Institute for Environmental Studies) and forced by the IPCC's A1B emissions scenario. Also using the A1B emissions scenario, Cornerstone B uses the CSIRO mk3.5 model developed by the Commonwealth Scientific and Industrial Research Organization of Australia. Cornerstone C employs an older version of the CSIRO model (mk2) forced by the IPCC's

B2 emissions scenario. Cornerstone D uses version 3 of the Hadley Centre Coupled Model forced by the IPCC's B2 emissions scenario.

IPCC emissions scenarios combine two sets of divergent tendencies: one set varies between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (Nakicenovic and others 2000). The A1 scenario family describes a future of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Within that family, A1B represents a balance between fossil fuels and alternative energy sources. The B2 scenario describes a world with continuously increasing global population, moderate levels of economic development, and less rapid but more diverse technological change than in the A1B scenario.

The climate and wildfire potential information presented in this chapter is based on decadal averages, rather than on individual years. Therefore, data for 2010 represents the average of all the years from 2001 to 2010. Monthly data is also expressed as a decadal average, for example, April 2060 would represent the average of the 10 Aprils from 2051 to 2060.

Measuring Wildfire Potential

Wildfire potential is a complex function of recent weather conditions, vegetation and topography. Of these three components, weather exhibits the most variability at any given spot. Wildfire potential is often determined using a system such as the National Fire Danger Rating System (Burgan 1988) that utilizes afternoon weather observations of temperature, humidity, wind speed, and precipitation amount/duration. In general, the output from general circulation models does not include all the information that would be required by such a system to project future changes in wildfire potential.

The Keetch-Byram Drought Index (KBDI) is a rather simple drought index designed specifically for assessing wildfire potential in the South (Keetch and Byram 1968). The KBDI is a cumulative measure of the balance between evapotranspiration and rainfall; and only requires three inputs: daily high temperature, daily rainfall and annual average rainfall. The high temperature and annual rainfall are used to estimate daily evapotranspiration (annual rainfall acts as a surrogate for the amount of vegetation as higher annual rainfall supports more vegetation which leads to increased evapotranspiration).

The KBDI has two potential limitations for climate change work. First, because the function defining evapotranspiration was derived for historical rainfall and temperature regimes, the fit may not be as good under climate change conditions. Secondly, the index scale is fixed to be from 0 (very wet) to 800 (extremely dry) with a nonlinear, asymptotic approach to this maximum value. For a changing climate where conditions could potentially get much drier than they are currently, use of the KBDI could underestimate the potential drought conditions by compressing the changes into the asymptotic portion of the curve.

As an alternative index, referred to as simply the potential drought index (PDI), we use the balance between 0.75 times the potential evapotranspiration minus precipitation. The 0.75 scaling is designed to reflect the fact that the potential evapotranspiration is an overestimate of the actual evapotranspiration (Eagleman 1967). The exact value of this scaling coefficient is not critical; the primary requirement is that it provides reasonable estimates of the current water balance conditions to serve as a basis for evaluating future changes. The slight change in how evapotranspiration is calculated compared to the KBDI will cause the PDI to accentuate drought conditions and thus highlight areas of potential increases in wildfire potential. The PDI has an open-ended scale with units of millimeters. Positive values of the PDI indicate drought conditions.

RESULTS

Future Wildfire Potential Changes

Annual fire potential—Wildfire reports compiled as part of the Southern Wildfire Risk Assessment (Buckley and others 2006) reveal three primary areas of wildfire activity from 1997 to 2002: the Coastal Plain, the western Appalachian Mountains (eastern parts of Kentucky and Tennessee) and eastern Oklahoma/Arkansas (fig. 17.1). Other areas may be important locally but are of limited geographic extent, such as the Coastal Plain sandhills, where longleaf pine burns regularly. Care must be taken when examining this figure as not all States provided wildfire records with latitude/longitude for each fire; some States located all wildfires at the geographic center of counties. This is especially noticeable in Texas, where counties are larger.

All four Cornerstone Futures provide a consistent view of the current annual fire potential as expressed by the PDI (fig. 17.2). On these maps brown areas define regions where evapotranspiration exceeds precipitation (positive PDI) while in blue regions precipitation dominates (negative PDI). White areas show a balanced moisture budget (PDI near zero). Areas farthest west are dominated by the highest PDI values because of lower precipitation and higher summer temperatures; areas farther east are dominated by higher precipitation, leading to negative PDI values. The primary differences among the Cornerstone Futures are primarily

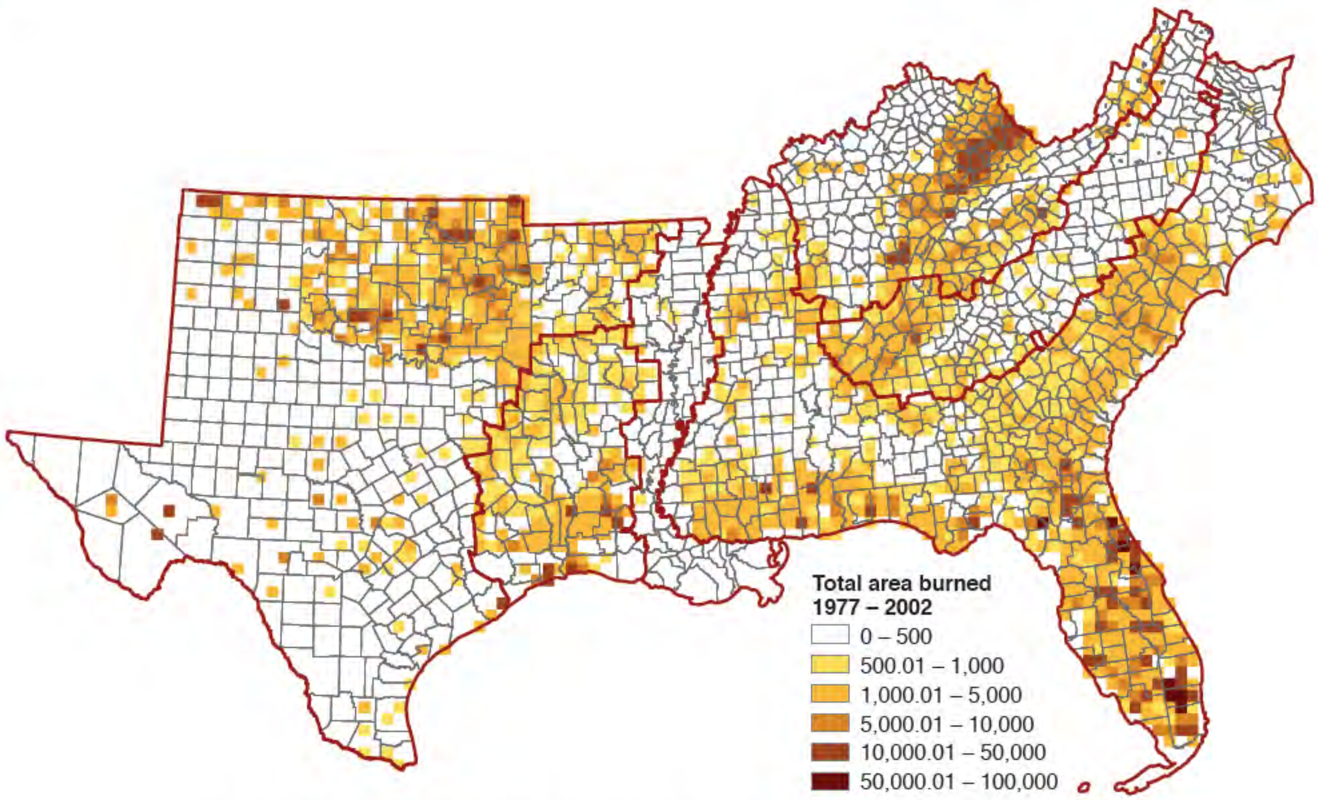


Figure 17.1—Total area burned by wildfires, 1997 to 2002, displayed as a raster image with 25-km cell size. (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

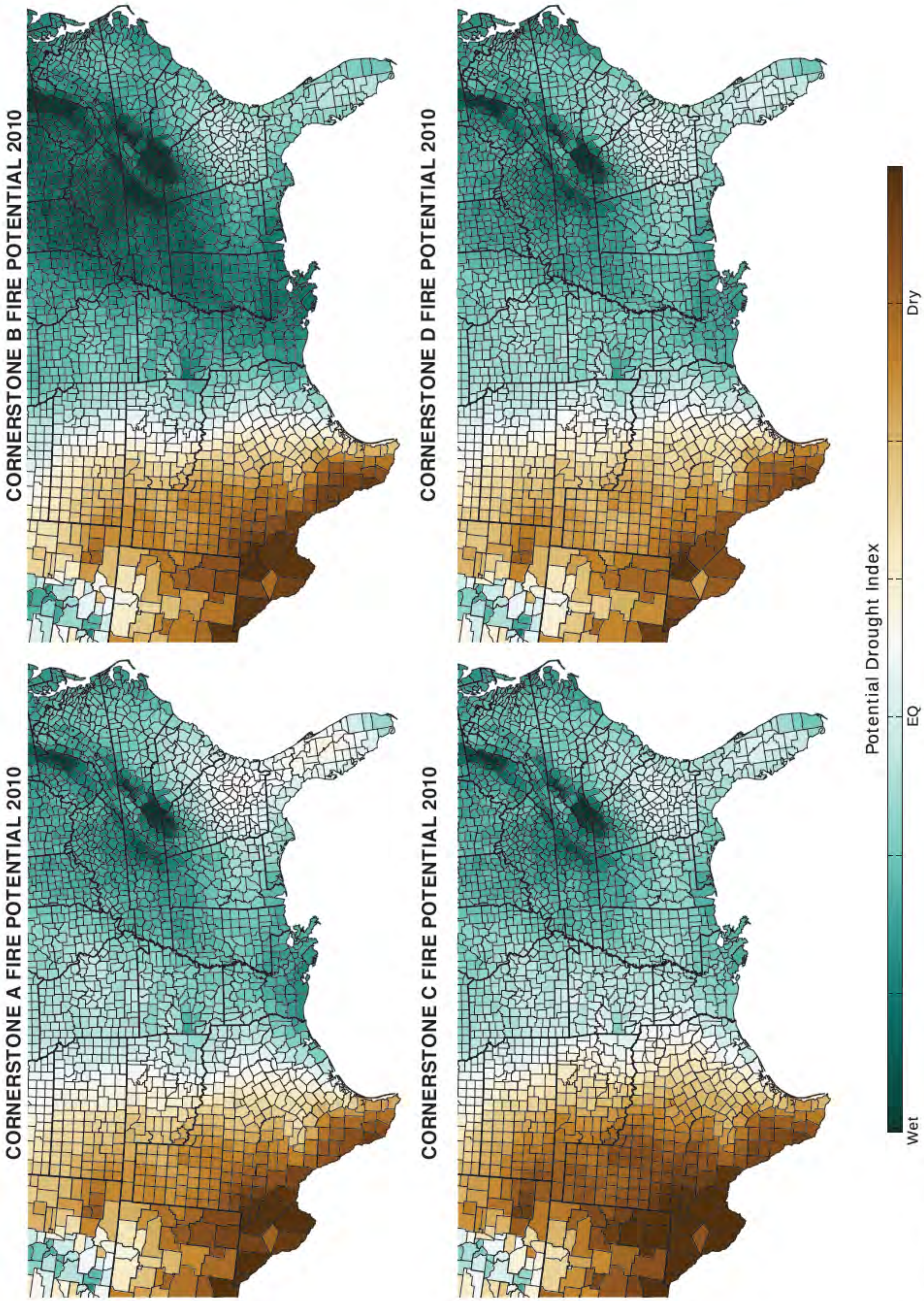


Figure 17.2—Comparison of annual fire potential for current conditions (2010) by Cornerstone Future.

focused in the Ohio River Valley where Cornerstone B is the wettest, and along a band just inland of the coast where the PDI is near zero. This band is most evident for Cornerstones C and D.

Comparing these PDI maps to the map of acres burned in figure 17.1 shows that areas with the driest conditions (highest PDI) do not necessarily have the highest acres burned. The Coastal Plain, whose annual PDI in Cornerstones B, C and D is near zero has some of the highest amounts of burned area. The areas with highest positive PDI values are not productive enough to support sufficient build up of fuels to support frequent wildfires. The eastern Oklahoma/Arkansas region is another area of transition in the PDI reflecting near balance between rainfall and precipitation. The western Appalachians shows significant areas burned despite having the lowest PDI values.

In 50 years, all Cornerstone Futures depict drier conditions (fig. 17.3). Cornerstone A depicts the most severe conditions with an eastward expansion of the western dry area and the development of a similar area in southern Georgia and Florida; only the Appalachians maintain a negative PDI. The other Cornerstone Futures are very consistent in their depiction of drier conditions, though the magnitude of the drying is far less than in Cornerstone A. The central part of the region shifts from negative PDI values to a more balanced condition and the band of near zero PDI in the Coastal Plain becomes better defined. All three of the primary fire areas depicted in figure 17.1 experience an increase in wildfire potential, with Cornerstone A showing the most dramatic increase and B, C and D showing more modest increases.

Seasonal variation of wildfire potential—These annual numbers provide a glimpse of future wildland fire conditions, but examination of PDI changes at the seasonal scale provides more information. Splitting the area burned information presented in figure 17.1 by season provides insight into the current wildfire season. Figure 17.4 shows the number of acres burned during the winter months (December, January and February). South Florida and the western Appalachians are the areas showing highest wildfire activity; although wildfire activity is present at a low level across much of the South. For southern Florida, the heart of the dry season is the winter months, when natural ignitions are uncommon, but human ignitions are sufficient to support significant winter wildfire activity. In the Appalachians, much of the winter wildfire season is tied to either the start or end of the season reflecting either a prolonged fall wildfire season or an early start to a spring wildfire season.

Spring (March, April, May) brings more wildfire activity, particularly to the Coastal Plain and Piedmont (fig. 17.5). Along the Coastal Plain, sea-breeze induced thunderstorms provide a natural ignition source along with the ever present human ignition component. By summer (June, July, August), wildfire activity decreases throughout the Appalachians while a low level of wildfire activity persists in the Coastal Plain, where continuing thunderstorms produce sufficient rainfall to reduce the probability ignition by late June or early July (fig. 17.6). Fall brings a return of wildfire activity to the Appalachians and a great reduction in the Coastal Plain, particularly Florida (fig. 17.7). For much of the Appalachians the input of litter to the forest floor provides the fuel to support the spread of wildfires when coupled with dry conditions.

Although wildfires are possible in any season, the two areas discussed above have distinct wildfire seasons. For the Coastal Plain, wildfire activity is lowest in the fall and highest in the spring, with some activity spilling over into summer and winter. For the Appalachians, activity is lowest in the summer and highest in the fall, with spring providing a secondary peak in wildfire activity. Winter wildfire activity in the Appalachians is considerably more than during summer, but is largely tied to either an extended fall wildfire season or an early spring season. Although no other area shows a seasonal peak in wildfire activity as pronounced as the Coastal Plain or Appalachians, the eastern Oklahoma/Arkansas region experiences wildfire activity in all seasons.

For current conditions under Cornerstone A, winter is the primary rainy season, although the areal extent of this wet area is restricted to the Appalachians as reflected by the PDI (fig. 17.8). During the summer, Cornerstone A is dominated by pronounced drying and fails to capture the summer rains in Florida and along the Coastal Plain. Over the course of 50 years, this drying is further reinforced and virtually eliminates all areas of negative PDI values (fig. 17.9).

Cornerstone B offers a better representation of current conditions compared to Cornerstone A (fig. 17.10); especially in capturing the evolution of the spring/fall wildfire season of the Coastal Plain. Key features of note are the improved flow of moisture from the Gulf of Mexico northward across the Appalachians and dry conditions across Florida during winter. The area of moist conditions shifts northward during spring as dry conditions expand across the Coastal Plain. Summer brings dry conditions to much of the South, with the exception of the Coastal Plain where precipitation from afternoon thunderstorms balances the dry conditions. During fall, dry conditions return to the Coastal Plain.

