Climate Change and the Nation's Forests: Challenges and Opportunities[1]

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Abstract. Climate change is worsening fires and insect outbreaks in many of America's forests. It is also altering precipitation patterns and streamflows and causing plants and animals to change behavior and even to migrate to new locations. Although researchers remain uncertain about its effects, especially at the local scale, the risks are high; the human footprint on the land will keep many migrations from succeeding. However, land managers can help species and ecosystems adapt to climate change in various ways, such as assisted migration or forest health treatments to reduce ecological stress. Land managers can also help mitigate climate change by taking carbon storage and sequestration into account in their plans for afforestaton, reforestation, ecological restoration, and urban projects. Carbon markets can help private forest landowners address climate change, and public land managers can address climate change in a number of ways, including finding ways to utilize biomass and optimizing carbon storage and sequestration on public lands.

Climate change is already affecting America's forests. The fires of 2000 shocked the nation, the fires of 2006 burned an area greater than in any year since 1954, and the 2007 fires in southern California forced the evacuation of more than a million residents. Some of the largest individual fires ever recorded in the Western United States and Alaska occurred in the first 5 years of the 21st century. Scientists have linked growing fire season severity with warming temperatures and earlier snowmelt (Westerling et al. 2006). Higher temperatures and drought are also blamed for unprecedented bark beetle outbreaks and tree mortality across the West (Breshears et al. 2005; Logan and Powell 2005). However, forest productivity is increasing in some temperate areas due to warmer temperatures, a longer growing season, and the "fertilizer effect" of increasing atmospheric carbon dioxide (Nemani et al. 2003).

Such impacts signal two kinds of climate change—a cycle of natural variability that produces periods of cooling and warming, and progressive warming from an accelerating greenhouse effect (Bradley 1999, IPCC 2001). Natural variability is due to changes in the amount of heat received from the sun over time and the way it is distributed around the Earth, whereas progressive warming is a consequence of rising emissions from burning fossil fuels and loss of productive forestland. The impacts we are now seeing on forests result from small but cumulative increases in temperature and precipitation over the last hundred years, particularly in

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areas of severe drought in recent years (NAST 2001). Projections of future climate change based on 21st-century emissions estimates range from a relatively mild "warmer and wetter" scenario to a truly alarming "hot and dry" scenario.

What can we do about climate change? Forests are part of the solution because they can sequester greenhouse gases from the atmosphere, offsetting some of the emissions from burning fossil fuels. What can we do to increase carbon sequestration on the 749 million acres of public and private forestland in the United States? Would it affect other ecosystem services? Even with aggressive action by the world's governments to reduce greenhouse gases, atmospheric composition is already sufficiently altered to affect climate for the next century and beyond. Future forests will grow under a different climate than our generation—whether of people or of forests—is used to. Are there specific management actions that will reduce the vulnerability of forests to climate change and enhance their natural capacity to adapt? How can forest managers and policymakers work to minimize the adverse impacts of climate variability and change? These questions are critical to the future of America's forests.

Rising Carbon Emissions

Carbon is the basis of life. It provides food, fiber, and energy, and it contributes to the greenhouse gases—mainly carbon dioxide and methane—that keep the planet habitable by trapping heat in the atmosphere. The world's oceans and forests play a role in regulating greenhouse gases. Growing forests take up carbon dioxide from the atmosphere and store it as live biomass and organic matter; disturbed forests release stored carbon as carbon dioxide.

The amount of carbon in the atmosphere has varied widely over geological time. Air samples trapped in deep ice cores tell us that atmospheric carbon dioxide is now higher than at any time in the past 400,000 years (Petit et al. 1999). The main source today comes from burning fossil fuels. In the 1990s, global carbon emissions from fossil fuels were about 6.3 billion tons per year and from land use conversion about 2.2 billion tons per year (Houghton 2003). Total emissions were offset by an ocean uptake of about 2.4 billion tons of carbon per year and by an "unidentified sink" of about 2.9 billion tons per year—probably a terrestrial uptake in the temperate and boreal forest zones of the Northern Hemisphere. In the 1990s, the global carbon budget yielded a net greenhouse gas gain in the atmosphere of 3.2 billion tons of carbon per year.

