Modeling Vegetation Dynamics and Habitat Availability in the Southeastern U.S. Using GAP Data

Jen Costanza[1], Todd Earnhardt[1], Adam Terando[1], and Alexa McKerrow [1,2]
[1]North Carolina State University Department of Biology, Raleigh, NC
[2]USGS Core Science Systems, Raleigh, NC

Resource agencies are increasingly challenged to predict and respond to the potential effects of climate and land use change on the habitats they manage. Historically agencies have focused on managing individual public lands. Over time, the scale and extent of the potential impacts of these new threats will require that managers consider strategies across ownership boundaries and at a landscape scale. The Southeastern U.S. has experienced rapid land use change (Loveland and Acevedo 2006) with three primary drivers of change (timber management, regeneration of forests from farmland, and urbanization (Napton et al. 2010).

Given the need to make management decisions now without perfect knowledge, modeling provides a practical approach to studying the potential impacts of land use and climate change. Models can help identify sensitivities in a system that should guide future research, and they can serve as a meaningful tool for implementing an adaptive management strategy (Turner et al. 2001, Gardner et al.1999).

To help inform these management decisions we are leveraging existing data from the Southeast Gap Analysis Project to model vegetation dynamics across the region. The three core GAP datasets (land cover, stewardship and terrestrial vertebrate species models) were completed for the region in 2007. Those data have since been used in a variety of derivative projects and products, including the development of national datasets (i.e. the Public Areas Database and the National Gap Land Cover). In the Southeast, we have used the data to model future vegetation and habitat under two climate change scenarios as part of the Designing Sustainable Landscapes Project (DSL; http://www.basic.ncsu.edu/dsl), guided by the Atlantic Coast Joint Ventures Program. In the Southern Atlantic Migratory Bird Initiative (SAMBI), our objectives were to:

1. Project the effects of climate change on vegetation dynamics
2. Use the projected vegetation dynamics to model potential future habitat distribution for avian species

This article focuses on how the Gap Analysis datasets provided the foundation for our research. The outcome of this work will directly inform the development of optimal conservation strategies and decision support tools to guide conservation planning for the SAMBI.

Methods

Study area

The SAMBI area includes the coastal plain from Southern Virginia through Georgia and Northern Florida (Figure1). Within the area a variety of bird species and habitats have been identified as priority for conservation and management through a series of workshops led by the USFWS Joint Venture Program (Watson and M^c^Williams 2005). The Longleaf/Slash Pine Flatwoods and Savannahs and Longleaf Sandhills that occur throughout the region have been identified as important for the management of nine of the priority species including Red-cockaded Woodpecker, Northern Bobwhite, Loggerhead Shrike, Prairie Warbler, Bachman's Sparrow, Henslow's Sparrow, Brown-headed Nuthatch, American Kestrel and Red-headed Woodpecker. Conservation lands represent less than 10% of all lands in the SAMBI, with several larger managed lands scattered throughout (i.e. Apalchicola , Croatan, and Francis Marion National Forests; Camp LeJeune, Fort

Steward, and Fort Bragg; Okefenokee, Swan Quarter, Cedar Island, Pea Island and Alligator River National Wildlife Refuges; Cape Hatteras and Cape Lookout National Sea Shores). Omernik recognized three Level III (Southeastern Plains, Middle Atlantic Coastal Plain, and Southern Coastal Plain) and 29 Level IV ecoregions within the study area (USEPA 2010).

Modeling Vegetation Dynamics

An overview of the modeling approach is provided in Figure 1. For the SAMBI, we are focusing on a 100 year time period (2001 - 2100) and two climate change scenarios models (B1 and A2). We are using the spatially-explicit forest landscape simulation model TELSA (Tool for Exploratory Landscape Scenario Analyses; Kurz et al. 2000) to simulate vegetation dynamics. TELSA integrates state-and-transition vegetation models that are developed using the Vegetation Dynamics Development Tool (VDDT; ESSA 2007) with the spatial distribution of vegetation types to simulate both deterministic (i.e. aging) and stochastic (e.g. fire) processes.

