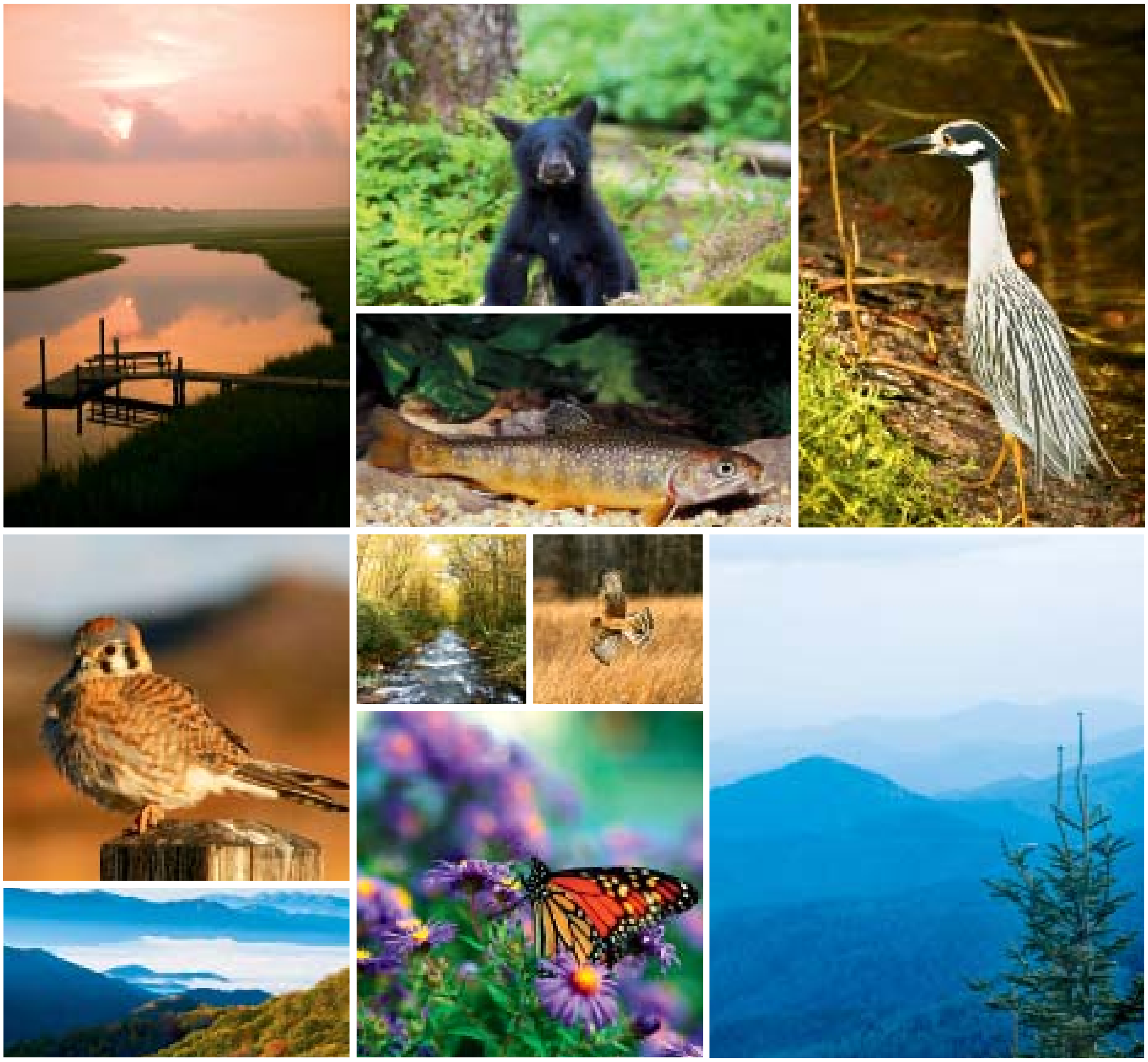
Understanding the impacts of climate change on fish and wildlife in North Carolina



A review of climate change science, impacts, and planning options for sensitive species and habitats

Conservation Planning Program, Defenders of Wildlife

Defenders of Wildlife is a national, nonprofit, membership organization
dedicated to the protection of all native wild animals and plans in their natural communities.

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North Carolina Wildlife Resources Commission

Gordon S. Myers, Executive Director

In 2005, the North Carolina Wildlife Resources Commission (WRC) completed its first comprehensive wildlife conservation strategy: the North Carolina Wildlife Action Plan (NC WAP). This plan was created as a blueprint for fish and wildlife conservation across the state, and has engaged numerous agency, industry, academic, and NGO partners to contribute to the sustainability of our state's wildlife resources. As a living document, the NC WAP will be updated to reflect new challenges, and opportunities, as the conservation landscape changes.