Greenhouse gas buildups tend to warm the Earth's surface by trapping increasing amounts of heat in the atmosphere. Average temperatures in the Northern Hemisphere have reached their highest level in 400 years and probably in a thousand years—and they continue to climb (NRC 2006). Changes in weather are familiar, readily recognizable as variations in daily temperatures, seasonal cycles, and annual differences that sometimes include extremes of drought, wet, heat, and cold (Millar and Brubaker 2006). This natural climate variability results from changes in the Earth's orbit around the sun, dynamics of solar activity, and ocean–atmospheric interactions. However, with the rise of agriculture, people further influenced climate by changing land cover—by clearing forests, altering vegetation types, and burning ecosystems, thereby adding to the carbon dioxide released through natural emissions and changing the surface albedo effect (Ruddiman 2005).

Such human influences have resulted in large increases in the concentration of greenhouse gases in the atmosphere. Recent studies at the global and North American spatial scales used large-scale patterns of surface temperature variation and climate models to investigate changes in climate over the 20th century. Researchers found that increases in North American temperatures from 1950 to 1999 were not likely due to natural climate variations alone (IPCC 2001, 2007). Observed trends were consistent with climate simulations that include "anthropogenic forcing"—changes caused by artificial emissions of greenhouse gases and sulfate aerosols. Researchers thus detected a human influence on North America's climate (Climate Change Science Program 2004).

Researchers have begun to document the environmental consequences of climate changes since the preindustrial era, with an emphasis on the last 50 years. Warmer temperatures are bringing more rain and less snow to higher elevations, reducing mountain snowpacks in the Western United States (Knowles et al. 2006). Snowmelt runoff is peaking earlier each year (Stewart et al. 2005). Researchers have teased out biological responses to climate change by focusing on climate-sensitive behaviors of plants and animals, such as breeding, emergence from hibernation, seasonal migration, productivity, and changes in species ranges (Parmesan and Yohe 2003). Using snowmelt timing and the first blooming of lilac and honeysuckle as proxies, researchers found that spring is coming earlier to much of the Western United States (Cayan et al. 2001). Other examples include earlier egg laying by Mexican jays; earlier emergence from hibernation by marmots (by nearly 3 weeks); northward migration of the sachem skipper butterfly; and the rising dominance of warmwater species in the intertidal community at Monterey, CA. Plants and animals have the capacity to adapt to natural climate changes, but they might not be able to keep up anymore because rates of climate change have increased and because land use changes have altered landscapes in ways that might prevent adaptation.

As noted, researchers have also documented changes in disturbance regimes. For example, about 4 million acres of forest in south-central Alaska have had 10 to 20 percent mortality from spruce beetle since 1969—one of the largest outbreaks on record. Moreover, a detailed analysis of fire records has revealed a strong correlation between the length and severity of recent fire seasons and rising spring and summer temperatures coupled with earlier snowmelts (Westerling et al. 2006).

Future Impacts of Climate Change

If such climate-related changes continue, what does the future hold? Forecasting climate change is inherently uncertain, but researchers provide a variety of possible climate scenarios based on a range of reasonable assumptions. The reliability of their models depends on scale; sophisticated global models have been available for some time, whereas regional downscaling, bringing the climate closer to the forest, range, and water management scale, is just starting to yield results. At a regional scale, different parts of North America are expected to show different trends for both temperature and precipitation, just as in the past.

All climate models project continued warming in the United States in response to projected increases in greenhouse gases (fig. 1; NAST 2001). The average temperature in the United States is expected to rise, depending on the model used, by 4 to 10 °F over the next hundred years, with the greatest increases likely in Alaska and the continental interior and in winter. Growing seasons will continue to lengthen in both spring and fall. Precipitation changes will vary, but rainfall events will probably increase in intensity. The hotter and drier conditions predicted under some scenarios will likely continue to intensify wildfire activity in many parts of the United States; projected increases in area burned annually range from 4 to 31 percent (Bachelet et al. 2003). Hotter, drier conditions also portend severe water deficits and increases in forest mortality due to insects and diseases in the Western United States; large areas of forest in Canada and Alaska are expected to be particularly sensitive to climate change as a result of projected greater warming at higher latitudes (Hogg and Bernier 2005).