Compared to Cornerstone A, the changes in wildfire potential in 50 years are much more subtle under Cornerstone B (fig. 17.11), which shows substantial drying along the Gulf of Mexico during winter and areas of dryness in spring and summer that are similar but smaller than in Cornerstone A. Unlike the domination by strong, widespread drying under

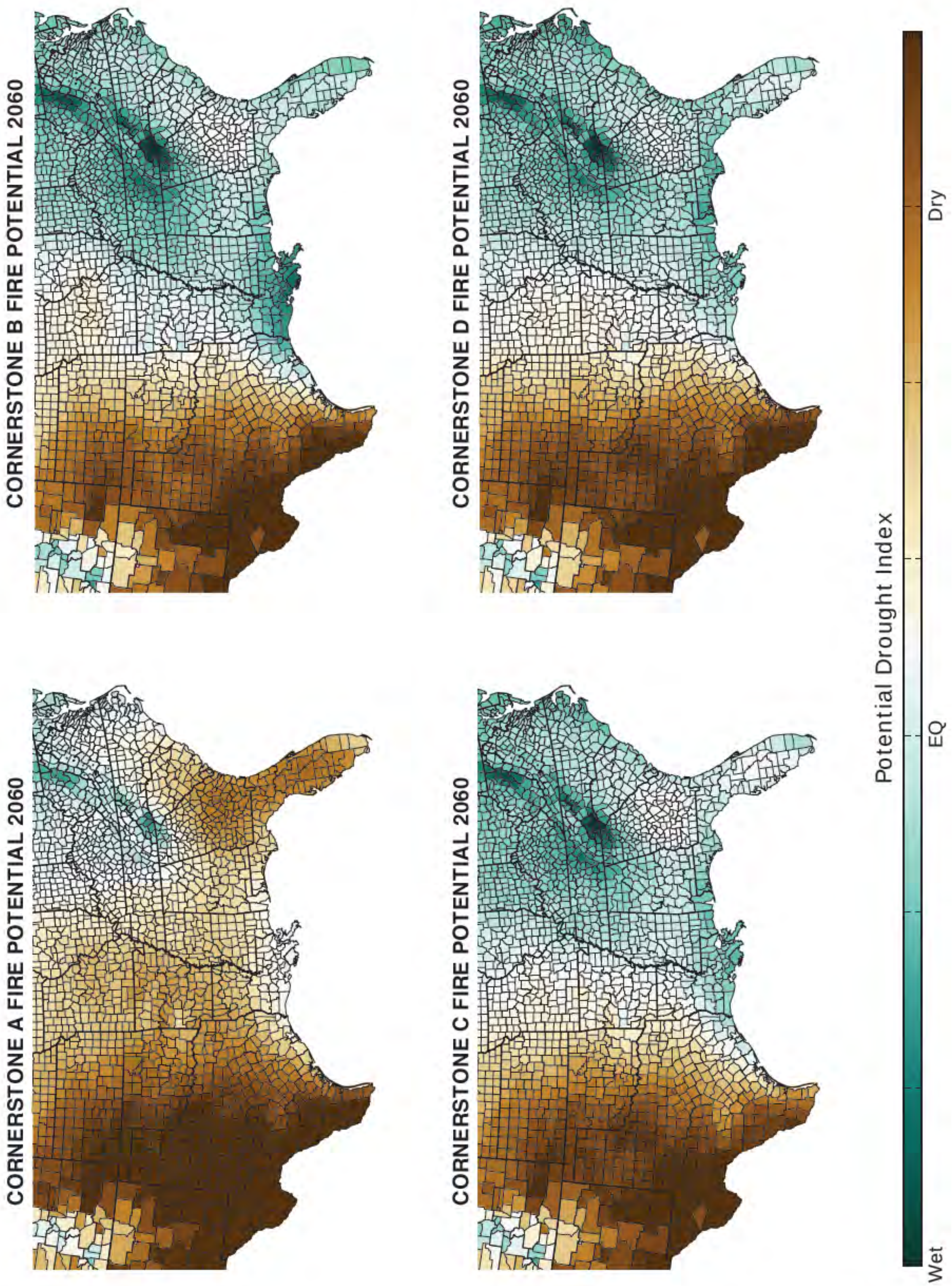


Figure 17.3—Comparison of annual fire potential for future conditions (2060) by Cornerstone Future.

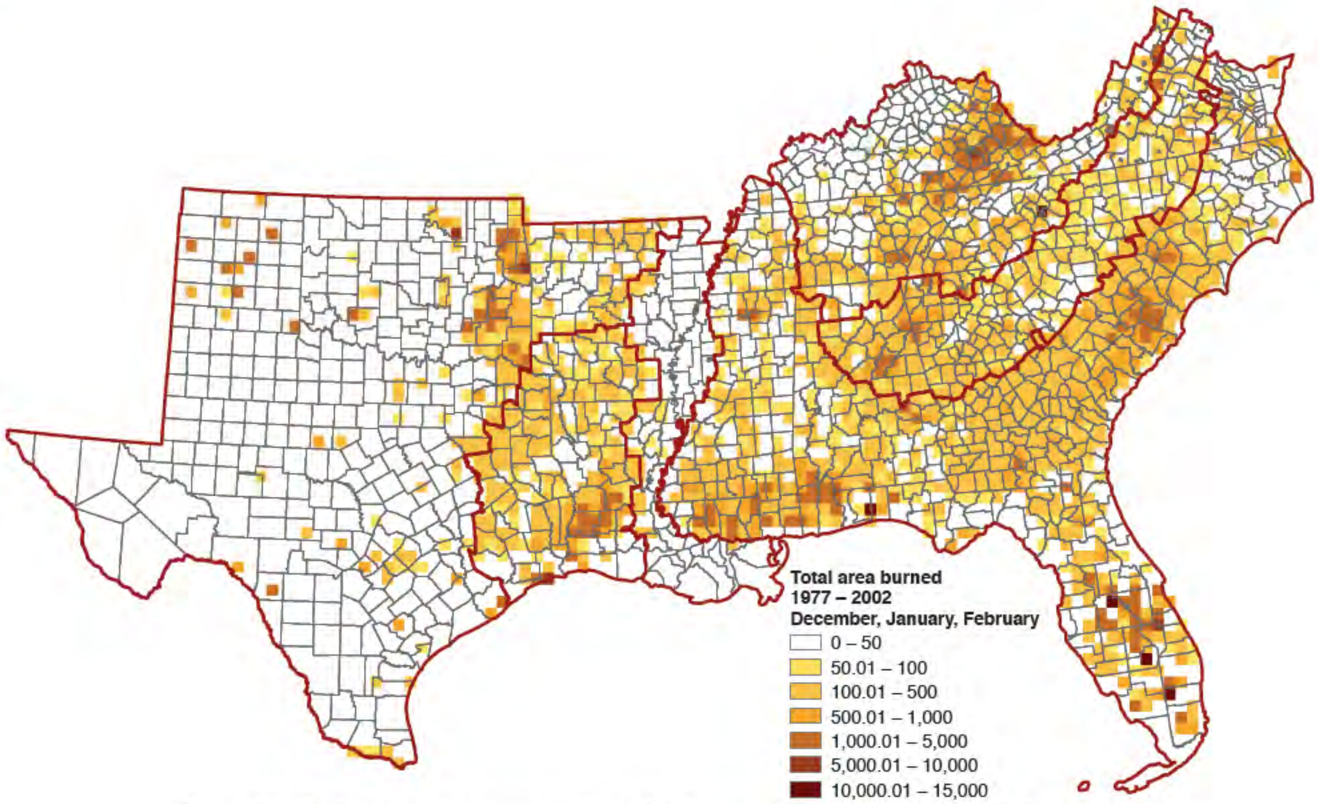


Figure 17.4—Total area burned during winter (December, January, and February) for 1997–2002, displayed as a raster image with 25-km cell size. (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

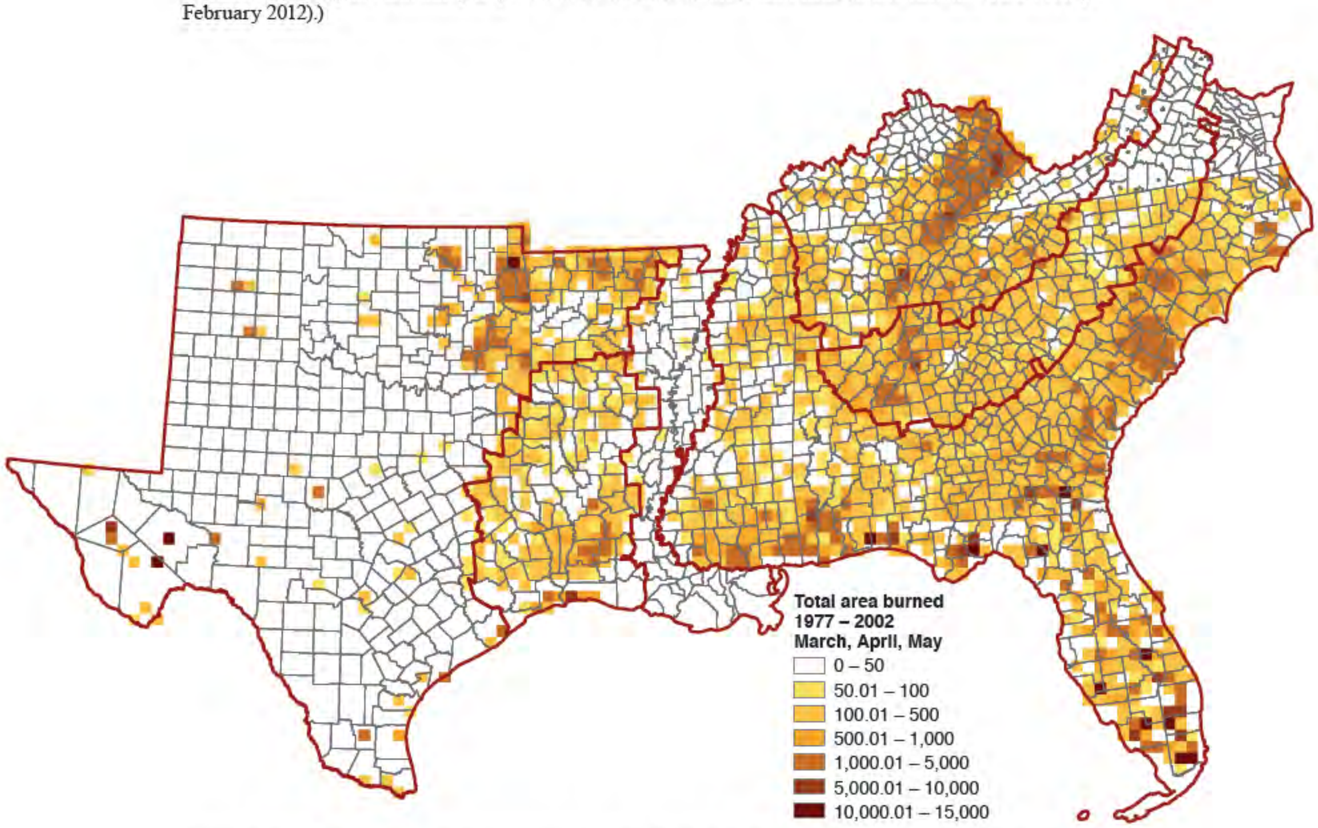


Figure 17.5—Total area burned during spring (March, April, and May) for 1997–2002, displayed as a raster image with 25-km cell size (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

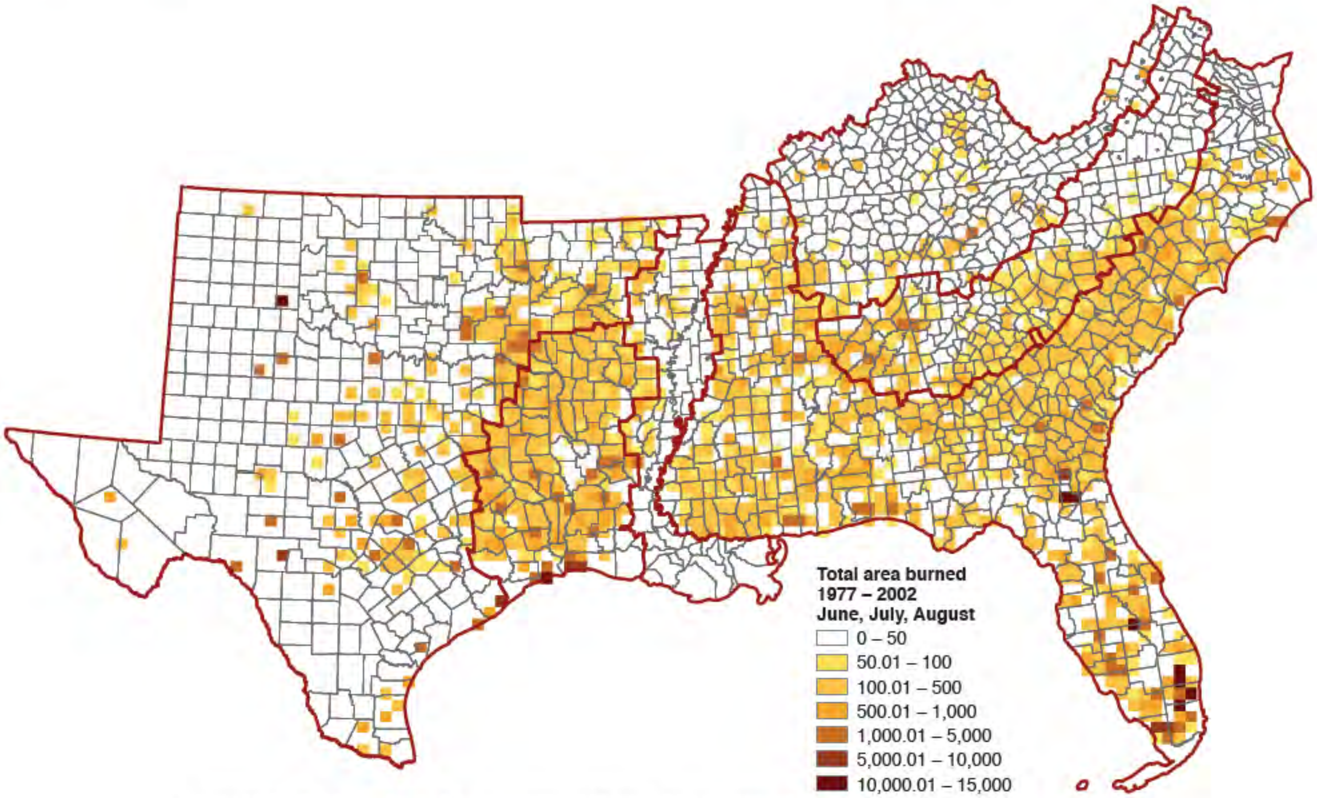


Figure 17.6—Total area burned during summer (June, July, and August) for 1997–2002, displayed as a raster image with 25-km cell size. (Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

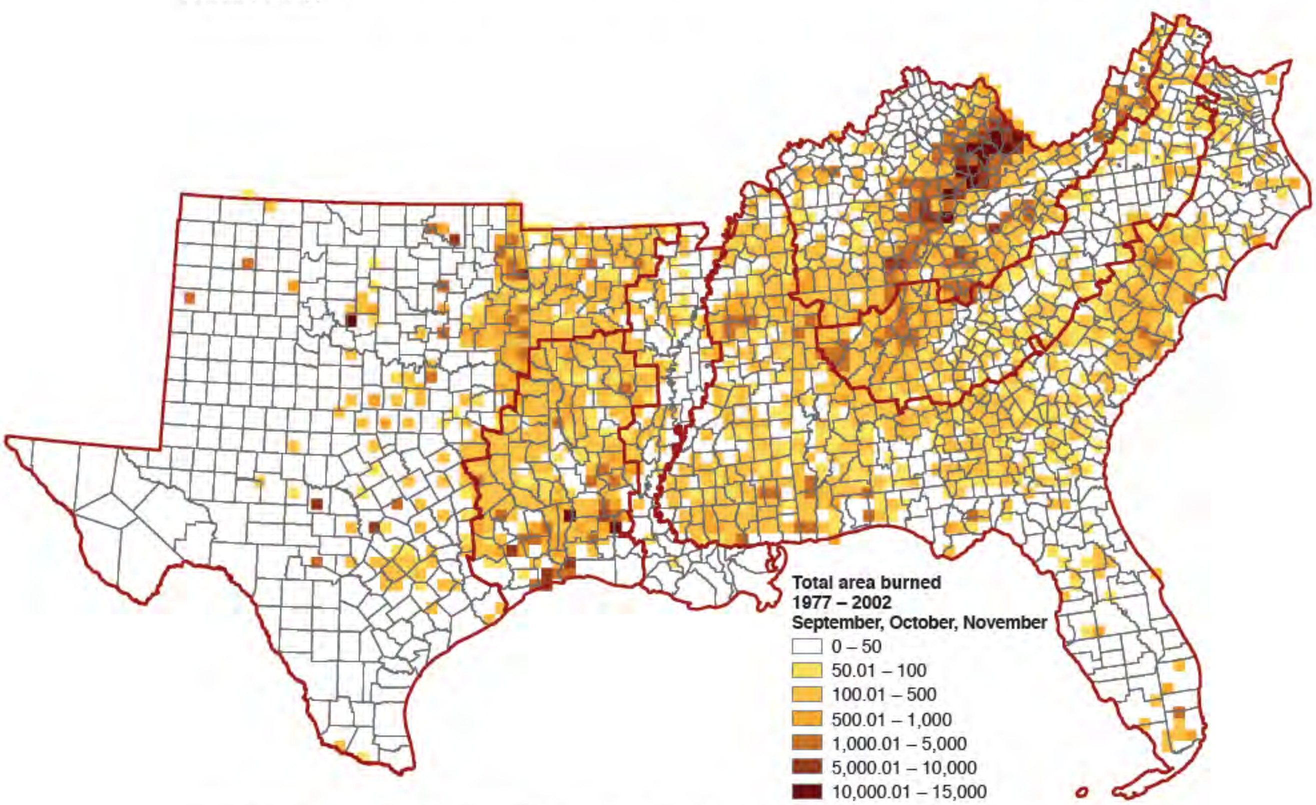


Figure 17.7—Total area burned during fall (September, October, and November) for 1997-2002, displayed as a raster image with 25-km cell size.(Data source: Sanborn Map Company (2008) Southern Fire Risk Assessment (version 9.3) [computer software]. http://www.southernwildfirerisk.com/sfras/aboutsfras.html. Retrieved (9 February 2012).)