Climate change is a serious threat to fish and wildlife across the nation. In response to this threat, Congress has begun to identify the need for supporting state wildlife agencies in their efforts to sustain natural resources under changing climate conditions. In an effort to ensure responsible stewardship of our state's wildlife resources, and to prepare for potential new funding initiatives, the WRC is taking action to help safeguard our fish and wildlife from the negative effects of climate change. These actions include a September 2010 workshop entitled "Incorporating Climate Change into North Carolina's Wildlife Action Plan."

Given the complexity and breadth of the current science and the global nature of these issues, it can be challenging to understand how climate change may affect our cherished natural heritage. I am therefore excited to present this report that has been prepared by Defenders of Wildlife for the WRC: *Understanding the Impact of Climate Change on Fish and Wildlife in North Carolina*. This report was developed with input from the WRC Wildlife Action Plan Workshop Steering Committee, and serves as an important reference for: understanding basic climate change science, identifying how climate changes impact fish and wildlife, reviewing potential impacts on species and habitats in North Carolina, and highlighting management and planning options to consider when updating the NC WAP. As our North Carolina partners continue to engage on climate change issues across the state, we hope this report will serve as a valuable resource for understanding how we can move forward to address this significant challenge.

Sincerely,

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PREFACE

Climate change is proceeding at a rate at which there will be unavoidable impacts to humans, wildlife, and habitat. Given current levels of heat-trapping greenhouse gas emissions, we are expected to experience substantial shifts in local, regional, and national climate patterns. These shifts have the potential to disrupt natural processes, and in some areas may cause significant degradation to ecosystems that provide services such as clean and abundant water, protection from flooding, and sustainable natural resources of timber products or game species.

Mitigation strategies, or policy and management actions that reduce greenhouse gas emissions that contribute to global warming, are and will continue to be an important part of any plan to reduce the impacts of climate change. These strategies include actions at the individual level, such as reducing your carbon footprint by driving less often, as well as strategies at a regional or national level to curb harmful greenhouse gas emissions from factories or other pollution sources. Despite the growing knowledge about and interest in climate change, greenhouse gas emissions continue to increase, exceeding even the "business as usual" trajectory that scientists warn will lead to dire consequences. Consequently, even if the most rigorous mitigation strategies were implemented today at the local, regional, and national level, we will continue to experience the effects of climate change for many years to come. Because of these lasting effects, it will be critical for fish and wildlife agencies to play a significant role in developing strategies to safeguard wildlife, fish, and their supporting ecosystems from the impacts of climate change.

Climate change adaptation refers to the adjustment in natural and human systems in response to expected climate change impacts that we cannot prevent. Adaptation is critical because we know that climate change is already happening, and that its effects on human and natural communities are already apparent in many regions across the globe. What's more, some additional warming is unavoidable. Because carbon persists for a long time in the atmosphere, there will be an inevitable lag between when we reduce emissions and when we start to see the results in the climate system and the natural world.

For fish, wildlife, and habitats, adapting to climate change will be a long-term, iterative process, and will be particularly challenging given existing threats such as habitat loss and fragmentation from development, introduction of invasive species, water pollution, and wildlife diseases. Shifts in local climate, such as temperature and precipitation, may further exacerbate these existing threats, putting some species at even more risk. Thus, climate change adaptation might best be seen as a new and permanent element of conservation planning and wildlife management, rather than a separate activity or a one-time planning process.

The southeastern United States contains some of the highest biological diversity, and some of the most endangered ecosystems, found anywhere else in the world. The State of North Carolina contributes to the Southeast's unique floral and faunal diversity, from supporting the nation's highest number of amphibian species to a rich portfolio of unique ecosystems such as spruce-fir and southern forested wetlands. In 2005, the North Carolina Wildlife Resources Commission (NCWRC) developed the State Wildlife Action Plan (NC WAP) to build on existing conservation efforts and develop a comprehensive blueprint for the conservation of fish and wildlife. In preparation of the NC WAP, the NCWRC and their partners identified over 350 species in greatest conservation need and provided a detailed array of management opportunities and approaches for partner-based, strategic conservation.

In recognition of the potential impacts of climate change on important North Carolina wildlife species and habitats, the NCWRC is preparing for a revision of the NC WAP. This revision is intended to highlight the special conservation issues associated with projected regional climatic shifts, and provide a critical first step towards safeguarding wildlife and habitats from climate change. However, given the complexity of climate change science, the breadth and depth of stakeholder groups who have been involved in the NC WAP, and the diversity of academics, NGOs, as well as state and federal agencies who are currently working on climate change issues in the region and state, the NCWRC identified a clear need for a review of the state of climate change science and potential impacts on species and habitats specific to North Carolina.