Under these climate scenarios, how will ecosystems respond? The answer is far from clear. Changes in climate at multiple scales—global, regional, and local—will affect ecosystems. Projected changes in live vegetation carbon under two climate scenarios illustrate both the uncertainty of climate projections and the regional differences in expected response (fig. 2). One simulation shows continued growth in eastern forests through the end of the 21st century, with forests declining in parts of the West and the Great Lakes region. Another suggests nearly the

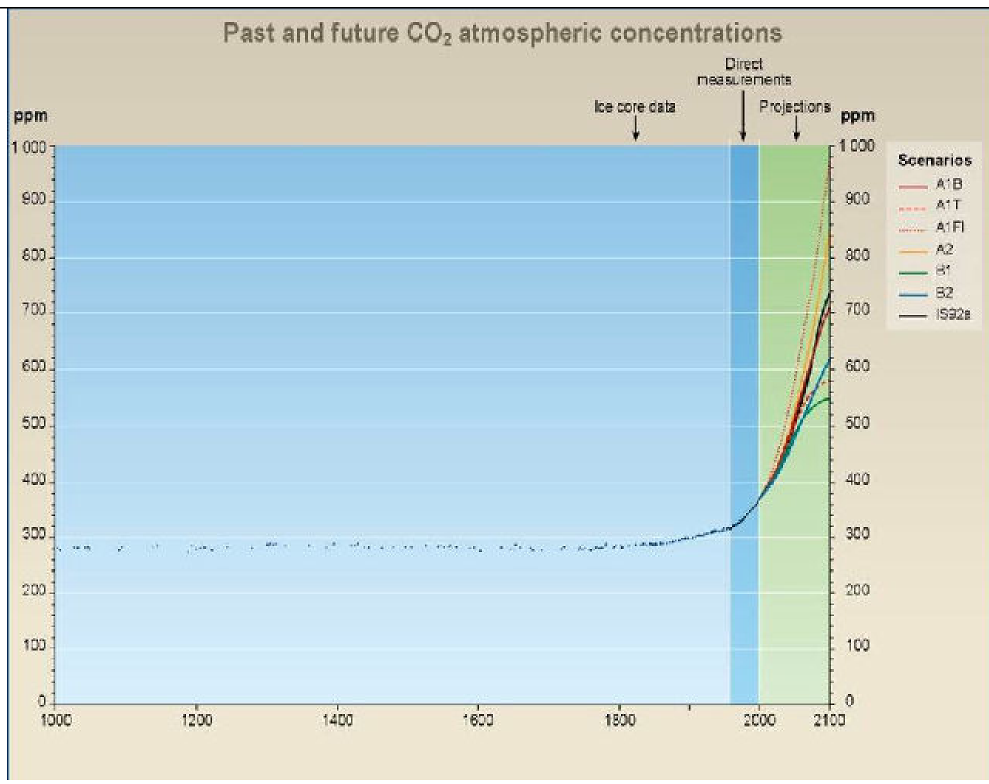

Figure 1. Past concentrations of atmospheric carbon dioxide are based on air samples from ice cores and direct atmospheric measurements. Projections are based on different assumptions about the global economy and use of fossil fuels (from IPCC 2001).

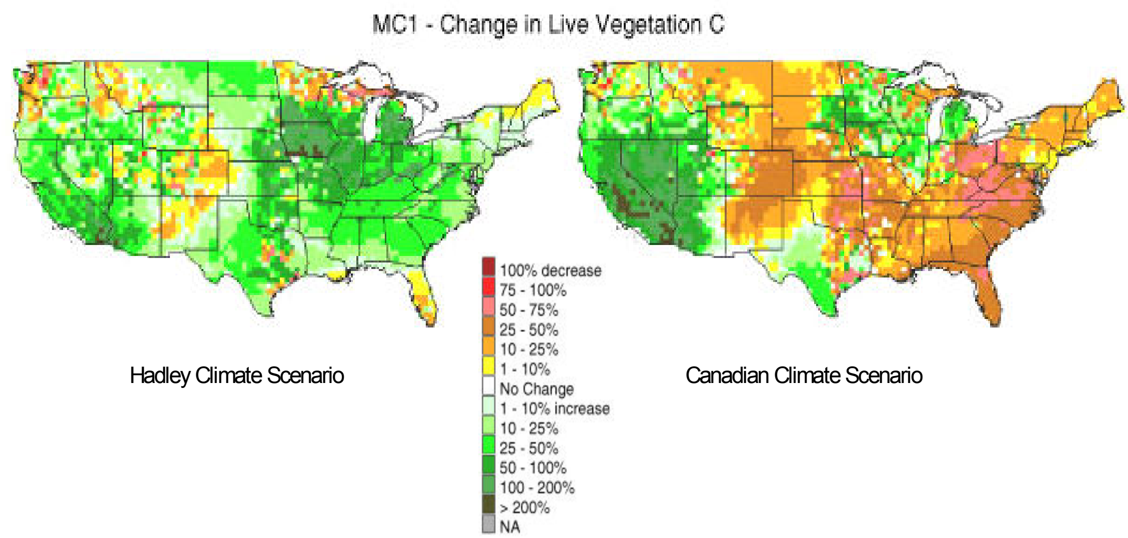

Figure 2. Change in live vegetation carbon over the 21st century for two climate scenarios, based on the MC1 model (Bachelet et al. 2001).