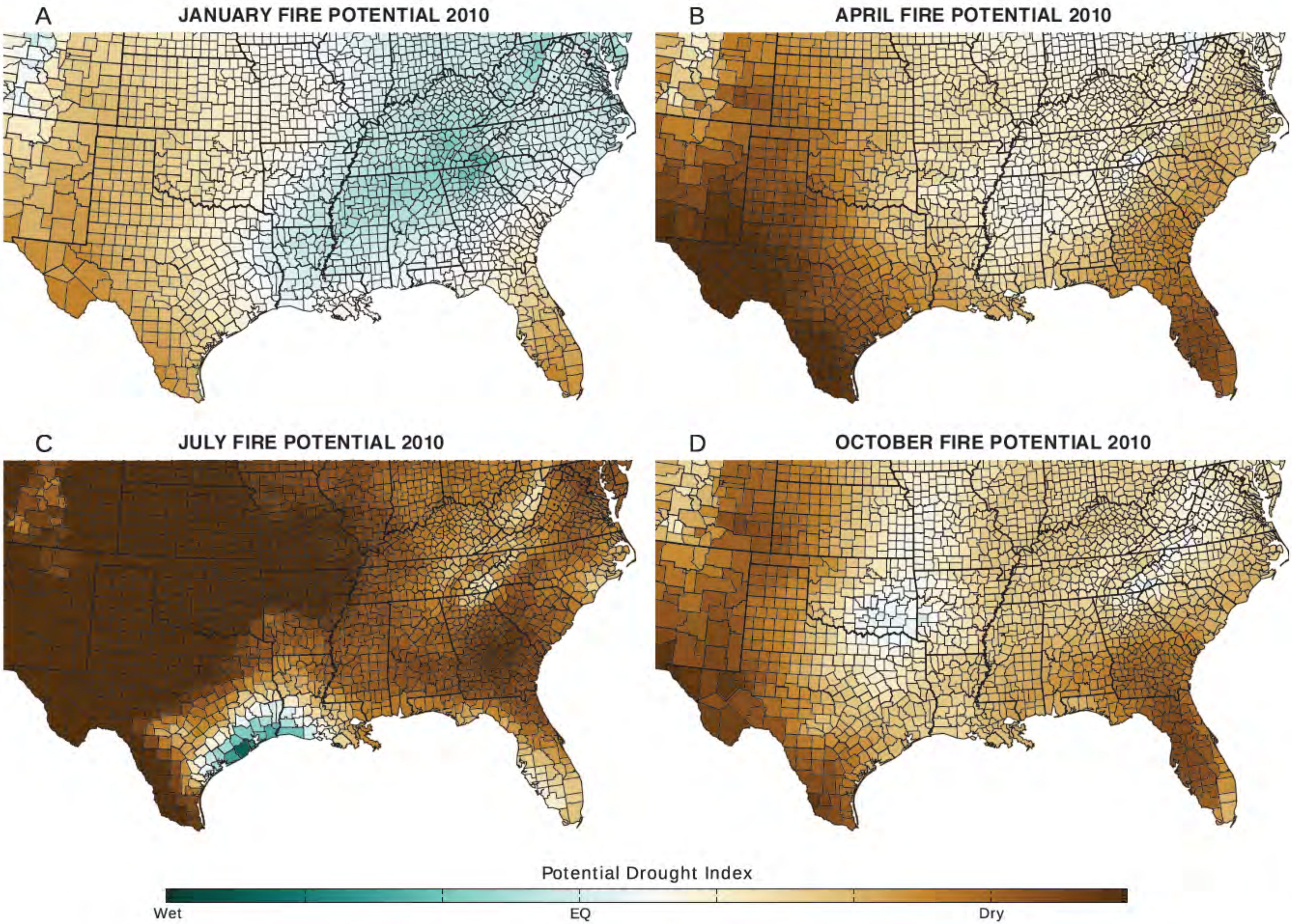


Figure 17.8—Seasonal view of fire potential under current conditions for (A) January, (B) April, (C) July, and (D) October (Cornerstone A).

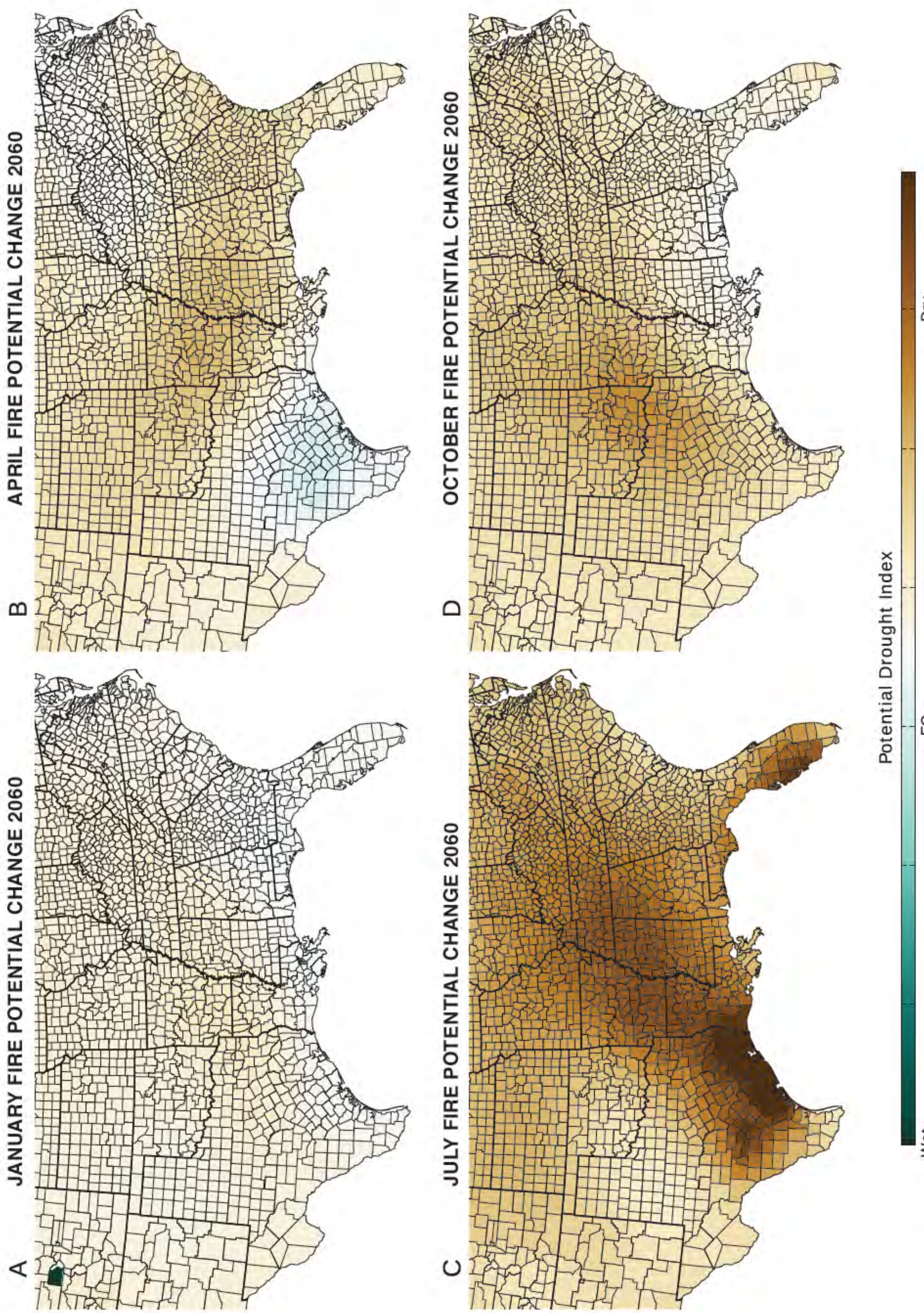


Figure 17.9—Change in seasonal fire potential in 2060 for (A) January, (B) April, (C) July, and (D) October (Cornerstone A).

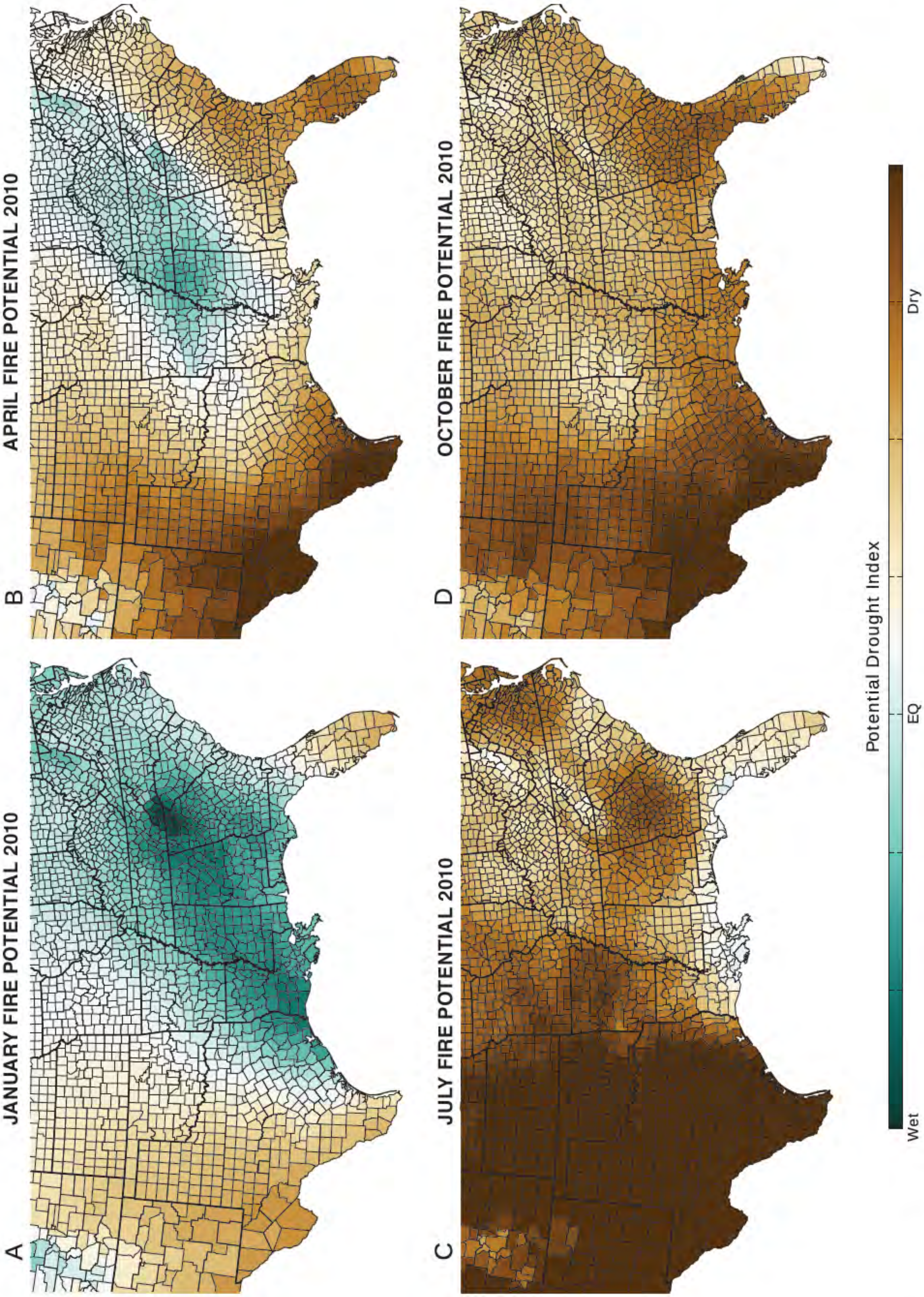


Figure 17.10—Seasonal view of fire potential for current conditions for (A) January, (B) April, (C) July, and (D) October (Cornerstone B).

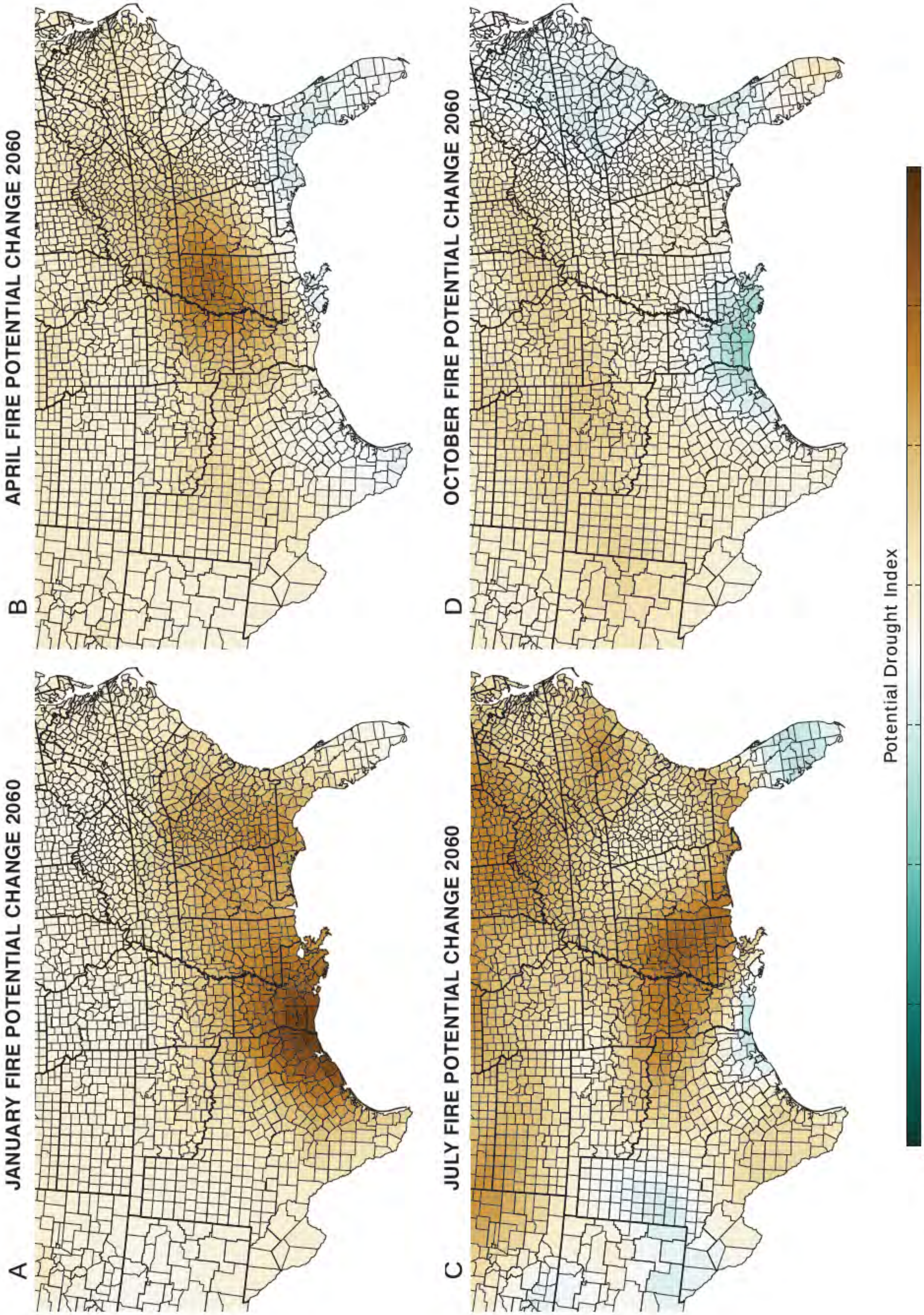


Figure 17.11—Change in seasonal fire potential in 2060 for (A) January, (B) April, (C) July, and (D) October (Cornerstone B).

Cornerstone A; Cornerstone B shows a much smaller area of change that is strongest during winter rather than summer. Wintertime drying could adversely affect prescribed burning by favoring conditions that promote escaped prescribed fires. Drier conditions would also promote increased fuel consumption on prescribed burns, increasing the likelihood of air quality problems. Cornerstones C and D resemble Cornerstone B in spatial patterns but their magnitudes of changes after 50 years are smaller.

Monthly variation in wildfire potential—To get a better feel for the spatial extent of these changes in wildfire potential as described by the PDI, we examine the changes in areal extent of wet and dry conditions within each State by month. What constitutes wet versus dry conditions for each Cornerstone is determined by taking all PDI estimates for 2010 and splitting this collection of values into thirds. The third with the highest PDI values represents dry conditions and the lowest third wet conditions. The breakpoints defining dry versus wet conditions are shown in table 17.1 along with maximum/minimum values for each Cornerstone.