For the simulation landscape, there are four major inputs to TELSA: (1) a polygon map of vegetation types, (2) a non-spatial state-and-transition model for each vegetation type, (3) an initial age for each polygon, and (4) an initial structural stage for each polygon. In order to develop the map of

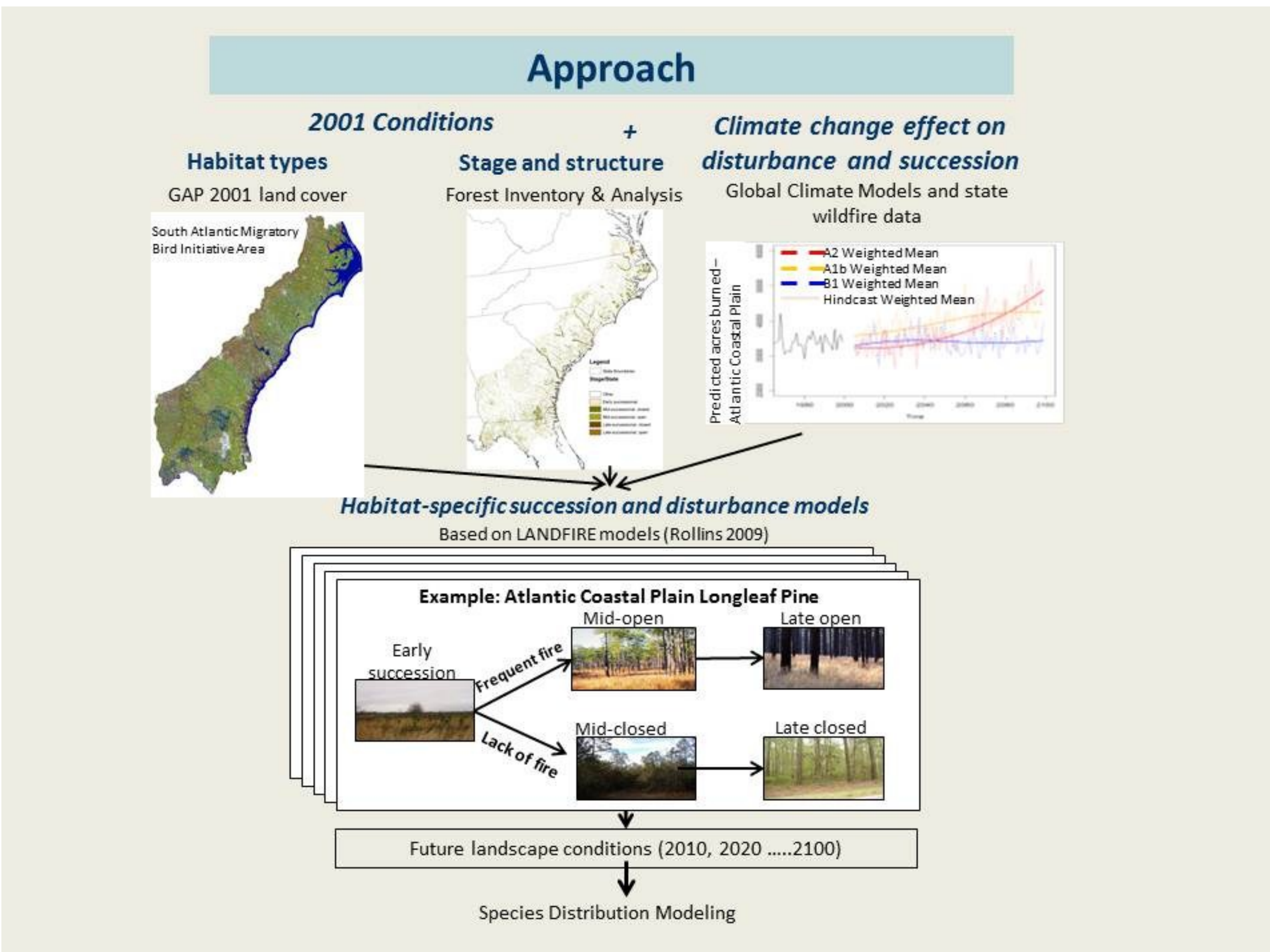

Figure 1. Modeling future landscape conditions and habitat availability in the Southern Atlantic Migratory Bird Imitative Area (SAMBI).

vegetation types, we divided the SAMBI into polygons using the SEGAP land cover map. This map represents 2001 era land cover at 30m resolution. The vegetation classes in the map generally correspond to NatureServe's Ecological Systems classification (Comer et al. 2003). We included modifiers to the Ecological Systems to accommodate variation in the vegetation. For example, we included three modifiers to the Atlantic Coastal Plain Sandhills Longleaf Woodland an Open Understory, a Scrub/shrub Understory, and a Loblolly Pine modifier. The National Land Cover Dataset 2001 (Homer et al. 2007) was used to represent the remaining land cover classes.

To the base map, we assigned a state-and-transition model to each of the vegetated map classes. For most of the ecological systems, those models were developed as a part of the LANDFIRE Project (Rollins 2009). Each of those models has states representing combinations of successional stage (early, mid, or late succession) and structural stage (open or closed canopy). Succession is deterministic, while disturbances such as fire are probabilistic. Models were drafted and reviewed by regional vegetation ecologists, who described the states, and developed probabilities to represent disturbance transitions.