opposite, with significant forest declines in the East and Midwest—especially in the South, where forests in some areas are projected to give way to savanna or even grassland.

Ecosystems might respond to environmental changes in nonlinear fashion when intrinsic thresholds are crossed or when extreme events exceed their resiliency (CACC et al. 2002). For example, severe drought in the Southwest during the 1950s and 1990s-2000s led to stresses on piñon pine that ultimately crossed tolerance thresholds, producing widespread mortality (Breshears et al. 2005). In some instances, a major decline in one ecosystem component can result from a significant increase in another. During the most recent piñon pine dieoff, for example, water stress weakened trees, increasing their vulnerability to bark beetles, which in turn might have benefited from warmer temperatures and longer growing seasons (Breshears et al. 2005). Larger bark beetle populations preying on weakened trees led to further beetle increases. Much of the drought-related piñon pine mortality was due to bark beetles feeding on weakened trees rather than to water stress alone.

Plants tend to thrive in a carbon-rich atmosphere, leading some observers to predict the opening of vast new lands to agriculture and forestry. However, soil development at higher elevations and more northerly latitudes is often poor, limiting potential agricultural and forest productivity. Furthermore, although forest productivity might increase in the short term as a result of warming temperatures and higher levels of carbon dioxide in the atmosphere, factors that decrease forest productivity, such as ground-level ozone, could prevail over time, resulting in regional changes in forest cover and the loss of some sensitive species (Aber et al. 2001). Moreover, different plants respond differently to increases in atmospheric carbon; some produce more flowers and fruit rather than larger stems. Changes in vegetation could result in positive feedback loops due to changes in the albedo effect. For example, as plants colonize arctic landscapes formerly covered by snow, ice, and barren soil, the Earth's surface will absorb more radiation, further warming the climate (Chapin et al. 2005).

Invasive plants could benefit from climate change. Ziska (2003) explored the response of six invasive weeds (Canada thistle, yellow starthistle, leafy spurge, spotted knapweed, field bindweed, and perennial sowthistle) to concentrations of carbon dioxide from the beginning of the 20th century to the end of the 21st century. Increases in atmospheric carbon dioxide from the early 20th century to the present stimulated invasive plant biomass by an average of 110 percent, raising the possibility that increased atmospheric carbon might be partly responsible for the spread of invasive weeds in the 20th century. The trend is expected to continue: Likely future concentrations of carbon dioxide in the atmosphere will stimulate invasive plant biomass in the six species studied by Ziska (2003) by an average of 46 percent, with the largest response for Canada thistle.

Plant and animal species have migrated in response to large climate changes in the past. As the glaciers retreated and temperatures warmed, species migrated to new locations, yielding today's forest patterns. In relatively flat regions, the migration was primarily northward, whereas in the mountainous areas of western North America and central Europe, the migration tended to be upslope—although it could also be downslope, depending on local climatic and ecological conditions. For example, Utah juniper, bristlecone pine, and limber pine migrated up to about 4,000 feet uphill, whereas shadscale moved downhill by about 1,100 feet.

However, similarly broad shifts in vegetation are unlikely today for two related reasons. First, skyrocketing carbon levels in the atmosphere will have a tremendous global greenhouse effect. If carbon dioxide levels double in the 21st century (a distinct possibility), they will reach the highest concentrations in the past 80 to 100 million years. When Earth last saw such high levels of atmospheric carbon—during the Cretaceous Period, when forests were dominated by tree ferns and palmlike cycads—it was a very different place.

Second, developed landscapes form barriers to migration for both plants and animals. Throughout their evolutionary histories, North American species have never encountered the gridlock created by today's human footprint on the landscape. Land use conversion, landscape fragmentation, urban roads and development, public expectations and demands, and traditional conservation and land management mindsets will all tend to block species migration.