For current conditions, Cornerstones A, C and D have many of the States predominantly in the wettest category for November through March, then transitioning to the driest category for June through August (tables 17.2 to 17.5). Cornerstone B has a much more prolonged and gradual transition in the spring for many of the States. These transition periods in spring and fall are typical of the southern wildfire season, and they largely depend on the annual evolution of live fuel moisture conditions. In spring, live fuel moisture values are low until the start of green up. Periods of drought during this time create periods of high fire danger. When live fuel moisture peaks, the moisture content acts as a heat sink, reducing the fire danger. In the fall, live fuel moistures begin to decline in many species, which along with drying from high summer temperatures brings about the fall wildfire season. The onset of winter rains typically signals the end of the fall wildfire season.

Notable Exceptions to this Pattern are Florida, Texas, and Oklahoma

Florida has a complex climate as the northern part of the State has both a summer and winter rainy season, while the southern part exhibits only a single summer rainy season. In Florida the primary wildfire season is in the spring as this is the time of year when most of the acres burn. For the southern part of Florida, spring marks the peak of dry conditions prior to the start of the summer rainy season. During May and June, the summer rainy season begins with isolated thunderstorms. Lightning from these storms provides a major ignition source until the rainy season progresses to a point where most areas are receiving rain on a regular basis.

Texas and Oklahoma represent the dry western portion of the region. During winter, the storms that move eastward out of the Rocky Mountains are dry and must begin rebuilding their moisture levels from southerly winds coming from the Gulf of Mexico. This process is just getting started as the storms move across Texas and Oklahoma, only reaching significant moisture levels in those States' eastern parts (hence the very low acreage in the wet category).

In 50 years, Cornerstone A has almost every acre of the South in the driest category during the summer (table 17.6). This scenario completely erases Florida's summer rainy season. This reveals a possible flaw in the downscaling used to generate the Cornerstone Futures. Florida's summer rains are small-scale local events, far below the resolution of the underlying general circulation models. These storms are forced by the difference in temperature between the land and ocean, which is not going to disappear due to climate change. Cornerstones B, C and D show only subtle differences (tables 17.7 to 17.9). The gradual transition from winter rainy season to summer dry season in Cornerstone B is largely erased which brings the 2060 conditions into much closer alignment with Cornerstones C and D.

Impacts of climate change—Results from the four Cornerstone Futures indicate that wildfire potential is likely to increase over the next 50 years. The magnitude of that increase is likely to be fairly slight, although one scenario (Cornerstone A) predicts a significant increase. Predicted results for Cornerstone B are much more aligned with Cornerstones C and D despite being forced with the same emissions scenario as Cornerstone A (A1B). This suggests that the simulated severe drying of Cornerstone A may be more closely tied to the general circulation model used for the simulation than any forcing from the emissions scenario.

From Cornerstone B we can expect both the spring and fall wildfire seasons to increase in duration across the Coastal Plain. Drier conditions in winter, spring, and summer will likely both extend and worsen the spring wildfire season. Although the results presented above reflect average conditions, it is likely that we will see shifts in variability that will result in the bad wildfire seasons being worse than they currently are. Winter and summer drying will likely extend the fall wildfire season, but the overall fall magnitude is little changed from current conditions. Outside of the Coastal Plain, the western Appalachians would see drier summers, resulting in a prolonged spring and earlier fall wildfire season.

These changes in wildfire potential in the South would lead to longer fire seasons, but for the elevated fire potential to translate to increased acres burned requires ignitions. Because the vast majority of southern wildfires are human caused, not natural; changes in ignitions will be more

Table 17.1—Breakpoints defining the wettest and driest thirds of potential drought index (PDI) values for current conditions in the South for each Cornerstone Future

Scenario	Wet breakpoint	Dry breakpoint	Wettest value	Driest value
Cornerstone A	95	562	-585	1162
Cornerstone B	-3	530	-708	1169
Cornerstone C	133	634	-510	1222
Cornerstone D	19	500	-582	1083
Average	61	556	—[a]	—

[a]Averages are not provided for extreme values.

Table 17.2—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone A

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	100	32	85	0	0	0	0
Arkansas	0	0	0	0	0	100	75	100	36	0	0	0
Florida	0	0	0	32	48	33	6	0	0	37	0	0
Georgia	0	0	0	0	0	97	73	56	1	1	0	0
Kentucky	0	0	0	0	0	91	16	30	0	0	0	0
Louisiana	0	0	0	0	0	100	0	20	51	0	0	0
Mississippi	0	0	0	0	0	100	19	61	30	0	0	0
North Carolina	0	0	0	0	0	63	0	2	0	0	0	0
Oklahoma	0	0	0	0	0	100	100	100	54	0	0	0
South Carolina	0	0	0	0	0	100	28	12	0	0	0	0
Tennessee	0	0	0	0	0	88	20	49	0	0	0	0
Texas	0	0	19	55	45	100	73	93	96	18	0	0
Virginia	0	0	0	0	0	63	6	10	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	100	9	0	0	0	0	0	0	99	100
Arkansas	96	100	97	0	0	0	0	0	0	14	100	100
Florida	21	41	22	0	0	5	0	18	18	0	8	22
Georgia	84	100	82	4	1	0	0	0	0	1	31	84
Kentucky	100	100	100	0	0	0	0	0	0	0	100	100
Louisiana	100	100	82	0	0	0	18	34	0	0	100	100
Mississippi	100	100	100	27	0	0	0	0	0	0	100	100
North Carolina	100	100	100	4	3	0	0	0	2	11	45	100
Oklahoma	3	12	4	0	0	0	0	0	0	36	5	16
South Carolina	98	100	100	0	0	0	0	0	0	0	19	96
Tennessee	100	100	100	5	0	0	0	0	0	0	100	100
Texas	12	8	0	0	0	0	8	1	0	3	7	15
Virginia	100	100	100	0	0	0	0	0	0	12	97	100

Table 17.3—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone B

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	0	0	94	17	0	0	0
Arkansas	0	0	0	0	0	17	61	100	73	0	0	0
Florida	0	0	0	0	0	0	0	1	0	0	0	0
Georgia	0	0	0	0	0	0	7	71	20	0	0	0
Kentucky	0	0	0	0	0	0	0	26	3	0	0	0
Louisiana	0	0	0	0	0	85	0	58	34	0	0	0
Mississippi	0	0	0	0	0	11	0	93	73	0	0	0
North Carolina	0	0	0	0	0	0	0	19	0	0	0	0
Oklahoma	0	0	0	0	0	26	100	100	52	8	0	0
South Carolina	0	0	0	0	0	0	0	47	0	0	0	0
Tennessee	0	0	0	0	0	0	0	92	30	0	0	0
Texas	0	0	25	32	65	80	97	99	75	64	0	0
Virginia	0	0	0	0	0	0	0	4	0	0	0	0

Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	66	61	39	0	0	0	0	0	26	100
Arkansas	100	89	100	97	9	0	0	0	0	0	100	100
Florida	49	39	0	0	3	45	17	57	7	0	0	11
Georgia	100	100	32	21	16	0	0	0	1	0	11	55
Kentucky	100	100	100	100	100	0	0	0	0	0	96	100
Louisiana	100	100	48	38	88	0	26	0	0	0	32	100
Mississippi	100	100	83	89	91	0	5	0	0	0	43	100
North Carolina	100	100	87	22	86	2	1	0	15	0	16	96
Oklahoma	39	13	32	10	0	0	0	0	0	0	20	62
South Carolina	100	100	26	6	17	0	0	0	0	0	6	53
Tennessee	100	100	100	100	93	0	0	0	1	0	92	100
Texas	30	32	3	4	0	0	0	0	0	0	93	33
Virginia	100	100	100	45	51	0	0	0	0	0	35	100

Table 17.4—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone C

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	64	0	92	0	0	0	0
Arkansas	0	0	0	0	0	93	98	100	1	0	0	0
Florida	0	0	0	9	0	0	0	0	0	2	0	0
Georgia	0	0	0	0	0	23	0	64	25	0	0	0
Kentucky	0	0	0	0	0	14	17	63	0	0	0	0
Louisiana	0	0	0	0	0	84	48	67	11	0	0	0
Mississippi	0	0	0	0	0	97	39	93	10	0	0	0
North Carolina	0	0	0	0	0	0	0	8	0	0	0	0
Oklahoma	0	0	0	15	10	96	100	100	49	24	0	0
South Carolina	0	0	0	0	0	0	0	21	0	0	0	0
Tennessee	0	0	0	0	0	35	17	83	0	0	0	0
Texas	0	0	28	60	63	99	99	100	73	50	0	0
Virginia	0	0	0	0	0	0	10	0	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	100	1	0	0	0	0	0	0	26	100
Arkansas	99	96	100	0	0	0	0	0	0	0	99	100
Florida	32	32	20	0	7	17	25	16	17	0	0	16
Georgia	99	99	62	5	0	0	0	0	0	0	15	67
Kentucky	100	100	100	0	0	0	0	0	0	0	100	100
Louisiana	100	100	88	0	0	0	0	0	0	0	58	100
Mississippi	100	100	100	0	0	0	0	0	0	0	64	100
North Carolina	100	100	100	9	3	0	0	0	1	4	28	76
Oklahoma	12	5	25	0	0	0	0	0	0	0	6	6
South Carolina	100	100	81	0	0	0	0	0	0	0	6	43
Tennessee	100	100	100	4	0	0	0	0	0	0	99	100
Texas	13	7	3	0	0	0	0	0	0	0	4	13
Virginia	100	100	100	0	0	0	0	0	0	2	92	99

Table 17.5—Percent of area in dry and wet classes for current conditions (2010) by State and month for Cornerstone D

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	96	0	79	7	0	0	0
Arkansas	0	0	0	0	0	71	70	70	87	0	0	0
Florida	0	0	0	0	1	8	0	0	0	24	0	0
Georgia	0	0	0	0	5	72	0	47	19	0	0	0
Kentucky	0	0	0	0	0	7	7	45	17	0	0	0
Louisiana	0	0	0	0	0	83	7	36	44	0	0	0
Mississippi	0	0	0	0	0	100	2	68	53	0	0	0
North Carolina	0	0	0	0	0	0	0	2	0	0	0	0
Oklahoma	0	0	0	0	0	76	100	94	71	26	0	0
South Carolina	0	0	0	0	0	6	0	15	0	0	0	0
Tennessee	0	0	0	0	0	39	8	72	16	0	0	0
Texas	0	0	7	40	35	96	97	99	77	64	1	0
Virginia	0	0	0	0	0	0	0	7	0	0	0	0

Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	95	0	0	0	0	0	0	0	56	100
Arkansas	99	97	100	2	0	0	0	0	0	0	100	100
Florida	32	35	5	0	4	22	15	15	35	0	0	22
Georgia	100	100	36	1	0	0	0	0	0	0	21	74
Kentucky	100	100	100	0	0	0	0	0	0	0	100	100
Louisiana	100	100	100	0	0	0	0	0	0	0	82	100
Mississippi	100	100	100	0	0	0	0	0	0	0	93	100
North Carolina	100	100	97	5	3	0	11	0	0	0	21	100
Oklahoma	6	5	16	0	0	0	0	0	0	0	29	32
South Carolina	100	100	32	0	0	0	0	0	0	0	6	82
Tennessee	100	100	100	2	0	0	0	0	0	0	100	100
Texas	16	9	12	0	0	0	0	0	0	0	18	20
Virginia	100	100	98	0	0	0	0	0	0	2	42	100

Table 17.6—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone A

Percent area in driest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	0	0	0	0	46	100	100	100	100	0	0	0
Arkansas	0	0	0	0	0	100	100	100	100	0	0	0
Florida	0	0	0	81	60	93	96	95	93	59	4	0
Georgia	0	0	0	44	80	100	100	100	98	52	0	0
Kentucky	0	0	0	0	0	100	100	100	100	0	0	0
Louisiana	0	0	0	0	0	100	83	100	88	0	0	0
Mississippi	0	0	0	0	1	100	100	100	100	0	0	0
North Carolina	0	0	0	0	8	98	93	95	88	0	0	0
Oklahoma	0	0	1	60	26	100	100	100	100	23	0	0
South Carolina	0	0	0	10	83	100	100	100	100	0	0	0
Tennessee	0	0	0	0	0	100	100	100	99	0	0	0
Texas	0	0	68	59	89	100	96	100	100	66	21	0
Virginia	0	0	0	0	0	100	100	97	98	0	0	0

Percent area in wettest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	100	100	8	0	0	0	0	0	0	0	0	98
Arkansas	38	93	0	0	0	0	0	0	0	0	65	100
Florida	20	8	0	0	0	0	0	0	0	0	0	5
Georgia	74	58	15	0	0	0	0	0	0	0	2	32
Kentucky	100	100	12	0	0	0	0	0	0	0	0	100
Louisiana	98	52	0	0	0	0	0	0	0	0	0	93
Mississippi	100	100	0	0	0	0	0	0	0	0	16	100
North Carolina	100	100	16	0	0	0	0	0	0	1	7	86
Oklahoma	0	3	0	0	0	0	0	0	0	0	8	0
South Carolina	89	84	6	0	0	0	0	0	0	0	0	26
Tennessee	100	100	35	0	0	0	0	0	0	0	14	100
Texas	3	0	0	0	0	0	0	0	0	0	1	1
Virginia	100	100	8	0	0	0	0	0	0	0	0	100

Table 17.7—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone B

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	0	93	100	21	0	0	0
Arkansas	0	0	0	0	0	10	100	100	50	0	0	0
Florida	0	0	0	0	0	0	3	11	12	0	0	0
Georgia	0	0	0	0	0	30	83	65	77	1	0	0
Kentucky	0	0	0	0	0	30	66	0	30	0	0	0
Louisiana	0	0	0	0	0	0	45	55	0	0	0	0
Mississippi	0	0	0	0	0	2	91	90	0	0	0	0
North Carolina	0	0	0	0	0	0	64	41	8	0	0	0
Oklahoma	0	0	0	8	14	36	100	100	87	55	0	0
South Carolina	0	0	0	0	0	18	68	45	58	0	0	0
Tennessee	0	0	0	0	0	0	59	34	3	0	0	0
Texas	0	0	40	59	85	50	97	100	63	78	11	0
Virginia	0	0	0	0	0	3	76	32	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	94	45	0	6	0	0	0	0	0	0	100
Arkansas	76	46	0	8	0	0	0	0	0	0	25	61
Florida	16	1	0	0	14	57	33	42	4	0	0	32
Georgia	71	42	19	4	4	0	0	0	0	0	2	100
Kentucky	100	100	16	43	0	0	0	0	0	0	0	100
Louisiana	43	89	0	0	21	17	12	0	22	0	11	93
Mississippi	100	100	24	4	15	0	0	0	0	0	0	100
North Carolina	100	71	59	10	7	0	0	0	0	3	6	100
Oklahoma	0	0	0	0	0	0	0	0	0	0	0	0
South Carolina	76	32	13	0	0	0	0	0	0	0	0	100
Tennessee	100	100	74	43	0	0	0	0	0	0	0	100
Texas	0	5	0	0	0	7	0	0	3	0	12	2
Virginia	100	100	66	6	0	0	0	0	0	0	2	100

Table 17.8—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone C

Percent area in driest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	0	0	0	0	65	75	17	89	9	0	0	0
Arkansas	0	0	0	0	12	100	100	100	12	0	0	0
Florida	0	0	0	23	67	0	0	0	0	0	0	0
Georgia	0	0	0	0	73	52	28	60	41	0	0	0
Kentucky	0	0	0	0	0	38	38	100	0	0	0	0
Louisiana	0	0	0	0	0	48	54	61	17	0	0	0
Mississippi	0	0	0	0	36	87	73	92	28	0	0	0
North Carolina	0	0	0	0	0	1	31	30	0	0	0	0
Oklahoma	0	0	0	27	78	100	100	100	78	23	0	0
South Carolina	0	0	0	0	19	13	27	32	0	0	0	0
Tennessee	0	0	0	0	0	61	42	98	0	0	0	0
Texas	0	0	37	71	64	94	99	100	75	37	12	0
Virginia	0	0	0	0	0	9	64	76	0	0	0	0

Percent area in wettest class												
State	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Alabama	100	100	100	15	0	0	0	0	0	0	15	100
Arkansas	21	82	27	0	0	0	0	0	0	0	65	99
Florida	27	8	21	0	0	12	0	25	4	0	0	25
Georgia	97	46	60	6	0	0	0	0	0	0	8	88
Kentucky	100	100	96	5	0	0	0	0	0	0	72	100
Louisiana	96	75	40	0	0	0	0	0	0	0	0	100
Mississippi	100	100	100	18	0	0	0	0	0	0	32	100
North Carolina	100	79	99	9	0	0	0	0	3	4	13	100
Oklahoma	0	0	0	0	0	0	0	0	0	0	0	3
South Carolina	100	29	68	0	0	0	0	0	0	0	4	96
Tennessee	100	100	100	35	0	0	0	0	0	0	91	100
Texas	4	0	0	0	0	0	0	0	1	0	0	11
Virginia	100	100	60	0	0	0	0	0	0	0	3	100

Table 17.9—Percent of area in dry and wet classes for future conditions (2060) by State and month for Cornerstone D

Percent area in driest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	0	0	0	0	0	91	83	94	3	0	0	0
Arkansas	0	0	0	0	0	100	100	100	100	0	0	0
Florida	0	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	6	63	56	61	2	0	0	0
Kentucky	0	0	0	0	0	85	82	100	34	0	0	0
Louisiana	0	0	0	0	0	91	78	88	54	0	0	0
Mississippi	0	0	0	0	0	99	94	96	73	0	0	0
North Carolina	0	0	0	0	0	53	15	14	0	0	0	0
Oklahoma	0	0	0	36	11	100	100	100	100	44	0	0
South Carolina	0	0	0	0	0	37	33	29	0	0	0	0
Tennessee	0	0	0	0	0	83	81	98	42	0	0	0
Texas	0	0	25	75	55	97	100	100	98	76	17	0
Virginia	0	0	0	0	0	77	44	47	0	0	0	0
Percent area in wettest class												
State	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alabama	100	100	100	0	0	0	0	0	0	0	22	100
Arkansas	51	74	99	0	0	0	0	0	0	0	82	100
Florida	23	39	25	0	4	20	1	39	6	0	0	22
Georgia	91	100	89	1	1	0	0	0	0	0	11	74
Kentucky	100	100	100	38	0	0	0	0	0	0	50	100
Louisiana	100	100	85	0	0	0	0	0	0	0	49	100
Mississippi	100	100	100	0	0	0	0	0	0	0	58	100
North Carolina	100	100	100	8	3	0	0	0	0	1	13	100
Oklahoma	0	3	8	0	0	0	0	0	0	0	8	6
South Carolina	100	100	100	0	0	0	0	0	0	0	6	57
Tennessee	100	100	100	2	0	0	0	0	0	0	91	100
Texas	3	8	3	0	0	0	0	0	0	0	3	9
Virginia	100	100	100	2	0	0	0	0	0	0	2	100

closely tied to social issues than to climate. As the population in the South continues to increase and the wildland-urban interface continues to expand, ignitions caused by human carelessness are likely to increase, creating wildfire conditions that quickly exceed local suppression capabilities.