This report provides a comprehensive and up-to-date review of climate change science relevant to the state of North Carolina, the potential vulnerability of wildlife and their habitats, and the options for response through conservation planning, adaptive management, strategies, and actions. Although decreasing greenhouse gas mission will be critical for reducing the severity of climate change impacts, this report focuses on adaptation rather than mitigation, in an effort to provide guidance for updating the NC WAP. As each chapter provides a standalone component of specific elements of climate change in the state, readers may benefit from reading the report from start to finish or individually by chapter depending on their current level of understanding and potential application of the available science. Collectively, this report provides a general overview of available climate science (how do we know what we know), as well as a synthesis of the fundamental process for projected shifts in temperature, precipitation, hydrology, and sea level rise. In addition, we provide maps and a review of the fundamental ecological principles that underlie potential climate change impacts on natural systems. We then use that analysis to identify potential impacts of projected shifts on species and habitats in the southeast and North Carolina. The potential impacts of climate change on species and habitats are also reviewed through the lens of synergistic threats such as alternative energy development and land use change. Finally, we outline a template for effective conservation planning, adaptive management, and adaptive management considerations in the face of climate change. Each of these topics is covered in 5 chapters and appendices described below:

In Chapter 1, we provide a review of the fundamental components of climate change science, such as climate modeling, functional and physical impacts on wildlife and habitat, and vulnerability. This review can serve as a baseline for understanding the latest climate science as well as provide a framework for thinking about how wildlife species and habitats may respond to climatic shifts.

In Chapter 2, we describe some of the projections of temperature, precipitation, and sea level rise in the southeast under climate change, and highlight the available research on potential impacts to terrestrial and aquatic species.

In Chapter 3, we apply climate modeling scenarios to map state-specific projected temperature and precipitation changes, and use this information to identify a broad subset of species and habitats in North Carolina that may be particularly susceptible to climate change impacts in the state.

In Chapter 4, we examine several synergistic threats to species and habitats, including land use change, demand for land intensive alternative energy sources, and spread of invasive species, as well as how climate change may amplify the impact of these stressors on wildlife in North Carolina.

In Chapter 5, we describe the conservation planning process, as well as important considerations for implementation, with specific reference to adaptive management. We also identify climate change adaptation strategies, actions for wildlife and habitat, and discuss the importance of social and institutional adaptive capacity for developing and implementing actions. Finally, we provide information on what other states are currently doing and identify emerging federal programs and partnerships, which may be critical for regionally coordinated climate change adaptation.

In the Appendices, we provide a detailed review of available geospatial data, reports, invasive species, and policy/legislative opportunities that may support the NCWRC in revising the NC WAP.

Acknowledgments

We would like to take this opportunity to acknowledge the North Carolina Wildlife Resources Commission and our partners on the NC WAP and Climate Change Steering Committees. We would specifically like to thank Shannon Deaton and Perry Sumner for their leadership in organizing and guiding this committee, and for tackling this challenging and important issue. We also appreciated the thoughtful edits and insights provided by the Steering Committee during each stage of report development. In addition to Shannon and Perry, the following Steering Committee members contributed valuable edits to this report: Scott Anderson, Naomi Edelson, Todd Ewing, Chris Goudreau, Jamie Hammerman, Austin Kane, and Chris McGrath. It is our hope that this synthesis will serve as a valuable resource for engaging the conservation community and laying the groundwork for revising the North Carolina State Wildlife Action Plan.

Understanding Climate Change and Impacts on Wildlife

> *“[T]he direct impacts of anthropogenic climate change have been documented on every continent, in every ocean, and in most major taxonomic groups.”*
>
> *C. Parmesan, 2006*

There is now scientific consensus that global warming is caused by increases in greenhouse gas emissions that are higher today than they have been at any other time in the last 650,000 years (IPCC 2007). The scientific evidence is overwhelming, with numerous independent studies showing patterns of increase in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level. The last decade was the warmest on record since weather records began in the 1880s (Arndt et al. 2009), and global average temperatures have increased 0.4°F (0.2°C) per decade since the 1970s (IPCC 2007).