We then assigned each polygon an initial age based on county level summaries of the US Forest Service Forest Inventory and Analysis (FIA) data (USFS-FIA 2010) based on a crosswalk between the forest types and the mapped cover forest classes. Initial ages were assigned so that the age distribution for the given forest type in each county was the same as the age distribution of plots in the FIA database. The ages were used as a basis for assigning the appropriate stage label (early, mid, or late successional) to each polygon. Finally, we assigned an initial structural stage to each polygon based on the s-class dataset produced by LANDFIRE (Zhu et al. 2006).

The combination of ecological system, age (early, mid, and late stages), and structure (early successional, closed, open) constitutes a state-class label for each polygon. TELSA simulates succession, disturbance, and management on an annual time step. The result of each time step for each polygon is a condition (structure and successional stage). We produced outputs from TELSA every 10 years from 2010 to 2100.

Climate Change

There is a growing body of evidence that anthropogenic emissions of greenhouse gases are warming the planet and will likely cause significant climatic changes in this century (IPCC 2007). In order to simulate vegetation dynamics under these projected future climate conditions, we are using observation data to relate climate variables (temperature and precipitation) to ecosystem processes. Once the relationship is established, we then project the change in disturbance probability under the two climate change scenarios developed by the IPCC (A2, B1). The SAMBI study area falls completely within the Coastal Plain Ecoregion, where fire is a dominant disturbance factor. For this study we used historic (1979 – 2010) climate and fire occurrence data to hindcast the relationships between the acres burned and climate variables (i.e. temperature and precipitation). Those relationships have then been incorporated in to the modeling as a fire probability multiplier in the TELSA model runs.

In addition to the vegetation dynamics modeling, we have incorporated urban growth and sea level rise model projections for the study area. Those methods and results will be presented in subsequent articles.

Modeling Habitat Dynamics

Five species were considered for the pilot test of this approach: Bachman's Sparrow (*Aimophila aestivalis)*, Northern Bobwhite (*Colinus virginianus)*, Red-cockaded Woodpecker (*Picoides borealis), Cerulean Warbler (Dendroica cerulean)* and Brown-headed nuthatch (*Sitta pusilla*). For each species, habitat availability was modeled based on habitat associations to land cover classes, as well as to a variety of ancillary variables (e.g. species range, distance to water, and elevation). The modeling approach and development of the data layers is described in detail on the Southeast Gap Website (www.basic.ncsu.edu/segap). For this project the habitat associations included the structural attributes based on the projected age and stage for each polygon being modeled. For example, the literature suggest that brown-headed nuthatch prefers evergreen woodlands with open under-stories, therefore they would be attributed to polygons in which longleaf woodlands were modeled as having open understory and excluded from closed structure class.

Results

Vegetation Dynamics

Vegetation dynamics were modeled for 94 of the 110 map classes in the SAMBI. The remaining 16 represented anthropogenic (e.g. urban, agriculture) or non-vegetated cover classes (e.g. water, barren land) that would not be impacted by the vegetation modeling, but would be impacted by urbanization, sea-level rise or management actions such as restoration and will be explored in subsequent research. Figure 1 shows the initial conditions used for modeling vegetation dynamics. Dominant vegetation types in the study areas include the evergreen managed pine forests (11%), Atlantic Coastal Plain (ACP) Upland Longleaf Pine Woodlands (7%), ACP Small Blackwater River Floodplain (5%), and ACP Blackwater Stream Floodplain Forest (3%) ACP Dry and Dry Mesic Forest (3%), ACP Fall Line Sandhills Longleaf Pine Woodland, and ACP Peatland Pocosin (2%).

In order to explore the potential impact of climate change on the vegetation, we focus on the results for the ACP Upland Longleaf Pine Ecological System. The longleaf pine system has been identified as one of the most important native ecosystems for conservation (Watson and McWilliams 2005). Historically this type was estimated to dominate the upland sites throughout the ACP (Frost 2006) and currently there a variety of conservation efforts focused specifically on restoration of this ecosystem. The distribution of the state and stage within the ACP Upland Longleaf Woodland is shown in Figure 2. The LANDFIRE estimates of the distribution for the presettlement conditions are that 80 percent of the type would have been in the mid- and late-successional open classes due to the frequent fires and large continuous blocks that allowed for efficient fire movement across the landscape (Frost 1998). Under current conditions the majority of the acreage (58%) was mapped in the mid-successional closed condition. Under the two climate scenarios (A2 and B1) the