Future of Prescribed Fire

Prescribed fire is an important tool used in the South to manage hazardous fuels. The potential for an extended wildfire season will magnify the importance of effective fuels management. However, the same drying that is extending the wildfire season could also limit the ability to use prescribed fire as the dry conditions will likely increase the potential for escaped fires and also increase the potential for the fires to harm resources. Dry conditions will promote increased fuel consumption and consequently increased emissions. With air quality standards continually being tightened, these added emissions could result in further constraints on prescribed fire usage to help protect the health of the growing population. Air quality issues could have the largest impact on prescribed fire, as air quality restrictions would restrict burning over large areas, not just within the wildland-urban interface.

The rapid expansion of the U.S. population since World War II into formerly rural areas has caused significant shifts in land use and land cover. Natural resource managers must cope with constraints on traditional tools as well as a new class of resource and societal problems in the interface zone where urban and wildland uses must coexist. A history of extensive clearing, farming, or grazing has left many legacies, including an extensive road system (fig. 17.12). Population growth since the middle of the last century has caused increasing urbanization and fragmentation of the forested landscape (Stanturf and Wimberly, in press; Wear 2002), increasing the size and importance of the wildland-urban interface. More people now live at the interface and the transportation system is expanding, becoming denser and more pervasive (Riitters and Wickham 2003).

Aside from the physical aspects of urbanization, changing demographic profiles and cultural values (Cordell and others 2004) have altered attitudes towards natural resource management in general (Bliss and others 1997, Hull and Stewart 2002, Jacobson and others 2001) and prescribed burning in particular (Duryea and Hermansen 2002, Loomis and others 2001). More than 50,000 U.S. communities on the wildland-urban interface have been designated as "at risk" for fire, and most of them (70 percent) are in the Southern States (Blue Ribbon Panel 2008). The values at risk are substantial: recent wildfire seasons have been expensive with suppression costs in 2002 at $1.5 billion nationwide (National Interagency Fire Center 2001) and damage estimates from the 1998 wildfires in Florida alone costing close to $800 million (Butry and others 2001).

The growing wildland-urban interface increases both the risk of wildfire occurring and the cost of wildfire by placing higher values at risk than in wildland areas. Use of prescribed burning in the wildland-urban interface is still practical but requires more planning and preparedness, safe conduct, and communication with landowners and local officials (Miller and Wade 2003, Wade and Mobley 2007). In addition to the increased complexity of fire management, State agencies are faced with a dwindling workforce as the number of firefighters dropped by 24 percent between 2004 and 2010.[2] Declining budgets impact more than just staffing as agencies incur increased costs for training their staff and cooperators to work in the interface (State of Georgia 2010). High rates of arson in some states add to the fire risk (USDA Forest Service 2011).

[2]Personal communication with David Frederick, Fire Director, Southern Group of State Foresters, P.O. Box 680235, Prattville, AL 36068-0235. Feb. 2011.

(A) (B)

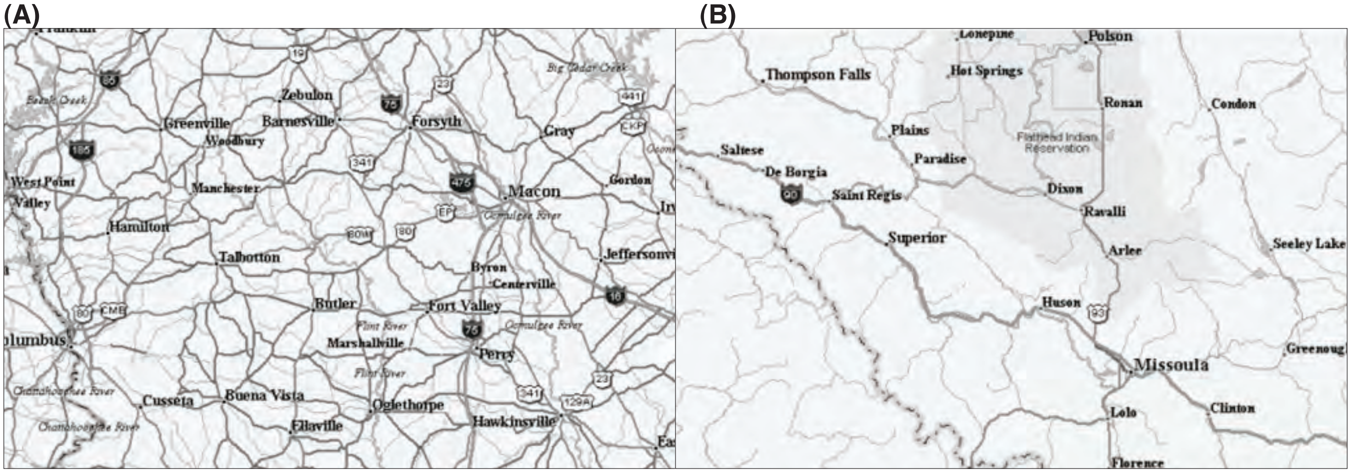


Figure 17.12—Legacy of roads in the South as compared to the West: (A) roads in an approximately 26,000 km^2 area of southwestern Georgia, the Flint River Valley, compared to (B) a similar area of the Bitterroot Valley in Montana. (Source: Stanturf and Wimberly, in press)

The South exemplifies the problems of mixing urbanized land uses with fire-adapted natural vegetation. Urbanization constrains traditional forest management and use of prescribed burning even at the wildland end of the urban-wildland gradient because of concerns for liability from escaped prescribed fire, transportation safety, and regional air quality. Moving toward the urban end of the gradient, these concerns greatly increase often resulting in abandonment of fuel management and increased risk of occurrence and severity of inevitable wildfire. Because of an extensive road system, the entire South may be regarded as a wildland-urban interface, at least in terms of managing smoke from prescribed burning.

Even when continued forest management is feasible, there will likely be further constraints on use of prescribed burning in the wildland-urban interface due to smoke. Smoke from prescribed burning is a critical issue in the South due to a combination of physical (meteorology, climate, topography), biological (fire-affected vegetation and hazardous fuels), and social (population density, road network) factors. In fact, smoke is probably the key issue in suitability of prescribed burning as a way to manage fuel loads in the interface. Concerns with smoke are several: local and regional air quality (Achtemeier 2003, Achtemeier and others 2001, Monroe 2002), visibility on roads (Mobley 1989), and health impacts especially on sensitive segments of the population with respiratory problems (Sorenson and others 1999).

Threat of escapes—Potential liability from escaped prescribed fire is often cited as a constraint on the use of prescribed burning (Brenner and Wade 2003, Haines and Busby 2001, Haines and Cleaves 1999). Even when the best available practices are applied, the possibility of an escape exists. Potential damage to neighboring properties, endangerment of human lives, and smoke-caused transportation accidents pose liability risk, along with litigation costs (Sun 2006).

Following the lead of Florida, all Southern States except Tennessee have revised their liability laws to limit liability unless negligence is involved (Brenner and Wade 2003, Sun 2006); some differentiate between simple and gross negligence. In the 10 States with simple negligence rules (Alabama, Arkansas, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Texas, and Virginia), a landowner who does not exercise the care that would be exercised by a "reasonable prudent person" could be held liable for damage from an escaped prescribed fire. In Florida and Georgia, where the gross negligence rule holds, the burden on the landowner or agent is even lower (Sun 2006). Thus State legislatures in the South offer legal protection for managers who use prescribed burning, provided they follow relevant laws and regulations, and exercise care in planning and execution.

Smoke—Smoke is produced when wood and other organic material combusts (Urbanski and others 2009) and produces a mixture of gases, solid particles, and droplets. Because wood fires are generally inefficient, they produce a large number of chemicals. Emissions from wildland fire are usually expressed as emission factors, defined as the mass of compound released per mass of dry fuel consumed (Urbanski and others 2009). Emission factors are influenced by fuel moisture and whether combustion is smoldering or flaming (Naeher and others 2007). In the South, the preferred time for prescribed burning is when fuel moisture is high and meteorological conditions favor low-intensity fires with lower fuel consumption as compared to wildfires that typically occur under drier conditions that favor high-intensity fires with more complete fuel consumption. Prescribed burning generally results in lower emissions than wildfire (Urbanski and others 2009). Typical emission factors from prescribed burns in a variety of southern forest ecosystems are given in table 17.10; the dominant compounds emitted are carbon dioxide, carbon monoxide, and particulates (Urbanski and others 2009).

Smoke is a problem when it in some way negatively impacts human habitation or activity (Achtemeier and others 2001). Smoke is a health problem when it invades the habitation of those with respiratory problems and other smoke-sensitive illnesses (Naeher and others 2007). Smoke is a nuisance when it irritates the eyes and mucus membranes of the nose and throat. Smoke is a nuisance when it deposits soot on clothes hung out to dry. Smoke is a safety problem when it impedes local visibility to create hazards to drivers of motor vehicles. The enormous wildland—urban interface and dense road network located in a region where up to six million acres of forest land per year are subject to prescribed fire combine to make problem smoke the foremost forestry-related air quality problem in the South. During the daytime, smoke becomes a problem when it drifts into areas of human habitation. At night, smoke can become entrapped near the ground and, in combination with fog, create visibility reductions that cause roadway accidents. Public complaints about smoke-related problems usually begin at levels well below national ambient air quality standards.

Air quality—One of the key indicators of air quality is whether monitoring shows that an area complies with the national air quality standards established by the Environmental Protection Agency (EPA). Although EPA does not directly regulate the use of wildland fire, it is responsible for enforcing the sections of the Clean Air Act that requires States and Tribes to attain and maintain the national ambient air quality standards (NAAQS). The EPA also must develop "primary" and "secondary" standards

Table 17.10—Modeled ranges of emission factors (g kg-1) for prescribed burning in several southern forest ecosystems (developed for illustrative purposes and not intended to be definitive because numbers of fires in each ecosystem varied and were conducted under varying conditions); these are fire-weighted average factors comparing compound emitted to dry fuel consumed

Vegetation type	MCE[a]	CO_2	CO	CH_4	C_2H_6	C_2H_4	C_2H_2	C_3H_8	C_3H_6	C_3H_4	$PM_{2.5}$
Longleaf pine, palmetto	0.934-0.952	1681-1712	55.3-75.2	1.26-1.45	0.13-0.18	0.94-1.34	0.40-0.74	.01	0.35-0.37	0.00-0.09	10.0-11.3
Sandhills longleaf pine	0.918	1653	94.0	3.39	0.39	0.95	0.30	0.11	0.50	0.05	11.5
Loblolly pine, wiregrass	0.928-0.942	1657-1687	66.5-81.5	1.78-2.31	0.26-0.28	1.19-1.27	0.33-0.42	0.10-0.11	0.45-0.46	0.05-0.07	13.2-15.6
Mixed pine, wax myrtle	0.904	1621	109.4	3.00	0.23	0.83	0.28	0.06	0.38	0.04	10.4
Oak, pine, grass	0.921-0.942	1647-1688	65.9-90.2	1.75-2.26	0.21-0.28	0.97-1.17	0.28-0.36	0.08-0.10	0.40-0.49	0.05-0.06	14.1-14.5
Mixed pine, wiregrass	0.936	1682	73.1	1.99	0.22	0.86	0.23	0.09	0.37	0.09	11.4
Sandhill shrub	0.921	1652	89.7	2.62	0.32	1.01	0.23	0.11	0.47	0.03	11.9
Palmetto, turkey oak	0.938	16.95	71.1	1.65	0.18	1.13	0.49	0.02	0.31	0.05	6.9
Palmetto	0.933	1665	76.4	2.13	0.23	1.12	0.35	0.08	0.45	0.05	15.7
Pocosin	0.935-0.943	1683	64.2-76.4	1.84-2.13	0.23	1.12-1.35	0.36	0.08-0.11	0.46	0.06	15.7-16.7
Sawgrass	0.914-0.97	1635-1752	34.7-98.3	0.90-4.12	0.07-0.59	0.52-1.60	0.21-0.49	0.02-0.23	0.10-0.79	0.02-0.08	9.9-9.1
Wiregrass	0.912-0.936	1626-1681	73.5-99.5	2.16-3.34	0.21-0.44	1.15-1.42	0.25-0.64	0.06-0.20	0.42-0.64	0.05-0.07	9.7-15.3

[a]MCE is modified combustion efficiency, calculated as the $\Delta CO_2/(\Delta CO+\Delta CO_2)$.
Source: Adapted from Urbanski and others 2009.

for six pollutants: ozone, particulate matter, sulfur dioxide, carbon monoxide, nitrogen dioxide and lead (table 17.11). Primary standards are for human health and secondary standards for public welfare, which includes damage to vegetation and crops as well as effects on visibility. Of these six pollutants, only two—sulfur dioxide and lead—are of little concern for prescribed burning. As a result of rapid dilution and its instability, carbon monoxide emissions from prescribed burning are not a concern to the general public (National Coalition of Prescribed Fire Councils 2007). However, carbon monoxide emissions may be a concern to firefighters and prescribed burning crews.

Although nitrogen oxides from prescribed burning are not of concern on a local level (National Coalition of Prescribed Fire Councils 2007), they combine with other emissions (volatile organic carbon, particulates, and carbon monoxide) in a photochemical process (Urbanski and others 2009) and contribute to ozone formation that may be a concern in some areas (National Coalition of Prescribed Fire Councils 2007). Figure 17.13 shows the current status of non-attainment areas in the South for ozone and highlights the relationship of urban areas to non-attainment status. Ozone and particulate levels are generally at their lowest ambient levels during the prescribed burning season in the South, winter and early spring (Southeast Regional Partnership for Planning and Sustainability 2010). But occasionally summer burns are recommended for ecological reasons (Brockway and others 2005), a practice that would be limited in an area designated as non-attainment for ozone and particulates.

After carbon dioxide and carbon monoxide, particulates account for the greatest share of emissions from wildland burning (Urbanski and others 2009) and because particulates are a criteria pollutant, currently they are the greatest concern from prescribed burning. Wood smoke particulates are relatively small but their size distribution can vary greatly, depending on the rate of energy release.