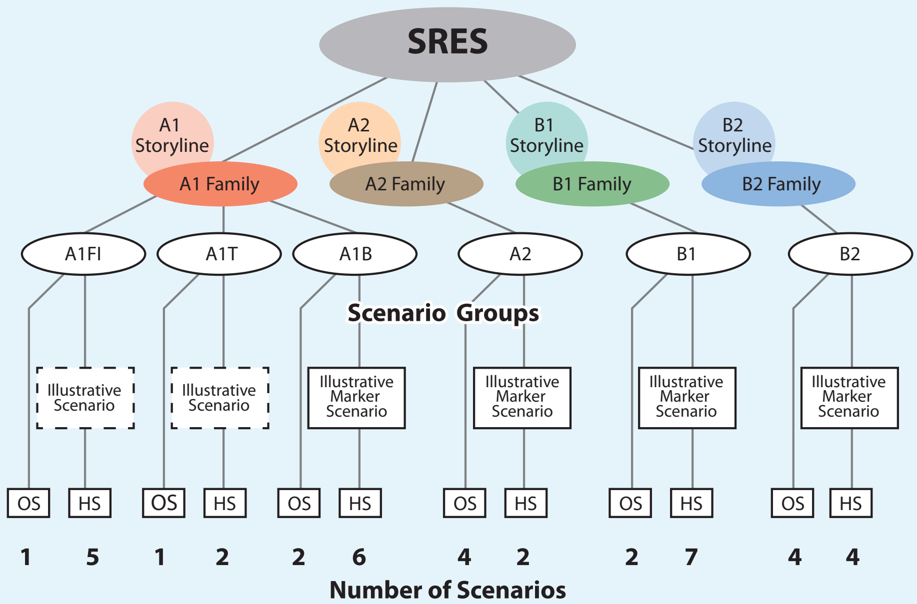
Continued greenhouse gas emissions at or above current rates will lead to further global warming during the 21st century, which would very likely be greater than that observed during the 20th century (IPCC 2007). The global warming trend has accelerated in recent decades, and the pace of climate change projected this century is occurring faster than most managed ecosystems have experienced previously (Barnosky et al. 2003). It is likely that rates of climate change will be more rapid than most species can adapt to through evolutionary changes or migration to more favorable climate locations (Davis and Shaw 2001, Pearson 2006). These projected changes threaten our conservation investments – which to date have existed mostly in the form of isolated protected areas and mandated management goals for species and ecosystems based on historical targets (Heller and Zavaleta 2009).

Most natural resource planning, management, and monitoring methodologies that are in place today are still based on the assumption that climate, species distributions, and ecological processes will remain stable. Approaches to conservation in a climate changed future will need to be dynamic, address changes across spatial and temporal scales, and incorporate flexibility to continue refinement as information increases (Hansen et al. 2010). Under climate change, natural resource agencies may be forced to adjust timeframes, plan for alternative future scenarios, and revise resource management plans or actions more often than in the past. In this chapter, we provide a review of the fundamental components of climate change science, such as climate modeling, functional and physical impacts on wildlife and habitat, and vulnerability. This review can serve as a baseline for understanding the latest climate science as well as provide a framework for thinking about how wildlife species and habitats may respond to climatic shifts.

1.1 Climate Models and Emissions Scenarios

In order to predict and prepare for the impacts of climate change on natural systems, it is necessary to have a basic understanding of the science of climate change. Climate is the accumulation of daily and seasonal weather events, over weeks, months, years, and longer. It is measured in the long-term averages of weather variables and departures of weather variables from normal. Weather is the condition of the atmosphere at any particular moment in time and place, and is the day-to-day state of the atmosphere.

The main characteristics of the four SRES storylines and scenario families



This figure shows a schematic illustration of SRES scenarios. Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. Altogether 40 SRES scenarios have been developed by six modeling teams. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (Balanced), and A1T (predominantly non-fossil fuel). Within each family and group of scenarios, some share "harmonized" assumptions on global population, gross world product, and final energy. These are marked as "HS" for harmonized scenarios. "OS" denotes scenarios that explore uncertainties in driving forces beyond those of the harmonized scenarios. The number of scenarios developed within each category is shown. For each of the six scenario groups an illustrative scenarios (which is always harmonized) is provided. Four illustrative marker scenarios, one for each scenario family, were used in draft form in the 1998 SRES open process and are included in revised form in this Report. Two additional illustrative scenarios for the groups A1FI and A1T are also provided and complete a sex of six that illustrates all scenario groups. All are equally sound.

By 2100 the world will have changed in ways that are difficult to imagine – as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key future characteristics such as demographic change, economic development, and technological change. For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of current economic, technological, and social trends.

- The A1 storyline and scenario family describes a future world 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. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological changes in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B)[1].
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reduction in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

[1] *Balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy and end use technologies.*

Figure 1-1. Schematic illustration of emissions scenarios and storylines from the *Special Report on Emissions Scenarios* (Source: Nakićenović et al. 2000). These scenarios are used to make predictions about future greenhouse gas emissions, which are then incorporated into projections of future global warming.

Increased emissions of greenhouse gases are changing average climate conditions, locally and across the globe. In order to understand the changes in climate that will result from increased concentrations of these gases, scientists rely on climate model simulations that are driven by assumptions about future population growth, socio-economic development, and technology change (Nakićenović et al. 2000). These assumptions, or scenarios, provide the basis for estimating future greenhouse gas emissions and are used as inputs to run global climate models that simulate changes in temperature, precipitation, and other climate-related conditions.