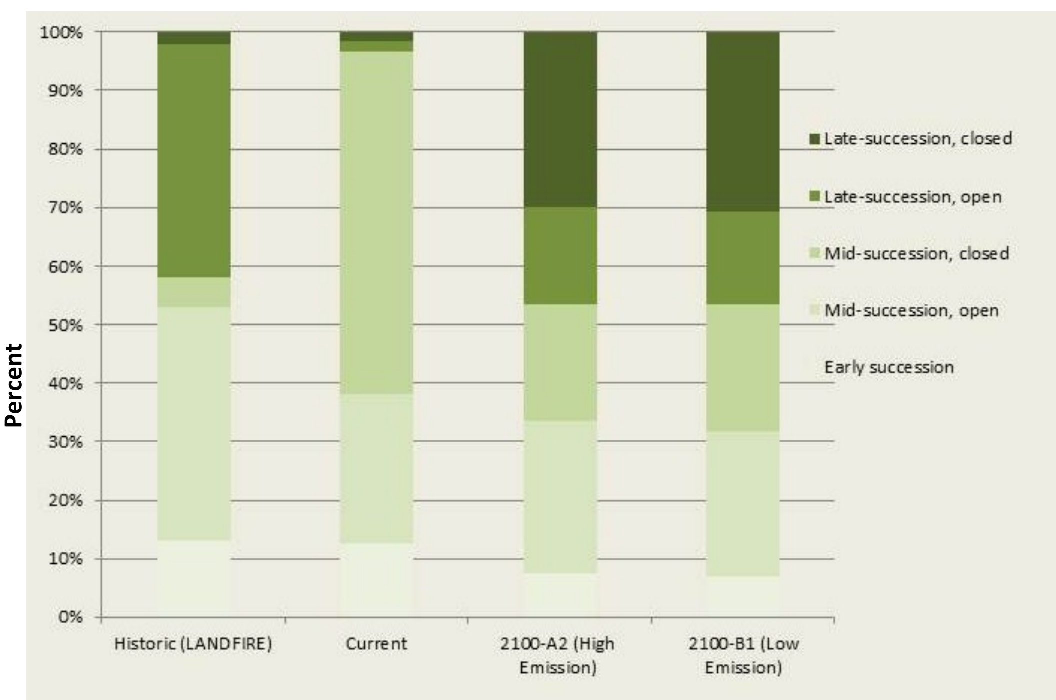

Figure 2. Proportion of Atlantic Coastal Plain Upland Longleaf for Presettlement (estimate), current conditions (mapped) and future projections based on vegetation dynamics modeling and two IPCC climate scenarios (A2 and B1).