Because of their size (generally, 70 percent are smaller than 2.5 microns in aerodynamic diameter or PM2.5), wood smoke particulates scatter light and reduce visibility (National Coalition of Prescribed Fire Councils 2007). Standards for particulate matter have been on a trend of increasing stringency since 1971 (Southeast Regional Partnership for Planning and Sustainability 2011)—with current thresholds of 35 $\mu g\ m^{-3}$ averaged for any 24 hour-period and 15 $\mu g\ m^{-3}$ averaged over a full year—and there is little evidence to suggest that standards will loosen in future reviews. Recent annual and 24-hour ambient PM2.5

Table 17.11—Current and proposed National Ambient Air Quality Standards

	National Ambient Air Quality Standards	
Pollutant	**Level**	**Averaging time**
Carbon monoxide (CO)	9 ppm (10 mg m^{-3}) 35 ppm (40 mg m^{-3})	8-hour 1-hour
Lead (Pb)	0.15 µg m^{-3}	Rolling 3-month average
Nitrogen dioxide (NO_2)	0.053 ppm (100 µg m^{-3}) 0.10 ppm	Annual (arithmetic mean) 1-hour
Particulate matter (PM_{10})	150 µg m^{-3}	24-hour
Particulate matter ($PM_{2.5}$)	15.0 µg m^{-3} 35 µg m^{-3}	Annual 24-hour
Ozone (O_3)	0.075 ppm (2008 standard) 0.08 ppm (1997 standard) 0.060-0.070 ppm	8-hour 8-hour 8-hour (proposed January 2010)
Sulfur dioxide (SO_2)	0.03 ppm 0.14 ppm 0.5 ppm 0.050 to 0.100 ppm	Annual (arithmetic mean) 24-hour 3-hour 1-hour (proposed December 2009)

Source: Southeast Regional Partnership for Planning and Sustainability 2011.

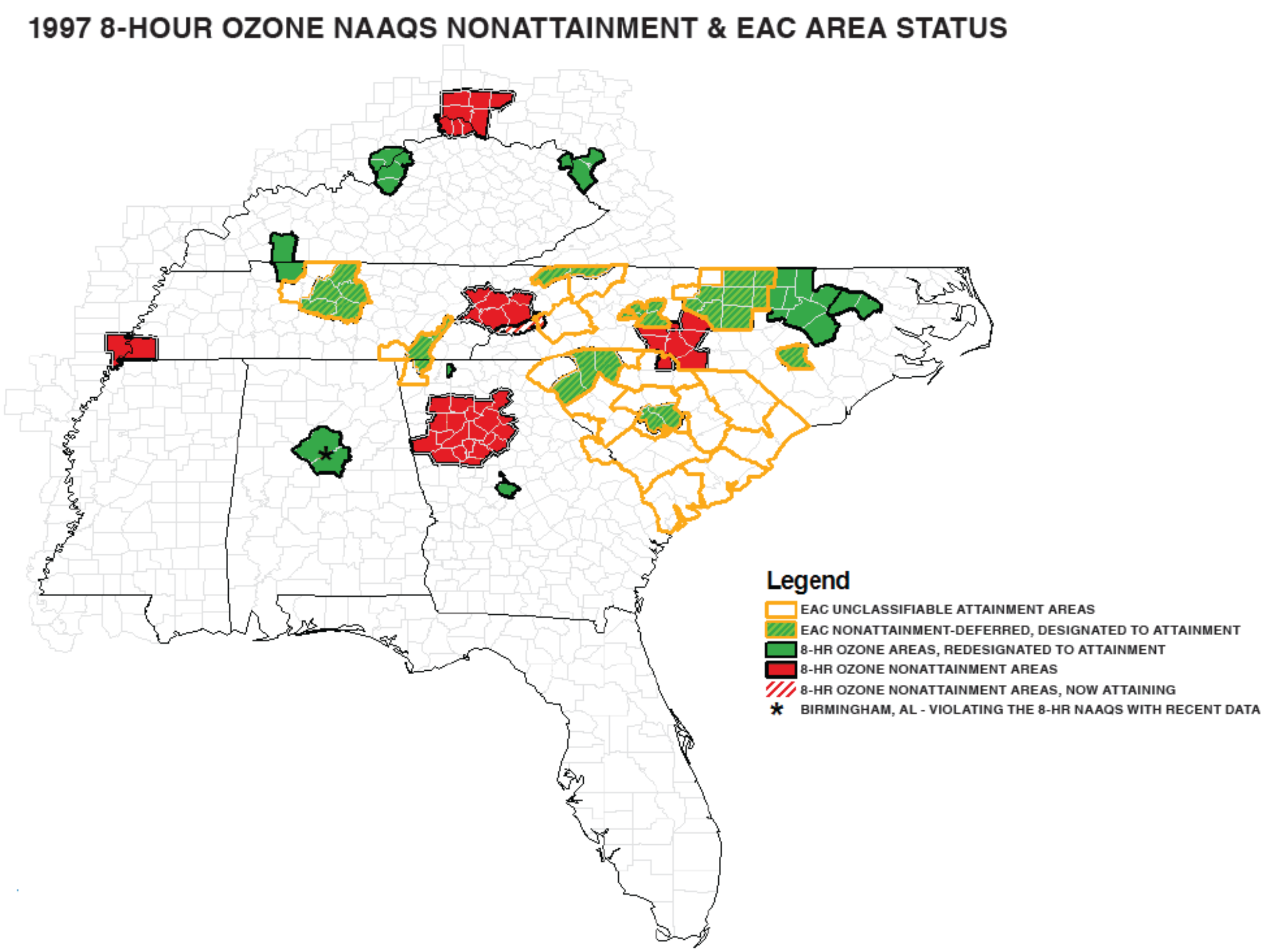


Figure 17.13—Eight-hour ozone non-attainment areas, 2008, in Environment Protection Agency Region 4. (Source: Jane Spann, map created by Nacosta C. Ward; http://www.epa.gov/region04/production/air/modeling/2009%20Workshop/March-19-09/JaneSpan%20Presentation%20wo%20talking%20pts19_4.ppt)

levels for the States east of the Mississippi River and south of Virginia (EPA Region 4) are displayed in figures 17.14 and 17.15. Although current levels for most of the Coastal Plain are below national standards (both the current standards and those being evaluated), the same cannot be said for areas in the Piedmont and Southern Appalachian Mountains.

EPA also monitors visibility in Federal Class I areas (Fox and others, in press), which consist of all international parks, national wilderness areas larger than 5,000 acres, national memorial parks larger than 5,000 acres, and national parks larger than 6,000 acres that were established before 1977. EPA's 1999 Regional Haze Rule (64 FR 35714) provides specific guidance on wildland fire for many Western States but takes a more general approach for the rest of the country (National Coalition of Prescribed Fire Councils 2007), requiring that all States with Class I areas consider the impacts of prescribed burning on visibility. Five Regional Planning Organizations were established to help States develop visibility protection programs; the Central Regional Air Planning Association serves Oklahoma, Texas, Arkansas, and Louisiana and the Visibility Improvement State and Tribal Association of the Southeast for all other Southern States. Their goal for each Class I area is to improve the 20 percent haziest days and ensure that no degradation occurs on the cleanest days.

The Regional Haze Rule requires all States and participating Tribes to develop State Implementation Plans for reducing emissions of visibility degrading aerosols, relative to "natural background conditions." Natural background haze is a complex concept that reflects contemporary, not pre-European settlement conditions (Fox and others, in press). One central issue is whether wildland fire is natural or anthropogenic. The policy developed for the Western States is that any wildfire or any fire being managed to the natural fire frequency is classified as natural; any fire ignited or managed to restore the natural fire frequency is anthropogenic (National Coalition of Prescribed Fire Councils 2007). This policy, which has not been applied beyond the West, would have serious implications for the South, especially in the mountains where prescribed burning for restoration objectives is increasing.

Transportation safety—The extensive transportation system in the South presents a formidable challenge to prescribed burners. Although most burns are carried out without incident, smoke and smoke/fog visibility obstructions on southern highways cause numerous accidents with loss of life and personal injuries. Mobley (1989) reported 28 fatalities, more than 60 serious injuries, numerous minor injuries, and millions of dollars in lawsuits from 1979 to 1988. Comparing three years of accident reports in Florida, Lavdas and Achtemeier (1995) found accidents are more closely associated with local ground radiation fogs (cooling of land after sunset) than with widespread advection fogs (formed when moist air passes over a cool surface) and that most serious accidents occur at night or near sunrise when smoke from smoldering fires is entrapped near the ground and carried by local drainage winds into shallow basins. Near sunset, under clear skies and near calm winds, temperatures in shallow stream basins can drop up to 20 °F in an hour (Achtemeier 1993) and strong, shallow valley inversions can develop. Weak nighttime drainage winds of approximately 1 mile per hour (0.5 m sec^{-1}) can carry smoke more than 10 miles, far enough to carry smoke/fog over a roadway in many areas. An example is the smoke from wildfires in 2000 that drifted across Interstate 10 and caused at least 10 fatalities, five in Florida and five in Mississippi.

Achtemeier (2006, 2008, 2009) demonstrated that under certain conditions, fog combined with smoke from prescribed burning can produce a "superfog" that reduces visibility to less than 10 feet (3 m, the definition of zero visibility). Motorists have no defense when driving from unlimited visibility to zero visibility in a manner of seconds. Because most prescribed burns take place in the winter when dry surface fuels overlay wet fuels, they often provide considerable moisture release both from the combustion and from heated soil and underlying wet fuels that do not ignite. At night, moisture from residual smoke can increase ambient relative humidity to 100 percent and contribute to the formation of superfog (Achtemeier 2009). Because we are just beginning to recognize the conditions for superfog formation, the full significance of this extremely hazardous phenomenon is yet to be realized or mitigated by the public safety community.

Human health—The greatest health threat from wood smoke appears to come from fine particles although a number of other constituents have health effects (Naeher and others 2007). Fine particles in wood smoke (less than 100 µg m^3) that penetrate far into lung tissue have toxic effects (Naeher and others 2007). Because ultra-fine particles (PM2.5) can be transported long distances from the combustion site and may form later through condensation and atmospheric chemical reactions, they can pose a health hazard to vulnerable populations at considerable distance from a prescribed burn. According to the World Health Organization, vulnerable groups are the very young, pregnant women, the elderly, and individuals with pre-existing respiratory (asthma, chronic obstructive pulmonary diseases) and cardiac diseases (Schwela and others 1999).

Other groups may be more susceptible due to higher exposures: outdoor workers, firefighters and emergency response workers ("Guidelines on vegetation fire emergencies for public health protection" also contains a review of studies linking health effects to biomass burning. Available online at http://www.who.int/docstore/

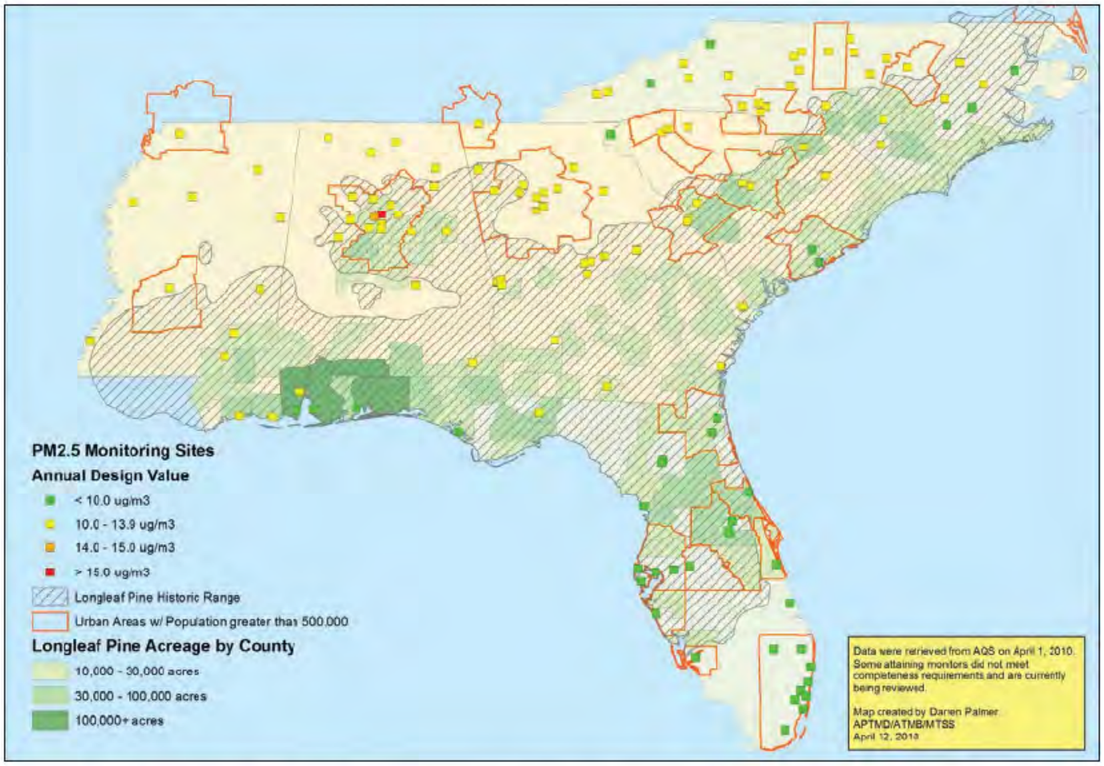


Figure 17.14—Annual average ambient air concentrations at particulate-matter (PM2.5) monitoring sites, 2007 to 2009, for States participating in the Southeast Regional Partnership for Planning and Sustainability; concentrations calculated according to the Clean Air Act regulations for comparison to the National Ambient Air Quality Standards. (Source: Southeast Regional Partnership for Planning and Sustainability 2010; map created by Darren Palmer)

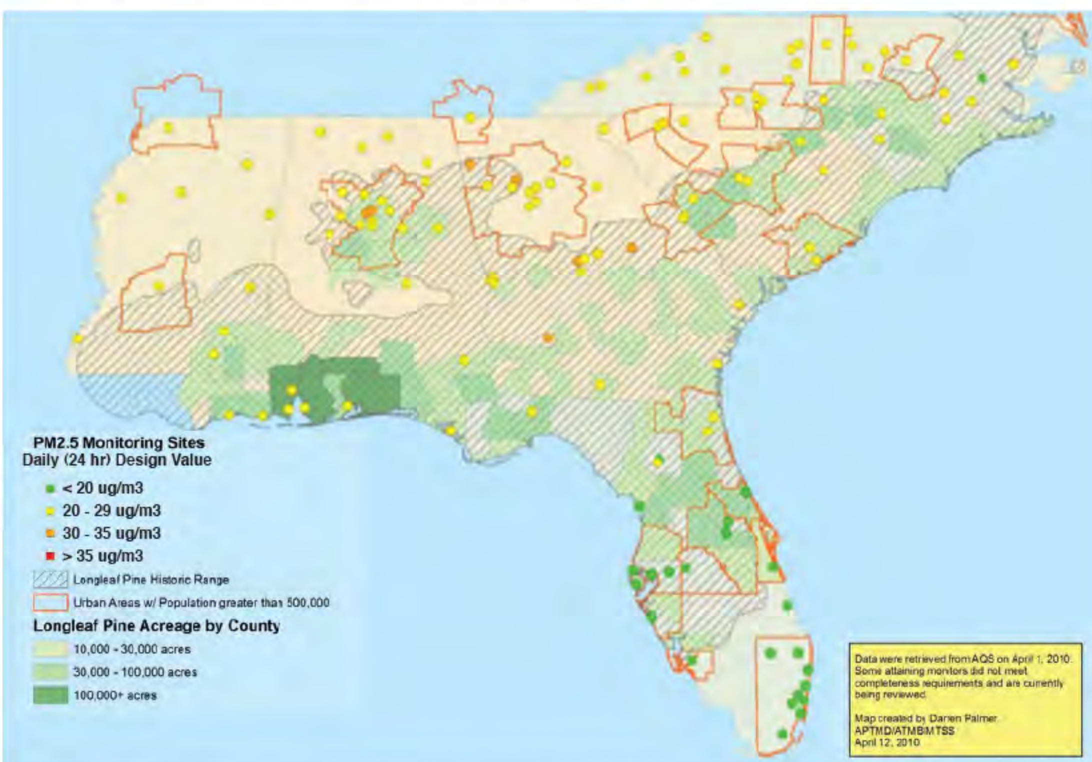


Figure 17.15—Twenty-four-hour average ambient air concentrations at particulate-matter (PM2.5) monitoring sites, 2007 to 2009, for States participating in the Southeast Regional Partnership for Planning and Sustainability; concentrations calculated according to the Clean Air Act regulations for comparison to the National Ambient Air Quality Standards. (Source: Southeast Regional Partnership for Planning and Sustainability 2010; map created by Darren Palmer)

peh/Vegetation_fires/Health_Guidelines_final_3.pdf , last accessed on 9 December 2010). Recent studies have shown that wildfires and prescribed burns expose fire personnel to smoke levels high enough to present potential occupational health concerns (Carlton and others 2004, Naeher and others 2007, Yanosky 2001). Naeher and others (2006) also found that current exposure standards for dust inhalation, although not intended to apply to wildland fire personnel, would be inadequate if applied to protect fire personnel from harmful particulate exposures.