In fact, climate change will likely be too rapid for today's forests to maintain their current structure, functions, and composition, given the landscape impediments that people have created. Land managers will face a high and growing risk of loss of local species populations as well as widespread tree mortality and increased threats from ecological stressors such as wildfire, insects, diseases, air pollution, and invasive species. Ecosystems and the services they provide will look very different. Climate variability and change can profoundly influence social and natural environments throughout the world, with potentially large and far-reaching effects on natural resources and industry (IPCC 2001, 2007).

Helping Forests and Society Adapt to Climate Change

Although countries around the world are taking steps to reduce greenhouse gas emissions, the changes already underway will be difficult to stop anytime soon. Even if net global carbon emissions are controlled and reversed by midcentury, it could take centuries for atmospheric carbon levels and temperatures to stabilize, and sea levels could continue to rise for thousands of years (IPCC 2001, 2007). Fortunately, America's forest managers have known for decades that the landscapes they manage are dynamic and changing; adaptive management is a recognized management tool. Now, due to buildups of atmospheric carbon, adaptive management has a new and pressing dimension—a challenge unprecedented in the history of conservation.

Meeting the adaptation challenge has a human dimension as well as an ecological one. People tend to place high and unyielding demands on ecosystems, expecting them to flourish while still delivering the resources needed to support high standards of living, even where such expectations tend to clash. In the 21st century, the changing climate is likely to exacerbate such contradictions by constraining the migration of species on a landscape where the human footprint has rendered conditions impassible. To support adaptation, land managers must be prepared not only for the migrating species and changing landscape dynamics, but also for potentially low levels of public understanding and support for the necessary management measures.

The nature of the changes is still unclear, but researchers are making progress in anticipating them. Using new technology, they are conducting experiments on intact forest communities under the effects of elevated greenhouse gases. They are using more sophisticated climate and vegetation models to increase confidence in their projections, and they are studying on-the-ground responses of plants and animals to understand behaviors. Forest managers can already use the results to monitor forests for the impacts of climate change and to adapt their management plans accordingly.

The goal of adaptation is to reduce the vulnerability of ecosystems to climate change and to increase their resilience to climate-induced changes in ecological conditions. Specific adaptation responses might include:

- reducing the impacts of stresses that can exacerbate the effects of climate change, particularly from wildland fire, air pollution, insects, and diseases;
- stepping up measures to prevent and control the spread of invasive species;
- preventing or reducing barriers to species migration, such as forest fragmentation;
- improving forest health monitoring for early detection of climate change impacts;
- helping forests regenerate following large-scale disturbances, for example through reforestation;
- increasing stand-scale resistance to drought and the spread of invasive species, as well as resilience in the aftermath of both;
- taking historical climate and projected climate changes into account in planning forest management;

- considering the impacts of climate change in selecting planting stock and choosing planting methods;
- supporting research to better understand forest vulnerability to multiple stresses and to find ways to enhance forest resilience; and
- perhaps most importantly, raising awareness among natural resource managers and concerned publics about climate change and other threats to forest health.

Each of these management strategies maximizes the flexibility needed to respond to the certainty of climate change—and to uncertainty about its effects. An overarching management goal should be ecological diversity, with a variety of species, nursery stock, and stocking levels across the landscape. Diversity can enhance forest resilience in the face of future challenges, increasing the options available to forest managers to learn from climate change and respond accordingly.

Using Forestry to Counter Anthropogenic Effects on Climate

Adaptive management is only part of what forest managers can do to respond to climate change. From the mid-1990s to the mid-2000s, forests in the United States have sequestered about 200 million tons of atmospheric carbon per year (Heath and Smith 2004), offsetting about 10 percent of the carbon dioxide emitted by Americans burning fossil fuels. A century ago, forests in the United States were a net source of carbon rather than a sink: They emitted as much as 750 million tons of carbon per year (fig. 3; Birdsey et al. 2006), mainly due to agricultural clearing, heavy logging, and losses to fire and pests. The switch from source to sink was due to forest regrowth, land use reversion from cropland to forestland, and successful fire and pest control. As forest managers, we can build on that success by analyzing our management practices, identifying the ones that increase carbon sequestration, and taking them into account in making future land management decisions.