The IPCC (2000) has developed a set of 40 scenarios that provide multiple alternative models of how future population growth, changes in wealth, and advances in technology may alter future emissions outcomes (Figure 1-1). These scenarios are based on four narrative storylines that represent different demographic, social, economic, technological, and environmental developments. For example, the A1 storyline describes a future with very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technology (Figure 1-1). Scenarios that capture the main driving forces behind greenhouse gas and sulfur emissions are then based on each storyline. For example, from the A1 storyline, three scenario groups have been distinguished based on technological emphasis: fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance across all sources (A1B). Each scenario results in a specific quantitative estimate of emissions based on a quantitative interpretation of each storyline (IPCC 2000). These emission scenarios are not predictions or forecasts, rather an alternative image of how the future might unfold based on a set of transparent assumptions.

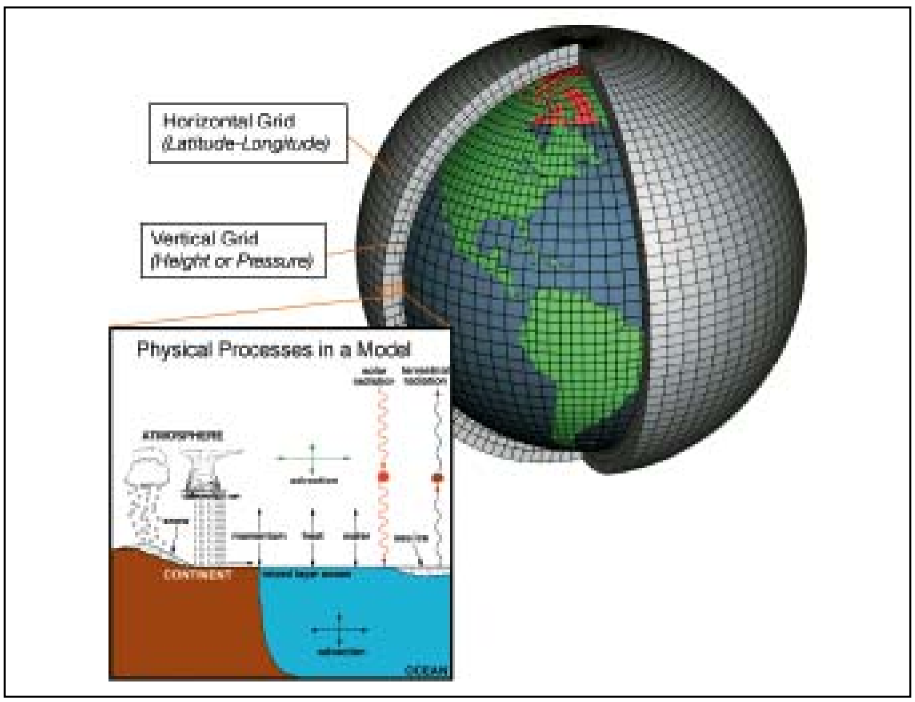


Figure 1-2. Climate models are systems of differential equations based on the basic laws of physics, fluid motion, and chemistry. Scientists divide the planet into a 3-dimensional grid, apply the basic equations, solve for the equation of state of the system, and update the results for the next model time step. Atmospheric models calculate winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points (Source: NOAA 2008).

It is difficult to predict the human choices that will shape our future emissions, and thus what the world might look like in 2100. For example, under the higher emissions scenario (A1F1) atmospheric concentrations of carbon dioxide (CO2) reach more than triple pre-industrial levels, or 960 ppm, by 2100. Similarly, a lower emissions scenario (B1) represents a world with high economic growth and mid-century population peak and subsequent decline. In contrast to the A1F1scenario, the B1 scenario includes a shift to less fossil-fuel intensive industries and the introduction of clean and efficient technologies with a resulting peak in emissions of greenhouse gases by 2050, and then a decline. In the B1 scenario, CO2 concentrations reach 550 ppm by 2100, which is about double pre-industrial levels (Nakićenović et al. 2000). In 2009, the global annual mean concentration of atmospheric CO2 was 386.27 ppm (NOAA/ESRL 2010). If recent emissions growth rates continue, CO2 levels, along with the associated effects of climate change, are very likely to exceed even the highest existing emissions scenarios (Rahmstorf et al. 2007).