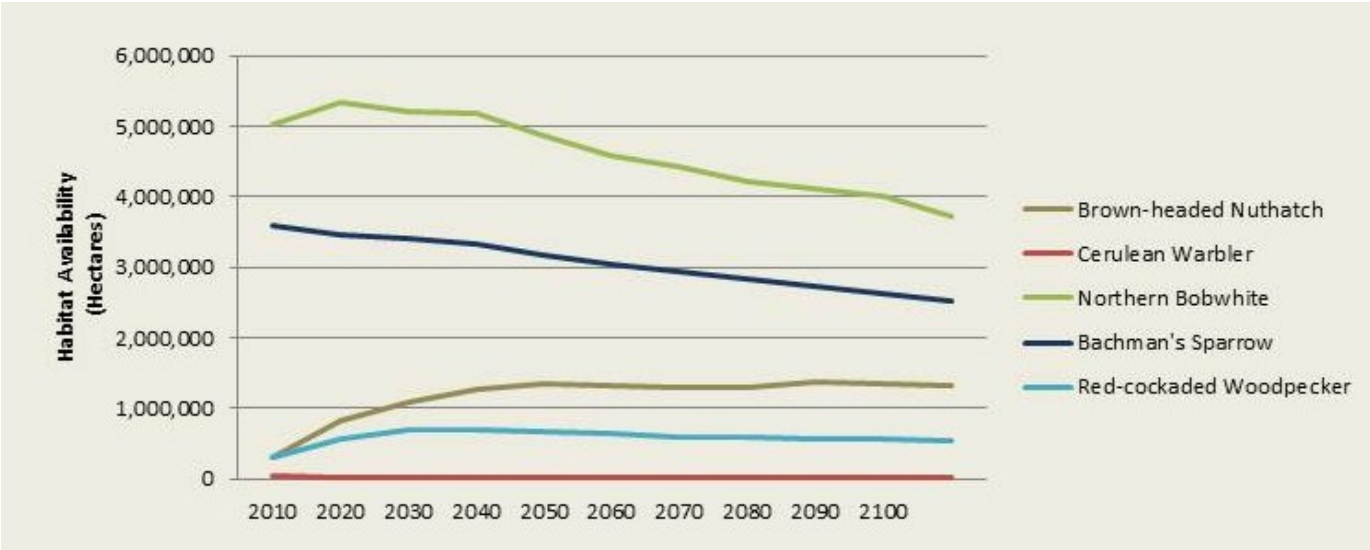

Figure 3. Modeled habitat availability through time for five priority bird species of the South Atlantic Migratory Bird Initiative Area (SAMBI).

model projections suggest a slight shift toward more stands with open under-story, but still a considerable proportion (approximate 50%) remaining in the closed condition.

Habitat Availability

Projected habitat availability by 2100 for three of the five priority species declines through 2100 in the A2 model scenario (Figure 3). The Brown-headed nuthatch and Red-cockaded woodpecker models show a slight increase in the modeled habitat availability at 2100 relative to the initial conditions, although following 2030 the trend is relatively flat. Both Brown-headed nuthatch and Red-cockaded woodpeckers prefer open understory in mature evergreen stands. The increase in the proportion of mid- and late-successional open stands due to increased burning would explain the increase in modeled habitat availability. Cerulean Warblers have a limited range within the SAMBI, primarily along the Roanoke River corridor. Figure 4 shows the difference based on a single monte-carlo simulation for the A2 scenario where habitat availability is projected to decline as a result of disturbances (e.g. fire, flood) in the floodplain habitats. Those disturbances lead to a transition from mature floodplain forest to early successional habitats considered unsuitable for the warbler. It is important to remember that sea-level rise and urbanization are two other model processes leading to some of the changes in habitat availability.

Discussion

In the Southeastern U.S., rapid urbanization, climate change, and the direct and indirect impacts of those two processes on ecosystems are major challenges to developing long-term conservation strategies. An effective conservation strategy must provide information that will allow managers to adapt to these changing conditions. In this project, we are modeling future landscape conditions under climate change scenarios in order to provide managers with that information.

Throughout this project, GAP datasets provide an ecologically rich foundation upon which to build a regional assessment. Detailed GAP land cover data provide the spatially explicit baseline conditions for vegetation dynamics modeling in the DSL project. General land cover products, while critical to addressing many resource management questions, do not provide the detail necessary to describe the important ecological processes that will drive dynamics. For example, ACP

Peatland Pocosin and Canebrake and the Central ACP Wet Longleaf Pine Savanna and Flatwoods are both wetland systems dominated by sparse evergreen trees in the over story that are mapped as Wetland Forest in a general land cover map. However, the understory composition and disturbance regimes for these two systems are quite different. The higher thematic resolution of the GAP land cover map captures those differences and provides the vegetation dynamics model with a more complete set of parameters with which to simulate the potential impacts of climate change on these systems. Finally, the GAP species models provide the link from landscape process to supporting species. The landscape dynamics model outputs are used to generate habitat availability maps for priority species through time and those maps are used in the conservation strategy.

Resource managers are going to continue to need access to decision support tools that integrate the state of the science information. Our ability to provide those tools will depend on a commitment to updating the core datasets through time and to provide for monitoring that will help reduce the uncertainty in an efficient and focused manner.

At the same time, the approach can be applied to explore a wide array of questions about species and ecosystems and their potential sensitivity to land use and climate changes. An adaptive management approach will require that the core datasets necessary to ask and refine the questions about these potential impacts be updated through time.