A forest has three main carbon pools—live biomass, woody debris, and soil organic matter. Each is affected by disturbance in different ways and over a different timescale (Pregitzer and Euskirchen 2004). In forests managed primarily for natural processes, the carbon balance is driven mainly by soil productivity and natural disturbance regimes; in intensively managed plantations, the main drivers tend to be site preparation, planting-stock selection, thinning treatments, and length of timber harvest rotations. For both types of forest, the disturbance return interval drives carbon dynamics, with both the timing and the intensity of the disturbance playing a role: The longer the average time between disturbances, the more carbon is stored; and the less severe the disturbance (for example, the less biomass consumed by a fire), the more carbon is retained.

For most forests, total carbon stored increases with time since the last disturbance, although carbon pools such as down woody debris might decline for awhile after a timber harvest. The pattern of carbon sequestration depends on climate, species, age classes, site

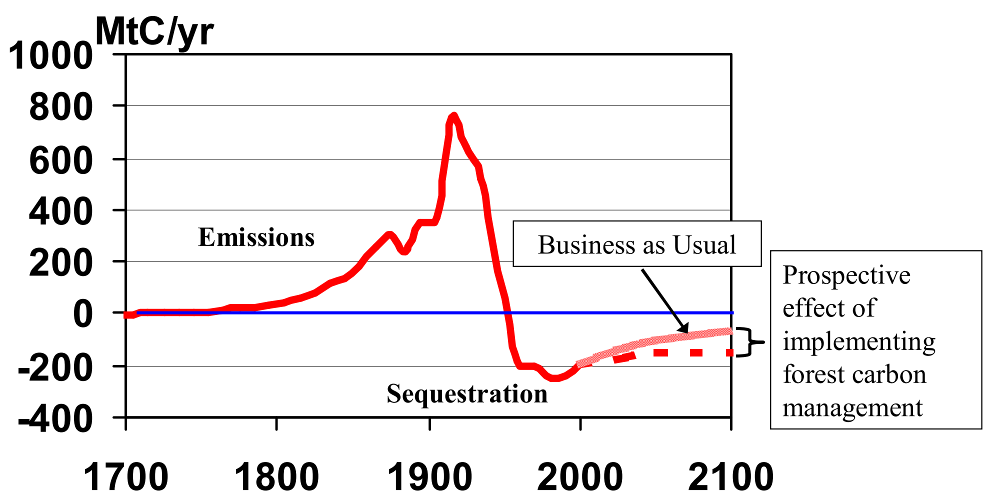

Figure 3. The carbon budget of the U.S. forest sector from 1700 – 2100. The large spike in emissions around 1900 is from land clearing and intense utilization of wood for industry and development, followed by regrowth of forests during the 20th century. The current rate of sequestration is projected to decline unless actions are taken to reverse this trend (from Birdsey et al. 2006).

productivity, type of disturbance, and other factors. Figure 4 shows a typical pattern following a timber harvest—increasing carbon storage, with the rate of increase falling over time. In very old forests, carbon stocks can actually begin to decline (Ryan et al. 1997).

Additional accounting is required for carbon sequestered in wood products. When wood is removed from a forest, all of the carbon does not immediately return to the atmosphere. Carbon pools in wood products include wood in use (such as lumber, furniture, and paper) and wood discarded in landfills. Wood used in construction can reduce the burning of fossil fuels to produce substitute building materials such as steel or concrete (Lippke 2006; MacCleery 2005). Woody biomass can be burned to heat or light buildings or converted to ethanol to power transportation, offsetting the use of fossil fuels.

Taking all this into consideration, and acknowledging the difficulty of carbon accounting, a range of forestry activities can help balance the global carbon budget by reducing greenhouse gas emissions or increasing carbon sequestration. They include:

- afforestation, particularly the conversion of marginal cropland to forestland;
- restoration of native vegetation and wildlife habitat;
- active regeneration of harvested forestland, particularly to establish fast-growing species;