Global climate/general circulation models (both GCMs) are computer-based models of the climate system developed from weather forecasting models (Goodess 2000) which incorporate interactions

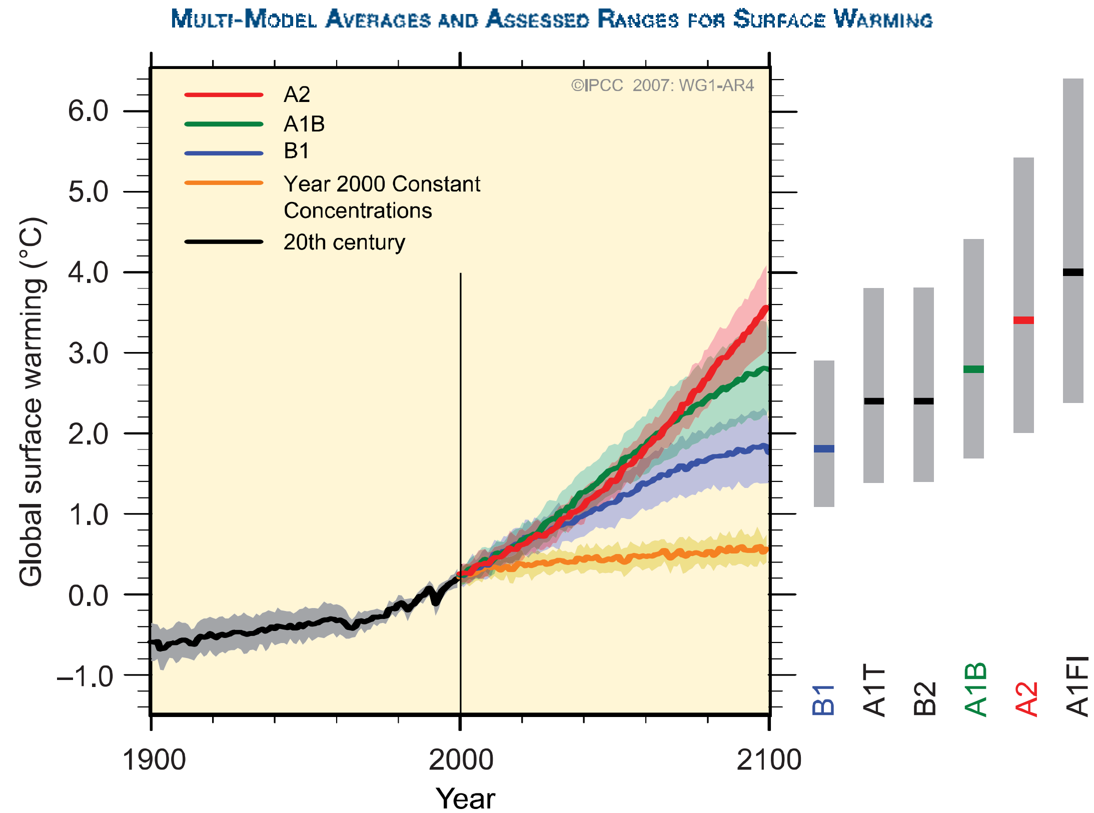


Figure SPM.5. *Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the **likely** range assessed for the six SRES marker scenarios. The assessment of the best estimate and **likely** ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}*

Figure 1-3. Multi-model averages and assessed ranges for global surface warming under different emissions scenarios (Source: Nakićenović et al. 2000). Regardless of which scenario is assessed, significant global warming is expected to occur.

among atmosphere, oceans, land surface, and ice in order to estimate the likelihood of changes in temperature, precipitation, and other climate factors (Hayhoe et al. 2010). These models are complex, as they simulate the climate system in three dimensions (Viner 2000) (Figure 1-2). Atmosphere-only GCMs were the first generation of climate models, and were used to simulate the equilibrium response of the climate system to a doubling of atmospheric CO_2 (Viner 2000). More recent models build on the AGCMs with coupled Atmosphere-Ocean General Circulation Models (AOGCMs). AOGCMs are more complex and incorporate additional factors such as sea ice, evapotranspiration over land, and the feedback interactions between the ocean and atmosphere (Randall et al. 2007, Hayhoe et al. 2010). Most importantly, these models are able to dynamically model the ocean, which has a significant impact on the climate system as a whole.

There have been major advances in the development of climate models over the last 20 years, and current models provide a reliable guide to future conditions at a coarse scale, given a particular scenario (Randall et al. 2007). One way GCMs are evaluated is by simulating the historic climate using past observed concentrations of greenhouse gas emissions, and then compare those model outputs to the observed climate (Weart 2009). Climate models have successfully reproduced the main features of the current climate, including temperature changes over the last hundred years, as well as the main features of the Holocene period (6,000 years ago) and the Last Glacial Maximum (21,000) years ago (Weart 2009). By evaluating models against past climate data, scientists are able to identify potential causal mechanisms of climate change, and use that information to project the main features of the future climate (Jones 2000). Models are continually tested and scrutinized, and there are ongoing improvements in computational ability as well as resolution. The ability of AOGCMs to simulate extreme events, such as hot and cold spells, has also improved, although the frequency and amount of precipitation falling in intense events are underestimated (Randall et al. 2007). Models are able to project some climate variables, such as temperature, with a higher degree of confidence than other variables, such as precipitation. However several decades of development have resulted in a robust and unambiguous picture of significant global warming in response to increasing greenhouse gases (Randall et al. 2007) (Figure 1-3).