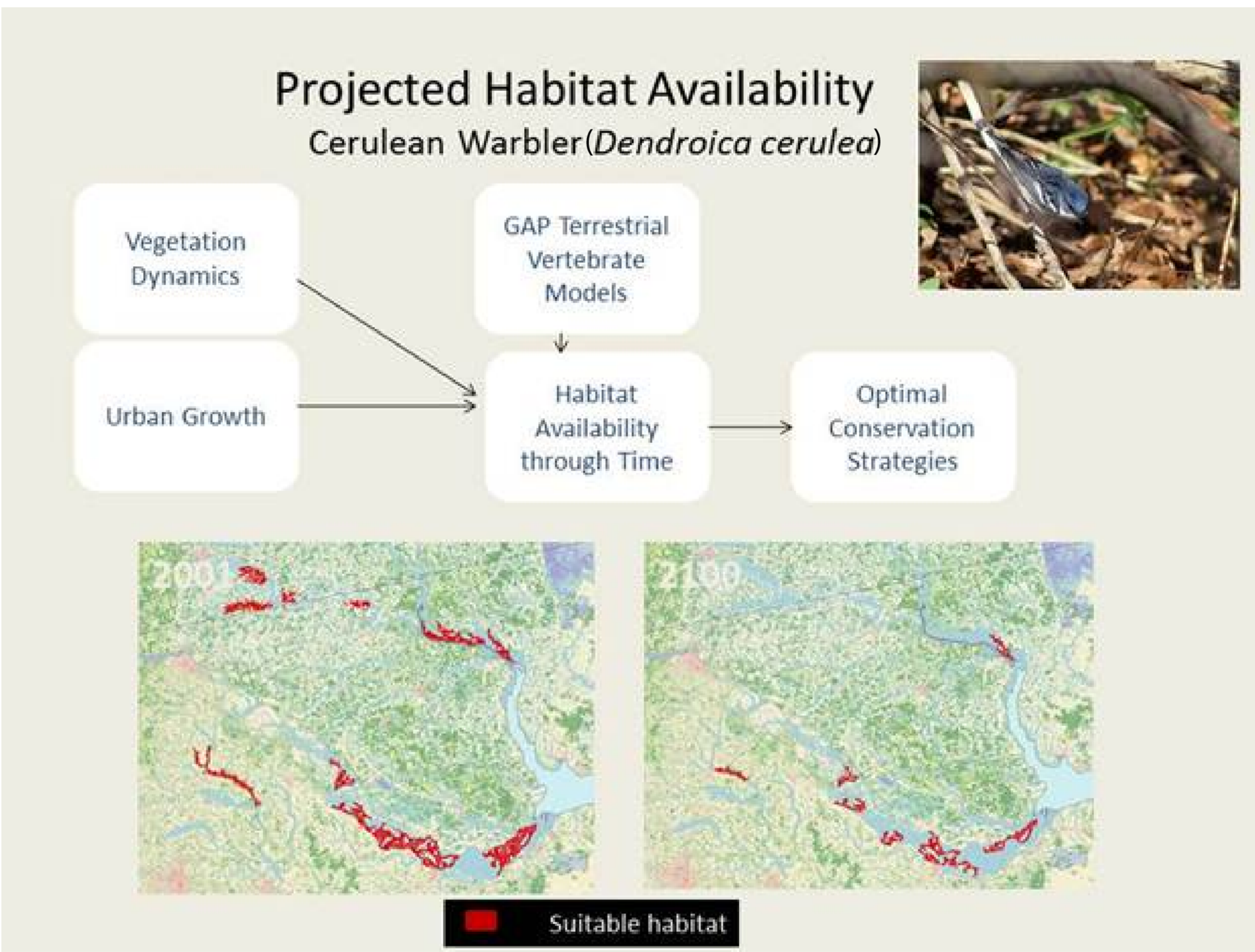

Figure 4. Current and future habitat availability for Cerulean Warbler. Future projection based on A2 emission scenario.

In the fall of 2009 the USGS brought together an interdisciplinary team of scientists to develop a research plan to assess the potential impacts of these changes Southeastern systems. Three broad focus areas were proposed; a coastal assessment to study sea-level rise and inundation modeling, an integrated terrestrial assessment to study changes in habitat availability and avian occupancy due to landscape change (i.e. urbanization and vegetation dynamics), and an aquatic assessment linking hydrologic processes to aquatic species occupancy (Dalton and Jones 2010). An overarching theme of the assessment was the integration of downscaled climate data projections and incorporating measures of uncertainly with respect to the use of global climate models in ecosystem assessments. The work described here provides the basis for the approach to the integrated terrestrial assessment and the Southeast GAP datasets help make that possible.

Literature Cited

Chen, X. and R. Fraser. 2009. Quantifying Impacts of Land Ownership on Regional Forest NDVI Dynamics: A Case Study at Bankhead National Forest in Alabama, USA. PERS. 75(8)997-1003.

Dalton, M. S., and S. A. Jones, comps., 2010, Southeast Regional Assessment Project for the National Climate Change and Wildlife Science Center, U.S. Geological Survey: U.S. Geological Survey Open-File Report 2010–1213, 38 p. (http://serap.er.usgs.gov/docs/SerapOFR2010_1213.pdf: last accessed 30 October 2010).

Gardner, R. H., W. H. Romme, and M. G. Turner. 1999. Predicting forest fire effects at landscape scales. In Spatial modeling of forest landscape change: approaches and applications. D. J. Mladenoff and W. L. Baker, pp 178 – 185. Cambridge University Press.