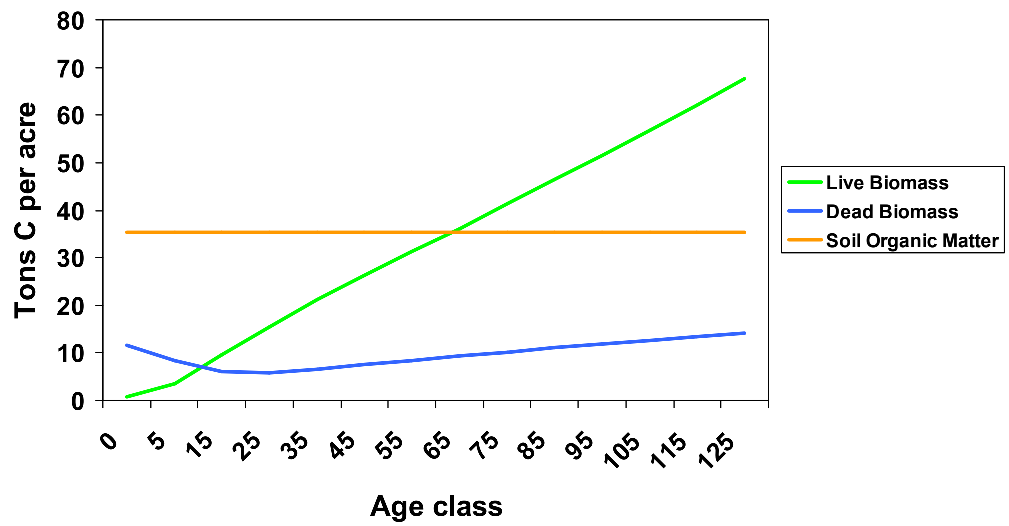

Figure 4. How carbon stocks in different pools change after a clearcut. Dead biomass includes standing dead trees, down woody debris, and forest floor. This example is for aspen-birch forests of the Lake States (Smith et al. 2006).

- agroforestry—that is, cultivating trees with crops or pasture—by sequestering carbon and by decreasing the need for fossil fuels and energy-intensive chemicals in producing food and fuel;
- modification of forest management practices to increase the rate of carbon sequestration or reduce emissions from decay;
- short-rotation woody biomass plantations, by sequestering carbon and providing energy feedstocks that displace fossil fuels in energy production;
- reduced-impact logging, by decreasing the soil disturbance and biomass decay that often result from traditional timber harvest methods;
- improvements in processing wood to reduce emissions from wood waste and energy use; and
- urban forestry, by increasing carbon sequestration in trees and reducing energy used in heating or cooling homes and businesses.

Wildfire activity in the West is growing, confronting the Nation with one of its most difficult forestry challenges. Fuels reduction and forest health treatments reduce rather than increase carbon stocks in forests; however, they also reduce the amount of biomass consumed—and carbon dioxide emitted—in the resulting low-severity fires. If the biomass removed during fuel reduction treatments can be used in durable wood products or converted to energy that reduces consumption of fossil fuels, the carbon removed is not counted as an emission in greenhouse gas accounting. Significant barriers to better utilization of small-diameter timber in the West are lack of markets and distance from or difficult access to utilization facilities.

Studies suggest that the right forestry activities in the United States could increase carbon sequestration by 100 to 200 million tons per year (Birdsey et al. 2000, EPA 2005, Lewandrowski et al. 2004, Stavins and Richards 2005), possibly doubling the amount of carbon annually sequestered by America's forests. However, the rate of increased carbon storage would likely decline over time as low-cost forestry opportunities run out, forestry sinks become saturated, and timber harvest takes place in newly afforested areas.

Opportunities in the Private Sector

About 430 million acres of the nation's 749 million acres of forestland are in private ownership. With more than half of the nation's forests, the private sector will play a central role in deciding whether or not America's forests are managed for climate change and its effects. Both market approaches and voluntary incentive programs to manage greenhouse gases are under development in the United States, the European Union, and elsewhere (Totten 1999). Some carbon sequestration projects are already underway, even though sequestered carbon currently has little market value in the United States, a situation that seems unlikely to greatly change unless limits on carbon emissions are imposed.

Widespread private participation in carbon sequestration activities will likely require financial incentives. One way would be through the sale of carbon offsets by landowners to developers, industries, and others whose activities add more carbon to the atmosphere. Studies suggest that improving forest management to sequester more carbon would become attractive to landowners at carbon prices below $10 per ton of carbon dioxide; afforestation at $15 per ton or more; and management for biofuels at $30 to $50 per ton (EPA 2005, Lewandrowski et al. 2004, Stavins and Richards 2005).

The success of a carbon market depends on various factors. The trading price of carbon is key, as are transaction costs; forest carbon credits must be exchangeable with credits for reduced emissions; and carbon sequestration must be accurately estimated and reported. In addition, a technical support system is needed to provide land managers with the knowledge and tools necessary to make competent decisions about how to manage particular forests to reduce greenhouse gases.