A number of other wood smoke constituents have health effects (Naeher and others 2007). Although carbon monoxide's instability and rapid dilution preclude any threats to the general public (National Coalition of Prescribed Fire Councils 2007), carbon monoxide emissions may be a concern to firefighters and persons on prescribed burning crews. At least five chemical groups with known carcinogenic properties are present in wood smoke along with 26 chemicals considered hazardous air pollutants by EPA (Naeher and others 2007). Currently EPA is focusing on acetaldehyde, acrolein, 1,3 butadiene, formaldehyde, and polycyclic organic matter (Southeast Regional Partnership for Planning and Sustainability 2010). Naeher and others (2007) found that even limited exposure to wood smoke can reduce resistance against infections, that most effects are associated with the particle phase, and that an associations exists between wildfires and increased emergency room visits for upper and lower respiratory illnesses and decreased lung functioning (Naeher and others 2007).

Alternatives to Prescribed Burning

Various mechanical and chemical alternatives to prescribed burning are used or have been proposed and recent reviews provide details (Guldin 2010, Marshall and others 2008, Mercer and Prestemon 2008, O'Brien and others 2010, Outcalt 2009, Reilly and others 2009, Schwilk and others 2009). Equipment such as mowers, mulchers and choppers are used to cut, chop, or sever mostly midstory and understory fuel layers (Outcalt 2009). This equipment is most effective where large stems are widely spaced and is often used in areas with high fuel loads. Mechanical methods change fuel configurations but do not remove fuels from the site and may not completely mitigate the wildfire threat. Most often they are used as a pre-treatment prior to prescribed burning. Although slope limitations have traditionally hindered usage of mechanical methods in the mountains, increasingly smaller crawler units are now available for steep slopes (Reilly and others 2009). Harvesting with mechanized equipment is a normal forestry operation and clear-cutting or thinning for fuels management or restoration is increasingly utilized especially in pine types (Guldin 2010, Outcalt 2009). Harvesting to remove unwanted species or to reduce stem density is often followed by prescribed burning to maintain stand structure and composition.

Herbicides that target broadleaved trees have been a standard treatment in pine plantation management for more than 30 years. Managers also use herbicides for fuel reduction (Outcalt 2009). Similar to mechanical fuel reduction methods, herbicides are often the precursor to prescribed burning in stands with dense shrub-layer vegetation. Herbicide application followed by burning can be more effective than burning alone (Outcalt 2009).

Prescribed burning remains the most widely used fuel treatment in the South although significant acres are treated with mechanical means, mostly on Federal lands in the wildland-urban interface zone (Outcalt 2009). Each method has benefits and drawbacks (table 17.12) with prescribed burning often costing the least and providing the most ecosystem benefits (Glitzenstein and others 2003, Kirkman and others 2004a, b).

Carbon and Climate

Wildfire can affect climate through emitting carbon dioxide and aerosol particles into the atmosphere (National Academy of Sciences 2010). The greenhouse gas effect is one of the major contributors for climate change at long-term (decade and century) scale. Greenhouse gases in the atmosphere can absorb long-wave radiation emitted from the ground, which prevents heat energy from radiating into space. As a result, the temperature of the earth-atmosphere system increases. A number of atmospheric general circulation models have projected that greenhouse gases will increase global temperature by 4 to 6 °C by the end of this century, accompanied by significant changes in precipitation. It is estimated that average annual global fire carbon emissions were about 2 Pg (petagrams) in the recent decade, about a third of all carbon emissions. This indicates that wildfire emission is one of the major sources of atmospheric carbon dioxide and therefore an important contributor to future climate change, even though they comprised only 4 to 6 percent of anthropogenic emissions in the United States (Wiedinmyer and Neff 2007).

Charlson and others (1992) showed that smoke from wildfires can affect global climate by scattering and absorbing short-wave (solar) radiation (direct radiative forcing) and modifying cloud microphysics (indirect radiative forcing). These processes can further modify clouds and precipitation and atmospheric circulation (Ackerman and others 2000, Liu 2005a). In contrast, smoke aerosols (including black carbon or soot) have a shorter life span, but greater spatial variability and the potential for long-range transport (Kopp and Mauzerall 2010). Thus, they mainly affect short-term (daily, monthly, or seasonal) regional climate variability.

For example, figure 17.16 shows the role of the smoke aerosols from the Yellowstone National Park wildfires in the development of the 1988 drought in the Northern United States (Liu 2005b). The precipitation change in response to radiative forcing of smoke aerosols was mostly negative in the Northwest, with the largest negative response of about -30 mm found in the northeastern portion of the Midwest. This was accompanied by positive responses in the Southwest, Northeast, and southeastern portion of the Midwest; and negative response in the South. This simulated pattern was similar to the observed pattern of precipitation anomalies, suggesting that the smoke particles from the wildfire might have exacerbated the drought.

Although much about the interaction between wildfire and climate has yet to be understood and great uncertainty surrounds U.S. policy and regulatory approaches, smoke from prescribed burning clearly will receive increased attention from the scientific and policy communities. Recent studies have called for a more complete accounting of fire in carbon budgets (Hurteau and others 2008) and have emphasized the need to consider black carbon in climate change projections (Kopp and Mauzerall 2010). If climate change increases the potential for wildfire and alters fire regimes (Running 2006), the ability of forests to sequester carbon as a mitigation strategy could be compromised; instead of a carbon sink, forests could become a carbon source. Although it is generally agreed that fuel management through prescribed burning emits less carbon into the atmosphere compared to more intense wildfires, only a few studies have quantified this comparison (Wiedinmyer and Hurteau 2010) or demonstrated how forest management techniques can significantly alter the emissions from prescribed burning (Tian and others 2008).

CONCLUSIONS AND DISCUSSION

The potential for an extended wildfire season magnifies the importance of effective fuels management. However, the same drying that is extending the wildfire season could also limit the ability to use prescribed fire because the dry conditions will likely increase the potential for escaped fires and harm to resources. Dry conditions promote increased fuel consumption and consequently increased emissions. If air quality standards continue to tighten, these added emissions could result in further constraints on use of prescribed fire to protect the health of the growing population. Air quality issues could have the largest impact on prescribed fire by restricting burning over large areas, not just within the wildland-urban interface.

Prescribed burning is an important forest management tool in the South, used to manage fuels and promote wildlife habitat. Because natural wildfires have been limited both by effective fire suppression to protect other resources and by forest fragmentation, prescribed burning plays a critical ecological role in restoring and maintaining the integrity of fire-dependent forest and grassland communities.

Nevertheless, the near-term future of prescribed burning in the South is problematic. Changing land use and demographics have increased the numbers of people and value of structures in close proximity to wildlands, the so-called wildland-urban interface. In this interface zone,

Table 17.12—Advantages, disadvantages, and costs of fuel treatment options in use in the South

Attributes	Treatment			
	Prescribed burn	Mechanical	Manual	Harvesting
Pros	Low cost	Facilitates burning	Selective	Selective
	Ecological benefits	Use in urban areas	Use in urban areas	Produces revenue
	Minimal soil disturbance			
Cons	Smoke	Can be costly	Can be costly	Fuel created
	Potential escapes	Fuel created	Fuel created	Potential site damage
	Resource damage	Equipment breakage		
		Potential site damage		
Cost (dollars per acre)	23 to 121[a]	120 to 350[b]		
		35 to 1000[c]		

[a]Cleaves and others 2000.
[b]Rummer and others 2002.
[c]Wolcott and others 2007.
Source: Outcalt 2009.

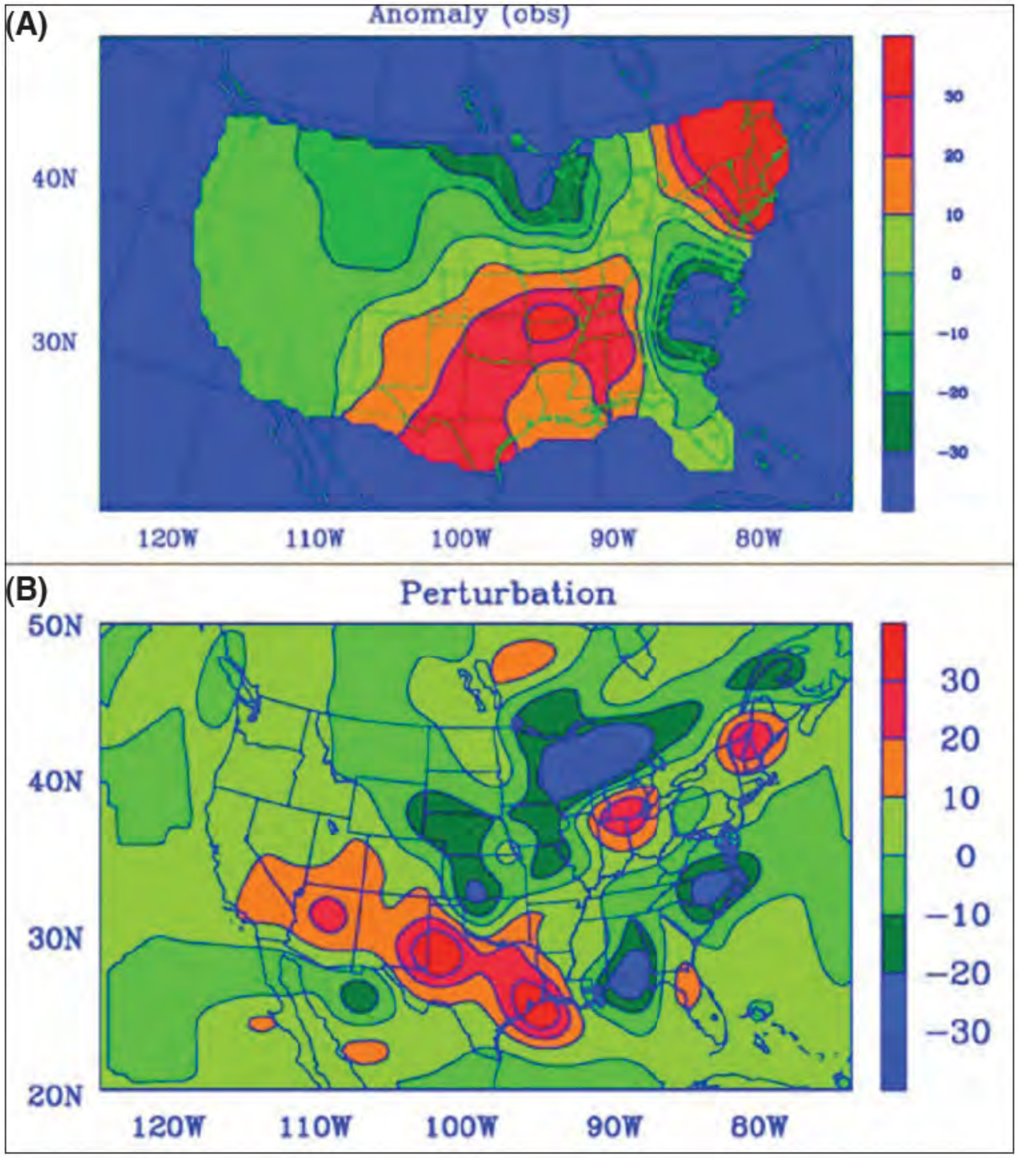


Figure 17.16—Following the Yellowstone National Park wildfires of July 1988, (A) observed U.S. precipitation anomalies and (B) differences in regional climate model simulations of U.S. precipitation with and without smoke particles. (Source: Liu 2005b)

prescribed burning requires greater skill and more attention to communication with the public, both of which increase costs (State of Georgia 2010). State legislatures have established limits on liability from responsibly conducted burns that escape, but laws can be changed. The greatest threat to continued use of prescribed burning comes from the effects of smoke on public health, transportation safety, and air quality; and from new regulations on carbon and greenhouse gas emissions to mitigate climate change. Air quality issues, including caps on carbon and greenhouse gas emissions, would have the greatest impact as they could restrict prescribed burning over large areas, not just the wildland-urban interface. Alternatives to prescribed burning are neither cost-effective nor do they provide the ecological benefits of fire in adapted ecosystems, (Glitzenstein and others 2003, Kirkman and others 2004a, 2004b) and do not achieve the same level of health and safety benefits to human communities.

Over the longer term and factoring in the effects of climate change, the need for prescribed burning will likely grow at the same time that obstacles, complexity and cost will increase. Restrictions on the use of prescribed burning to manage fuels would exacerbate potential climate change effects, particularly in the Coastal Plain and western Appalachian Mountains where wildfire potential is expected to increase. Fuels buildups combined with more intense wildfires under a changed climate potentially would have drastic consequences for fire-dependent communities that often support one or more threatened, endangered, or sensitive species. Drier conditions with more variability in precipitation could cause vegetation ranges to begin shifting, which could be initially resisted by active management, particularly in production conifer forests where reforestation through planting currently is the norm. Over longer time than the projections used here, the combination of climate change, extreme weather events, and severe wildfires could disrupt successful regeneration and result in new species assemblages, so-called novel ecosystems, with possibly novel fire regimes (Williams and Jackson 2007).

ACKNOWLEDGMENTS

The Atmospheric Science and Fire Science teams of the Center for Forest Disturbance Science (Gary Achtemeier, Yongqiang Liu, Tom Waldrop, and Joe O'Brien) contributed to this chapter both by contributing their knowledge and ideas. We would also like to thank three anonymous reviewers for their helpful comments and recommendations.

LITERATURE CITED

Achtemeier, G.L. 1993. Measurements of drainage winds along a small ridge. In: Proceedings of the 86th annual meeting of the air and waste management association. 93–FA–155.06. Pittsburgh, PA: Air and Waste Management Association. [Not paged].

Achtemeier G.L. 2003. On the origins of "superfog"—a combination of smoke and water vapor that produces zero visibility over roadways. In: Proceedings 2nd international wildland fire ecology and fire management congress and 5th symposium on fire and forest meteorology. J8.9. Boston: American Meteorological Society: 1–4.

Achtemeier, G.L. 2006. Measurements of moisture in smoldering smoke. International Journal of Wildland Fire. 15: 517–525.

Achtemeier, G.L. 2008. Effects of moisture released during forest burning on fog formation and implications for visibility. Journal of Applied Meteorology and Climatology. 47: 1287–1296.

Achtemeier, G.L. 2009. On the formation of superfog in woodland smoke. Meteorological Applications. 16: 215–225.

Achtemeier, G.L.; Jackson, B.; Brenner, J.D. 2001. Problem and nuisance smoke. In: Hardy, C.; Ottmar, R.D.; Peterson, J.L. [and others], eds. Smoke management guide for prescribed and wildland fire. National Wildfire Coordination Group, PMS 420–2 and NFES 1279. http://www.nwcg.gov/pms/pubs/SMG/SMG-72.pdf. [Date accessed: December 9, 2010].

Achtemeier, G.L.; Jackson, W.; Hawkins, B. [and others]. 1998. The smoke dilemma: a head-on collision. In: Transactions of the sixty-third North American wildlife and natural resources conference. Orlando, FL: Wildlife Management Institute: 415–421.

Ackerman, A.S.; Toon, O.B.; Stevens, D.E. [and others]. 2000. Reduction of tropical cloudiness by soot. Science. 288: 1042–1047.

Bliss, J.C.; Nepal, S.K.; Brooks, R.T.; Larsen, M.D. 1997. In the mainstream: environmental attitudes of mid-South landowners. Southern Journal of Applied Forestry. 21: 37–43.

Blue Ribbon Panel. 2008. National blue ribbon panel on wildland urban interface fire report. Washington, DC: International Code Council. 42 p. http://www.iccsafe.org/gr/WUIC/Documents/BlueRibbonReport-Hi.pdf. [Date accessed: December 8, 2010].

Brenner, J. 1991. Southern oscillation anomalies and their relationship to wildfire activity in Florida. International Journal of Wildland Fire. 1: 73–78.

Brenner, J.; Wade, D. 2003. Florida's revised prescribed fire law: protection for responsible burners. In: Galley, K.E.M.; Klinger, R.C.; Sugihara, N.G., eds. Proceedings of fire conference 2000: the first national congress on fire ecology, prevention, and management. Misc. Publ. 13. Tallahassee, FL: Tall Timbers Research Station: 132–136.

Brockway, D.G.; Outcalt, K.W.; Tomczak, D.; Johnson, E.E. 2005. Restoring longleaf pine forest ecosystems in the Southern United States. In: Stanturf, J.A.; Madsen, P., eds. Restoration of boreal and temperate forests. Boca Raton, FL: CRC Press: 501–519. Chapter 32.

Buckley, D.; Berry, J.K.; Spencer, T.; Carlton, D. 2006. Quantifying wildland fire risk in the South. 10 p. http://www.southernwildfirerisk.com/downloads_reports/Sanborn%20–%20Quantifying_Wildland_Fire_Risk_in_South.pdf. [Date accessed: January 4, 2011].

Burgan, R.E. 1988. 1988 revisions to the 1978 national fire danger rating system. Res. Pap. SE–273. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 39 p.

Butry, D.T.; Mercer, D.E.; Prestemon, J.P.; Pye, J.M. 2001. What is the price of catastrophic fire? Journal of Forestry. 99: 9–17.

Carlton, C.S. 2004. Personal PM2.5 exposures for firefighters doing prescribed forest burns in the Southeastern United States, 2004. Athens, GA: University of Georgia. 70 p. M.S. thesis.