Frost, C. 1998. Presettlement fire frequency regimes of the United States: a first approximation. In Tall Timbers Fire Ecology Conference Proceedings. 1998, pp. 70–81

Frost, C. 2006. History and Future of the Longleaf Pine Ecosystem. In The Longleaf Pine Ecosystem: Ecology, Silviculture, and Restoration. Eds. S. Jose, E. J. Joketa, and D. L. Miller, pp. 9-48.

Homer, C. J. Dewitz, J. Fry, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, J. Nick VanDriel, and J. Wickham. 2007. Completion of the 2001 National Land Cover Database for the Coterminous United States. Photogrammetric Engineering and Remote Sensing. 73(4) 2007 pp. 337-341.

IPCC. 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kurz, W. A., S. J. Beukema, W. Klenner, J. A. Greenough, D. C. E. Robinson, A. D. Sharpe, and T. M. Webb. 2000. TELSA: the tool for exploratory landscape scenario analyses. Computers and Electronics in Agriculture 27:227-242.

Loveland, T. R., and W. Acevedo. 2006. Land cover change in the Eastern United States, US Geological Survey. ((http://landcovertrends.usgs.gov/east/regionalSummary.html: last accessed 30 November 2010).

McKerrow, A. J., S. G. Williams, A. L. Silvano, E. A. Kramer, K. J. Kleiner, T. S. Earnhardt, J. W. Lee, M. J. Rubino, M. Pyne, K. W. Samples, Curtis M. Belyea, A. E. Ernst, J. B. Grand, M. D. MacKenzie, and J. A. Collazo. In prep. Southeast Gap Analysis Final Report. U.S. Geological Survey, Gap Analysis Program, Moscow, ID.

Napton, D. E., R. F. Auch, R. Headley, and J. L. Taylor. 2010. Land changes and their driving forces in the Southeastern United States. Reg. Environ Change. 10:37-53.

Rollins, M. G. 2009. LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire 18:235-249.

Turner, M. G., R. H. Gardener, and R. V. O'Neill. 2001. Chapter 10. Applied Landscape Ecology. In: Landscape ecology and theory and practice. Springer. 401 pages.

U.S. EPA. 2010. Level IV Ecoregions of the United States. May 10, 2010. EPA Office of Research and Development. (ftp.ftp.epa.gov/wed/ecoregions/us/Eco_Level_IV_US.zip: last accessed December 2010).

U.S.D. A. Forest Inventory and Analysis Program. 2010. The Forest Inventory and Analysis Database: Database Description and Users Manual Version 2.0 for Phase 2. Draft Revision 3. (http://fia.fs.fed.us/library/database-documentation/current/ver4/draft%20FIADB_user%20manual_v4-0_p2_03_11_2010.pdf : Last accessed December 2010).

Watson, C. and K. McWilliams. 2005. South Atlantic Migratory Bird Initiative Implementation Plan: An Integrated Approach to Conservation of "All Birds Across All Habitats". Atlantic Coast Joint Venture.

Wear, D. N, D. R. Carter, and J. Prestemon. 2005. The U.S. South's Timber Sector in 2005: A Prospective Analysis of Recent Change. 44 pp. General Technical Report SRS-99. http://www.srs.fs.usda.gov/sustain/report/pdf/gtr-srs-99.pdf: last accessed 2 November 2010).

Withgott, James H. and Kimberly G. Smith. 1998. Brown-headed Nuthatch (Sitta pusilla), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/349doi:10.2173/bna.349: last accessed December 2010.

Zhu, Z. J. Vogelmann, D. Ohlen, J. Kost, X. Chen, and B. Tolk. 2006. Mapping Existing Vegetation Composition and Structure for the LANDFIRE Prototype Project. In: The LANDFIRE Prototype Project. RMRS-GRT-175. U.S.D.A. Forest Service. Pp. 197-217.

Aquatic GAP Program Update

Andrea Ostroff
Aquatic Gap Program Manager, United States Geological Survey, Reston, VA

Over the last year, the Aquatic Gap Analysis Program (AGAP) has been focusing on several aspects of the program to address program development needs. The program's major initiatives have focused on completing several watershed basin analyses through the accomplishments of AGAP partners, integrating program efforts into national initiatives, and improving the process through which information and data dissemination of AGAP products is handled. Work to improve on these goals through the implementation of programmatic standards will provide additional guidance for future projects supported through Aquatic GAP.