Side effects might not all be beneficial. For example, taking land out of crop production might affect food prices; at higher carbon prices, nearly 100 million acres might revert from cropland to forestland (EPA 2005). Increasing carbon stocks in some areas might also reduce the availability of water for other uses because higher tree density will mean more water used for transpiration.

A sound forest carbon management policy for the private sector will need to take all effects into account, both positive and negative.

Opportunities in the Public Sector

For carbon markets to flourish, government must furnish a "driver," such as a regulatory cap on carbon emissions. The Bush administration has promoted a voluntary scheme for reducing greenhouse gas emissions, whereas states such as Maine and California are implementing regulatory action plans for both emissions reductions and carbon sequestration. In the Northeast, a regional greenhouse gas initiative based on emissions caps involves 11 states. Voluntary markets such as the Chicago Climate Exchange, though partly motivated by conservationism, are also driven by expectations of a future national cap on carbon emissions (Bayon and Hawn 2007).

Government plays an additional role in setting up and supporting carbon markets. The Forest Service is the lead agency for revising the national accounting rules and guidelines for reporting and registering emissions reductions and increases in carbon stocks—a national greenhouse gas registry that underpins the Administration's voluntary approach to reducing atmospheric carbon. Forest Service Research is developing the monitoring, accounting, and reporting protocols for the carbon registry; the Forest Service's State and Private Forestry staff can help implement the guidelines through state and landowner assistance.

Government also drives basic research, and for almost two decades the Forest Service has taken the lead. The Forest Service has conducted research on how forest management, storage of carbon in wood products, and natural factors affect the exchange of carbon with the atmosphere, both in the past and under projected future scenarios. Forest Service Research provides the fundamental knowledge needed to identify and develop forestry practices and management systems to increase carbon sequestration, accurately account for changes in carbon storage, and prepare scientifically credible reports.

With some 319 million acres of forestland in public management, government can play a key role in managing the Nation's forests for climate change and its effects. The role of state and federal programs in capturing the benefits of forest carbon management, particularly through state/federal partnerships, can be a model for the Nation. Specific activities might include:

- assessing the potential for sequestering more carbon in forests and wood products through afforestation, improved forest management, and substitution of wood for other materials that require more energy to produce;
- facilitating the removal and use of excess forest biomass for biofuel and providing incentives to increase the area of biomass energy plantations;
- identifying how increased carbon sequestration would affect other forest values, such as wood production and wildlife habitat;
- determining the level of financial incentives needed to increase carbon sequestration;

- providing landowners with information on what they can do to increase carbon sequestration on their lands;
- helping landowners take the necessary steps to increase carbon sequestration, record the gains, and earn the corresponding carbon credits;
- accelerating the development of carbon inventory methods, data access, and analysis tools;
- developing regional demonstration projects and training sessions;
- implementing an "early warning" system to detect adverse effects from climate change; and
- perhaps most importantly, reducing the ecological footprint of government by conserving energy, switching to green energy and green building techniques, and offsetting energy use through carbon sequestration.

Managing for Climate and Forests of the Future

The climate is changing. More carbon in the atmosphere is driving a wider range of temperature extremes, producing warmer summers and earlier snowmelts. The combined effects appear to be partly responsible for growing fire season severity, unprecedented activity by forest pests, and even the accelerated spread of invasive weeds.

The future outlook is troubling. Climate variability and change can alter the structure and function of ecosystems, in turn reducing ecological resources and benefits, shifting feedbacks between ecosystems and climate, and disrupting lives and livelihoods that depend on healthy forest ecosystems. Western forests are currently estimated to be a carbon sink (Heath and Smith 2004), but they could become a source due to increasing wildfire activity.

However, there is hope. As forest managers, the challenge we face is this: how to help forests adapt to climate change and how to build their capacity to store more carbon and offset sources of carbon emissions. Despite uncertainty about the changing climate, we do have opportunities to act. We can monitor the forests we manage for evidence of climate change, and we can prepare to adapt our management plans accordingly. The benefits of adaptive management go beyond climate change; we can already adopt them without regret.

We can also modify a broad range of forestry activities to reduce greenhouse gas emissions and increase carbon sequestration. However, implementing these modifications on a broad scale while continuing to produce forest goods and services will be a formidable challenge. Federal and state governments can play a key role in helping forest landowners ensure that forest carbon management and adaptation practices are sensitive to—and fully integrated with—management plans and practices that protect and enhance the entire suite of the Nation's forest values.

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