There are more than 20 climate models included in the third phase of the Coupled Model Intercomparison Project (CMIP3), which was developed to serve the IPCC Working Group I for the Fourth Assessment Report (Meehl et al. 2007). Some of these models are better at reproducing observed climate and trends over the past century in particular geographic regions than others (Hayhoe et al. 2010). However, for the purposes of analyzing the potential impacts of climate change, the multimodel ensemble average provides a more robust picture of future climate conditions than any one model (Pierce et al. 2009). Furthermore, choosing one model for use requires a detailed understanding of the climate dynamics in the region of interest (Hayhoe et al. 2010). In most cases, when evaluating the potential impacts of climate change in a given region it is best to use the multi-model ensemble average instead of choosing one or two (Pierce et al. 2009).

1.1.1 Downscaling climate models for use at the regional scale

One of the drawbacks of the current generation of GCMs is that the resolution is fairly course, upwards of several hundred kilometers (K. Hayhoe et al. 2010). To develop projections of regional climate changes based on global concentrations of greenhouse gas emissions, the global climate models must be downscaled to transform the large-scale output generated to a regional scale. The main approaches to downscaling are statistical and dynamical downscaling.

Statistical downscaling requires establishing an empirical relationship between the AOGCM output for the past record and observed climate variables of interest. This relationship is tested using a second historical evaluation period and then used to project future change across the region of interest (K. Hayhoe et al. 2010). Statistical downscaling is the approach that was used to generate the spatial data (Maurer et al. 2007) used in the Climate Wizard (Zganjar et al. 2009), which is a freely available online tool for obtaining downscaled climate projections. All of the climate projections that were created specifically for this publication were developed using Climate Wizard.

Climate Wizard (Zganjar et al. 2009) provides access to 16 global climate models that can be used to develop downscaled projections of climate change across North America (Figure 1-4). Climate Wizard can show climate data for the last 50 years, including how the climate changed over time. In addition, Climate Wizard shows climate projections for years 2040-2069 and 2070-2099. All of these data can be downloaded and exported into a mapping or imagery program. In addition, the Southeast Regional Assessment Project (SERAP) is the first regional assessment to be funded by the USGS National Climate Change and Wildlife Center, and will be converting a suite of global models into regional climate projections of likely changes to the Southeast's climate and ecosystems. For more on these and other data resources see Appendix A.

Regional, or dynamical downscaling relies on the development of a high resolution climate model built for a specific geographic location. The model is centered over the region of interest and relies on global climate model output fields at its boundaries (K. Hayhoe et al. 2010). These models, which can provide a resolution of 10 to 50 kilometers, are able