Charlson, R.J.; Schwartz, S.E.; Hales, J.M. [and others]. 1992. Climate forcing by anthropogenic sulfate aerosols. Science. 255: 423–430.

Christopher, S.A.; Gupta, P.; Nair, U. [and others]. 2009. Satellite remote sensing and mesoscale modeling of the 2007 Georgia/Florida fires. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2: 163–175.

Cleaves, D.; Martinez, J.; Haines, T. 2000. Influences on prescribed burning activity and costs in the National Forest System. Gen. Tech. Rep. SRS–37. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 34 p.

Cordell, H.K.; Bergstrom, J.C.; Betz, C.J.; Green, G.T. 2004. Socioeconomic forces shaping the future of the United States. In: Manfredo, M.J.; Vaske, J.J.; Bruyere, B.L. [and others], eds. Society and natural resources: a summary of knowledge. Jefferson, MO: Modern Litho: 349-361. Dixon, P.G.; Goodrich, G.B.; Cooke, W.H. 2008. Using teleconnections to predict wildfires in Mississippi. Monthly Weather Review. 136: 2804–2811.

Dixon, P.G.; Goodrich, G.B.; Cooke, W.H. 2008. Using teleconnections to predict wildfires in Mississippi. Monthly Weather Review. 136: 2804-2811.

Duryea, M.L.; Hermansen, L.A. 2002. Challenges to forest resource management. In: Macie, E.A.; Hermansen, L.A., eds. Human influences on forest ecosystems—the Southern Wildland-Urban Interface Assessment. Gen. Tech. Rep. SRS–55. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 67-68.

Eagleman, J.R. 1967. Pan evaporation, potential and actual evapotranspiration. Journal of Applied Meteorology. 6: 482–488.

Fox, D.G.; Riebau, A.R.; Lahm, P. [In press]. A review of wildland fire and air quality management. In: Qu, J.J.; Riebau, A.; Yang, R.; Sommers, W., eds. Remote sensing and modeling applications to wildland fires. Dordrecht: Springer Publishing. Chapter 5.

Glitzenstein, J.S.; Streng, D.R.; Wade, D.D. 2003. Fire frequency effects on longleaf pine (*Pinus palustris* P. Mill.) vegetation in South Carolina and northeast Florida, USA. Natural Areas Journal. 23: 22–37.

Goodrick, S.L.; Hanley, D.E. 2009. Florida wildfire activity and atmospheric teleconnections. International Journal of Wildland Fire. 18: 476–482.

Gramley, M. 2005. Fire in the South: a report by the Southern Group of State Foresters. Winder, GA: Southern Group of State Foresters. http://216.226.177.78/PDFs/fire_in_the_south.pdf. [Date accessed: September 12, 2010].

Guldin, J.M. 2010. Fuels management in the subtropical division—mountains. In: Audin, L.J., ed. Draft cumulative watershed effects of fuels management in the Eastern United States. http://www.na.fs.fed.us/fire/cwe.shtm. [Date accessed: December 9, 2010].

Haines, T.K.; Busby, R.L. 2001. Prescribed burning in the South: trends, purpose, and barriers. Southern Journal Applied Forestry. 25: 149–153.

Haines, T.K.; Cleaves, D.A. 1999. The legal environment for forestry prescribed burning in the South: regulatory programs and voluntary guidelines. Southern Journal Applied Forestry. 23: 170–174.

Hull, R.B.; Stewart, S.I. 2002. Social consequences of change. In: Macie, E.A.; Hermansen, L.A., eds. Human influences on forest ecosystems—the Southern Wildland-Urban Interface Assessment. Gen. Tech. Rep. SRS–55. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 115–129.

Hurteau, M.D.; Koch, G.W.; Hungate, B.A. 2008. Carbon protection and fire risk reduction: toward a full accounting of forest carbon offsets. Frontiers in Ecology and the Environment. 6: 493–498.

Intergovernmental Panel on Climate Change. 2007. IPCC fourth assessment report: climate change 2007 (AR4). http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm. [Date accessed: July 7, 2010].

Jacobson, S.K.; Monroe, M.C.; Marynowski, S. 2001. Fire at the wildland interface: the influence of experience and mass media on public knowledge, attitudes, and behavioral intentions. Wildlife Society Bulletin. 29: 929–937.

Keetch, J.J.; Byram, G.M. 1968. A drought index for forest fire control. Res. Pap. SE–38. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 32 p.

Kirkman, L.K.; Coffey, K.L.; Mitchell, R.J.; Moser, E.B. 2004a. Ground cover recovery patterns and life history traits: implications for restoration obstacles and opportunities in a species-rich savanna. Journal of Ecology. 92: 409–421.

Kirkman, L.K.; Goebel, P.C.; Palik, B.J.; West, L.T. 2004b. Predicting plant species diversity in a longleaf pine landscape. Ecoscience. 11: 80–93.

Kopp, R.E.; Mauzerall, D.L. 2010. Assessing the climatic benefits of black carbon mitigation. Proceedings of the National Academy of Sciences. 107: 11,703–11,708.

Lafon, C.W. 2010. Fire in the American South: vegetation, impacts, history, and climatic relations. Geography Compass. 4/8: 919–944.

Lavdas, L.; Achtemeier, G.L. 1995. A fog and smoke risk index for estimating roadway visibility hazard. National Weather Digest. 20: 26–33.

Liu, Y.-Q. 2005a. Atmospheric response and feedback to smoke radiative forcing from wildland fires in tropical South America. Agricultural Forest Meteorology. 133: 40–53.

Liu, Y.-Q. 2005b. Enhancement of the 1988 Northern U.S. drought due to wildfires. Geophysical Research Letters. 32: 4.

Liu, Y.–Q.; Stanturf, J.; Goodrick, S. 2009. Trends in global wildfire potential in a changing climate. Forest Ecology and Management. 259: 685–697.

Loomis, J.B.; Bair, L.S.; González-Cabán, A. 2001. Prescribed fire and public support: knowledge gained, attitudes changed in Florida. Journal of Forestry. 99: 18–22.

Macie, E.A.; Hermansen, L.A., eds. 2002. Human influences on forest ecosystems—the Southern Wildland-Urban Interface Assessment. Gen. Tech. Rep. SRS–55. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 160 p.

Marshall, D.J.; Wimberly, M.; Bettinger, P.; Stanturf, J. 2008. Synthesis of knowledge of hazardous fuels management in loblolly pine forests. Gen. Tech. Rep. SRS–110. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 43 p.

Mercer, D.E.; Prestemon, J.P. 2008. Economic analysis of fuel treatments. In: Audin, L.J., ed. Draft cumulative watershed effects of fuels management in the Eastern United States. http://www.na.fs.fed.us/fire/cwe.shtm. [Date accessed: December 9, 2010].

Miller, S.R.; Wade, D. 2003. Re-introducing fire at the urban/wild-land interface: planning for success. Forestry. 76: 253–260.

Mobley, H.E. 1989. Summary of smoke-related accidents in the South from prescribed fire (1979-1988). Tech. Release 90–R–11. Rockville, MD: American Pulpwood Association. 11 p.

Monroe, M. 2002. Fire. In: Human influences on forest ecosystems: the southern wildland-urban interface assessment. Gen. Tech. Rep. SRS-55. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 133-150. http://www.interfacesouth.org/swui-assessment/ch8.pdf. [Date accessed: April 18, 2011].

Naeher, L.P.; Achtemeier, G.L.; Glitzenstein, J.G. [and others]. 2006. Real-time and time-integrated PM2.5 and CO from prescribed burns in chipped and non-chipped plots: firefighter and community exposure and health implications. Journal of Exposure Science and Environmental Epidemiology. 16: 351–361.

Naeher, L.P.; Brauer, M.; Lipsett, M. [and others]. 2007. Woodsmoke health effects: a review. Inhalation Technology. 19: 67–106.

Nakicenovic, N.; Alcamo, J.; Davis, G. [and others]. 2000. Special report on emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. 599 p. http://www.grida.no/climate/ipcc/emission/index.htm. [Date accessed: December 9, 2010].

National Academy of Sciences. 2010. Advancing the science of climate change. Washington, DC: National Academies Press. 528 p.

National Coalition of Prescribed Fire Councils. 2007. National coalition of prescribed fire councils guide to smoke management. http://www.garxfire.com/pdf%20files/The_National_Coalition_of_Prescribed_Fire_Councils_Guide_to_Smoke _Management.pdf. [Date accessed: December 9, 2010].

National Interagency Fire Center. 2010. Fire information—wildland fire statistics. http://www.nifc.gov/fireInfo/nfn.htm. [Date accessed: December 9, 2010].

O'Brien, J.J.; Mordecai, K.A.; Wolcott, L. [and others]. 2010. Fire managers field guide: hazardous fuels management in subtropical pine flatwoods and tropical pine rocklands. Gen. Tech. Rep. SRS–123. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 55 p.

Outcalt, K.W. 2009. Fuel management in the subtropical and savanna divisions. In: Audin, L.J., ed. Draft cumulative watershed effects of fuels management in the Eastern United States. http://www.na.fs.fed.us/fire/cwe.shtm. [Date accessed: December 9, 2010].

Pyne, S.; Andrews, P.L.; Laven, R.D. 1996. Introduction to wildland fire. New York: John Wiley. 769 p.

Reilly, M.J.; O'Brien, J.J.; Waldrop, T.A. 2009. Fuels management in the hot continental division, Southern Appalachian Mountains. In: Audin, L.J., ed. Draft cumulative watershed effects of fuels management in the Eastern United States. http://www.na.fs.fed.us/fire/cwe.shtm. [Date accessed: December 9, 2010].

Riiters, K.H.; Wickham, J.D. 2003. How far to the nearest road? Frontiers in Ecology and Environment. 1: 125–129.

Rummer, R.; Outcalt, K.; Brockway, D. 2002. Mechanical mid-story reduction treatments for forest fuel management. In: Proceedings 55 annual weed science society meeting. Champaign, IL: Southern Weed Science Society: 76.

Running, S. 2006. Is global warming causing more, larger wildfires? Science. 313: 927–928.

Schwela, D.H.; Goldammer, J.G.; Morawska, L.H.; Simpson, O., eds. 1999. Health Guidelines for vegetation fire events, guideline document. Singapore: Institute of Environmental Epidemiology, Ministry of the Environment. 291 p.

Schwilk, D.W.; Keeley, J.E.; Knapp, E.E. [and others]. 2009. The national fire and fire surrogate study: effects of fuel reduction methods on forest vegetation structure and fuels. Ecological Applications. 19: 285–304.

SERPPAS Smoke Management and Air Quality Subcommittee. 2011. Southeast Regional Partnership for Planning and Sustainability (SERPPAS) Smoke Management Recommendations and Prescribed Fire Tracking. http://serppas.org [Date accessed: February 9, 2012].

Sorenson, B.; Fuss, M.; Mulla, Z. [and others]. 1999. Surveillance of morbidity during wildfires—central Florida 1998. Morbidity and Mortality Weekly Report. 48(4): 78–79.

Stanturf, J.A.; Wade, D.D.; Waldrop, T.A. [and others]. 2002. Background paper: fire in southern landscapes. In: Wear, D.N.; Greis, J.G., eds. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 607-622.

Stanturf, J.A.; Wimberly, M.C. [In press]. Demographic trends in the Eastern United States and the wildland urban interface: implications for fire management. In: Qu, J.J.; Riebau, A.; Yang, R.; Sommers, W., eds. Remote sensing and modeling applications to wildland fires. Dordrecht: Springer Publishing.

State of Georgia. 2010. Georgia statewide assessment of forest resources 2010. Macon, GA: Georgia Forestry Commission. http://www.gfc.state.ga.us/ForestManagement/documents/GAStateAssessment-6-17-10.pdf. [Date accessed: May 11, 2011].

Sun, C. 2006. State statutory reforms and retention of prescribed fire liability laws on U.S. forest land. Forest Policy and Economics. 9: 392-402.

Tian, D.; Wang, Y.; Bergin, M. [and others]. 2008. Air quality impacts from prescribed forest fires under different management practices. Environmental Science and Technology. 42: 2767–2772.

Urbanski, S.P.; Hao, W.M.; Baker, S. 2009. Chemical composition of wildland fire emissions. In: Bytnerowicz, A.; Arbaugh, M.; Riebau, A.; Andersen, C., eds. Wildland fires and air pollution. Developments in environmental science. Elsevier. 8: 79–107. Chapter 4.

U.S. Department of Agriculture Forest Service. 2011. Planning for the future of southern forests. R8–PR–61. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 33 p.

Wade, D.; Mobley, H. 2007. Managing smoke at the wildland-urban interface. Gen. Tech. Rep. SRS–103. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 28 p.

Wade, D.D.; Brenner, J.D. 1995. Florida's solution to liability issues. In: Weise, D.R.; Martin, R.E., tech. coords. The Biswell symposium: fire issues and solutions in urban interface and wildland ecosystems. Gen. Tech. Rep. PSW–GTR–158. Albany, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station: 131–138.

Wade, D.D.; Brock, B.L.; Brose, P.H. [and others]. 2000. Fire in eastern ecosystems. In: Brown, J.K.; Smith, J.K., eds. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS–42. Ogden, UT: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 53–96.

Wade, D.D.; Lunsford, J.D. 1989. A guide for prescribed fire in the Southern United States. Tech. Publ. R8–TP–11. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 56 p.

Wear, D.N. 2002. Land use. In: Wear, D.N.; Greis, J.G., eds. Southern Forest Resource Assessment. Gen. Tech. Rep. SRS–53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 153–173.

Westerling, A.L.; Swetnam, T. 2003. Interannual to decadal drought and wildfire in the Western United States. Eos. 84(49): 545, 554–555.

Wiedinmyer, C.; Hurteau, M.D. 2010. Prescribed fire as a means of reducing forest carbon emissions in the Western United States. Environmental Science and Technology. 44: 1926–1932.

Wiedinmyer, C.; Neff, J.C. 2007. Estimates of CO_2 from fires in the United States: implications for carbon management. Carbon Balance and Management. 2: 10. http://www.cbmjournal.com/content/2/1/10. [Date accessed: May 11, 2011].

Williams, J.W.; Jackson, S.T. 2007. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment. 5: 475–482.

Wolcott, L.; O'Brien, J.J.; Mordecai, K. 2007. A survey of land managers on wildland hazardous fuels issues in Florida: a technical note. Southern Journal of Applied Forestry. 31: 148–150.

Yanosky J.D. 2001. Fine particle exposure of prescribed fire workers in the Southeastern United States and a comparison of several particulate matter sampling methods, 2001. Athens, GA: University of Georgia. 120 p. M.S. thesis.

Wear, David N.; Greis, John G., eds. 2013. The Southern Forest Futures Project: technical report. Gen. Tech. Rep. SRS-178. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 542 p.

The Southern Forest Futures Project provides a science-based "futuring" analysis of the forests of the 13 States of the Southeastern United States. With findings organized in a set of scenarios and using a combination of computer models and science synthesis, the authors of the Southern Forest Futures Project examine a variety of possible futures that could shape forests and the many ecosystem services and values that forests provide. The science findings and modeling results could inform management and policy analysis of the South's forests. In the chapters of this technical report, the authors provide detailed findings and results as well as sets of key findings and implications.

Keywords: Forest conservation, futuring, integrated assessment, Southern Forest Futures Project, sustainability.

Non-Discrimination Policy

The U.S. Department of Agriculture (USDA) prohibits discrimination against its customers, employees, and applicants for employment on the bases of race, color, national origin, age, disability, sex, gender identity, religion, reprisal, and where applicable, political beliefs, marital status, familial or parental status, sexual orientation, or all or part of an individual's income is derived from any public assistance program, or protected genetic information in employment or in any program or activity conducted or funded by the Department. (Not all prohibited bases will apply to all programs and/or employment activities.)

To File an Employment Complaint

If you wish to file an employment complaint, you must contact your agency's EEO Counselor (click the hyperlink for list of EEO Counselors) within 45 days of the date of the alleged discriminatory act, event, or in the case of a personnel action. Additional information can be found online at http://www.ascr.usda.gov/complaint_filing_file.html.

To File a Program Complaint

If you wish to file a Civil Rights program complaint of discrimination, complete the USDA Program Discrimination Complaint Form, found online at http://www.ascr.usda.gov/complaint_filing_cust.html, or at any USDA office, or call (866) 632-9992 to request the form. You may also write a letter containing all of the information requested in the form. Send your completed complaint form or letter to us by mail at U.S. Department of Agriculture, Director, Office of Adjudication, 1400 Independence Avenue, S.W., Washington, D.C. 20250-99410, by fax (202) 690-7442 or email at program.intake@usda.gov.

Persons with Disabilities

Individuals who are deaf, hard of hearing or have speech disabilities and you wish to file either an EEO or program complaint please contact USDA through the Federal Relay Service at (800) 877-8339 or (800) 845-6136 (in Spanish).

Persons with disabilities who wish to file a program complaint, please see information above on how to contact us by mail directly or by email. If you require alternative means of communication for program information (e.g., Braille, large print, audiotape, etc.) please contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).