AGAP has a responsibility to uphold the standards of the US Geological Survey (USGS) to disseminate information products to our stakeholders in ways that contribute to their needs most effectively. Two efforts currently underway within AGAP – a web site and a map viewer - will address this priority. The new Gap Analysis Program web site <http://blogs.nbii.gov/gapanalysis/gap-analysis/aquatic-gap/> will include Aquatic GAP project reports, highlights, access to data products, and an Aquatic GAP map viewer. The Aquatic GAP Viewer, a web-based application, will enable the querying and visualization of the modeled presence of over 500 aquatic vertebrate and invertebrate species in streams and rivers across the continental United States. The tool brings together data from eight regional projects (Iowa, Flint River Basin in Georgia, Kansas, Upper Missouri, Missouri, Pennsylvania, South Dakota, and Ohio) into a unified inter-

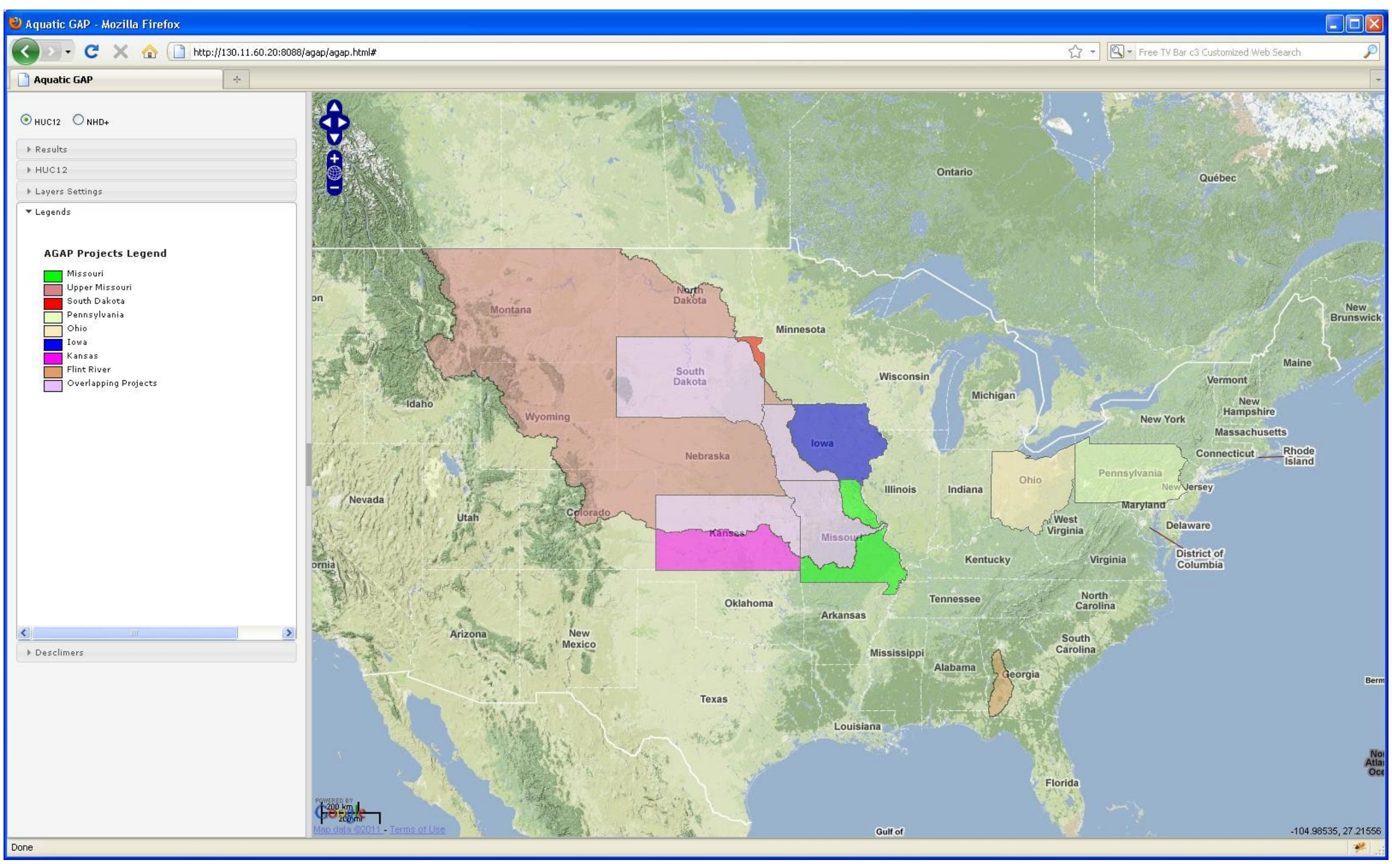

Figure 1: Distribution and spatial coverage of projects completed under the National Aquatic GAP program.