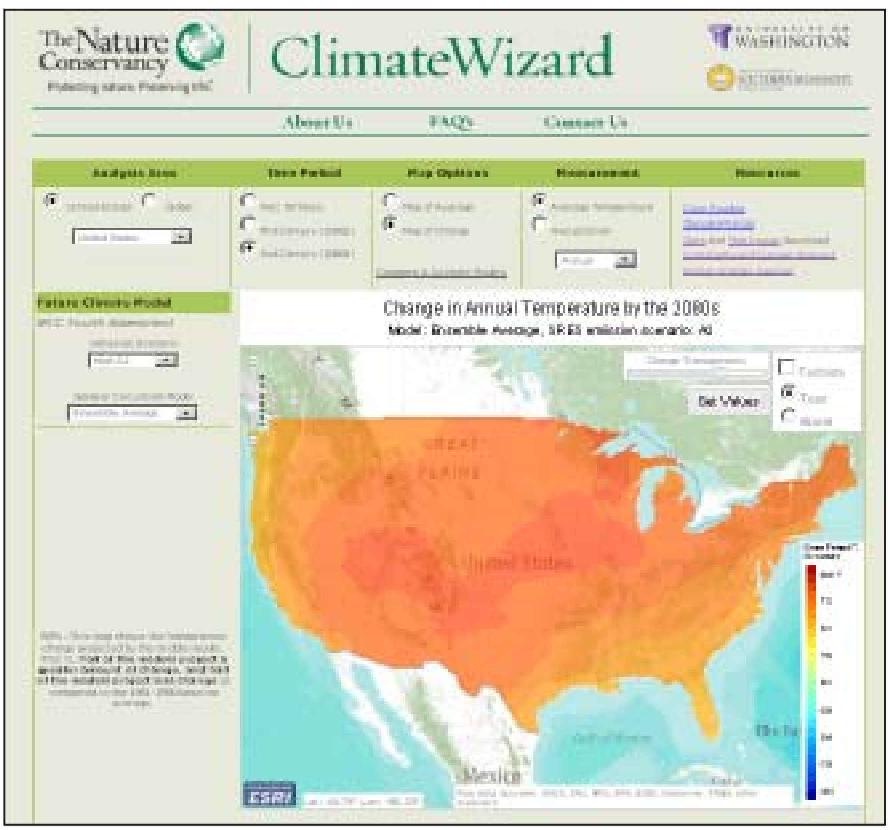


Figure 1-4.
The Climate Wizard user interface (http://www.climatewizard.org). The website allows the user to easily access statistically downscaled climate projections using 16 global climate models (Zganjar et al. 2009)

to simulate the dynamic changes expected to occur at a smaller scale as the global climate changes; they are also expensive to run and data-storage intensive (K. Hayhoe et al. 2010). The regional model simulations generated by the North American Regional Climate Change Assessment Program (NARCCAP) are currently the most comprehensive set of regional models currently available (NARCCAP 2007). The NARCCAP uses regional model/global model pairs to simulate conditions from 2041 to 2070 and compared to 1971-2000 (K. Hayhoe et al. 2010).

1.2 Overview of Impacts of Climate Change on Species and Habitats

Ecosystem processes are strongly influenced by climate, and changes in climate will affect ecosystem processes, ecological communities, and individual species. Climate change has been implicated in several recent species extinctions (McLaughlin et al. 2002, Pounds et al. 2006). Largely in response to environmental factors associate with changes in temperature, species ranges have shifted poleward and upward in elevation over the last century (Parmesan and Yohe 2003), and some species ranges, particularly in Polar Regions and at high elevations, are shrinking. Furthermore, changes in the timing of biological processes (phenology) are occurring, altering relationships between species and decoupling critical species interactions (Walther et al. 2002). Ecological communities are disaggregating, and as new and often novel communities assemble, warm-adapted and invasive species may be favored (Parmesan 2006, Hellmann et al. 2008). Species are also losing habitat due to sea level rise, changes in fire frequency and intensity, changes in water availability, glacial recession, pest outbreaks and altered weather patterns. Species invasions, as well as pest and disease outbreaks, are becoming more prevalent under climate change and, taken with other ongoing threats, are likely to significantly impact native species and ecosystems.

1.2.1 Climate Change Impacts on Community Composition

Climate exerts control over the natural distribution of species and the formation of ecological communities. The diversity of species within ecological communities is influenced by a combination of local and regional-scale processes (Caley and Schluter 1997). Local-scale interspecific interactions include competition, predation, parasitism, mutualisms or commensalisms, while regional-scale processes shape the species pool from which the community can be assembled. Regional processes that maintain diversity at a larger scale include long-distance dispersal, speciation, wide-spread extinction, and fluctuation in species distributions (Cornell and Lawton 1992). Ecological communities have always been dynamic–species diversity and composition within a community is temporary and, as species respond individualistically to changes in environmental conditions, communities may diasassociate, resulting in new species associations and interactions (Huntley 1991).

Climate change will alter the abiotic conditions experienced by communities, with resulting effects on community composition and species interactions. As climate changes across the globe, the current distribution of climate conditions will be rearranged, with some climates disappearing entirely and new, dissimilar climates occurring. Using two emissions scenarios, Williams et al. (2007) estimated that by 2100, 17-100% of global land area will experience novel climate regimes. For the U.S., approximately half of environmental domains, defined by edaphic, topographic and climatic factors, were projected to experience novel climates. Areas projected to experience novel climate conditions are considered to be at greatest risk of biodiversity loss (Saxon et al. 2005).

Paleoecological studies suggest that the majority of species will respond individualistically to changes in climate (Huntley 1991, Hansen et al. 2001, Bush 2002). The fossil record from the Quaternary Period contains significant evidence of species responses to climate change from a range of taxa including plants, insects, and mammals (reviewed in Keith et al. 2009). Perhaps one of the most widely recognized impacts of climate change on species is expected and observed range shifts. In regions experiencing warming temperatures, expected species range-shifts are generally poleward to higher latitudes and upward to higher elevations (Parmesan 2006). The distribution and abundance of plant, invertebrate, and vertebrate species that occur along the latitude and elevation margins of their range are already strongly influenced by climate change (Lenoir et al. 2008).

… most invasive species have rapid dispersal abilities and may have the capacity to survive and tolerate a range of environmental conditions

A review by Parmesan (2006) provides a number of examples of observed species shifts in response to climate change. In northern hemisphere temperate

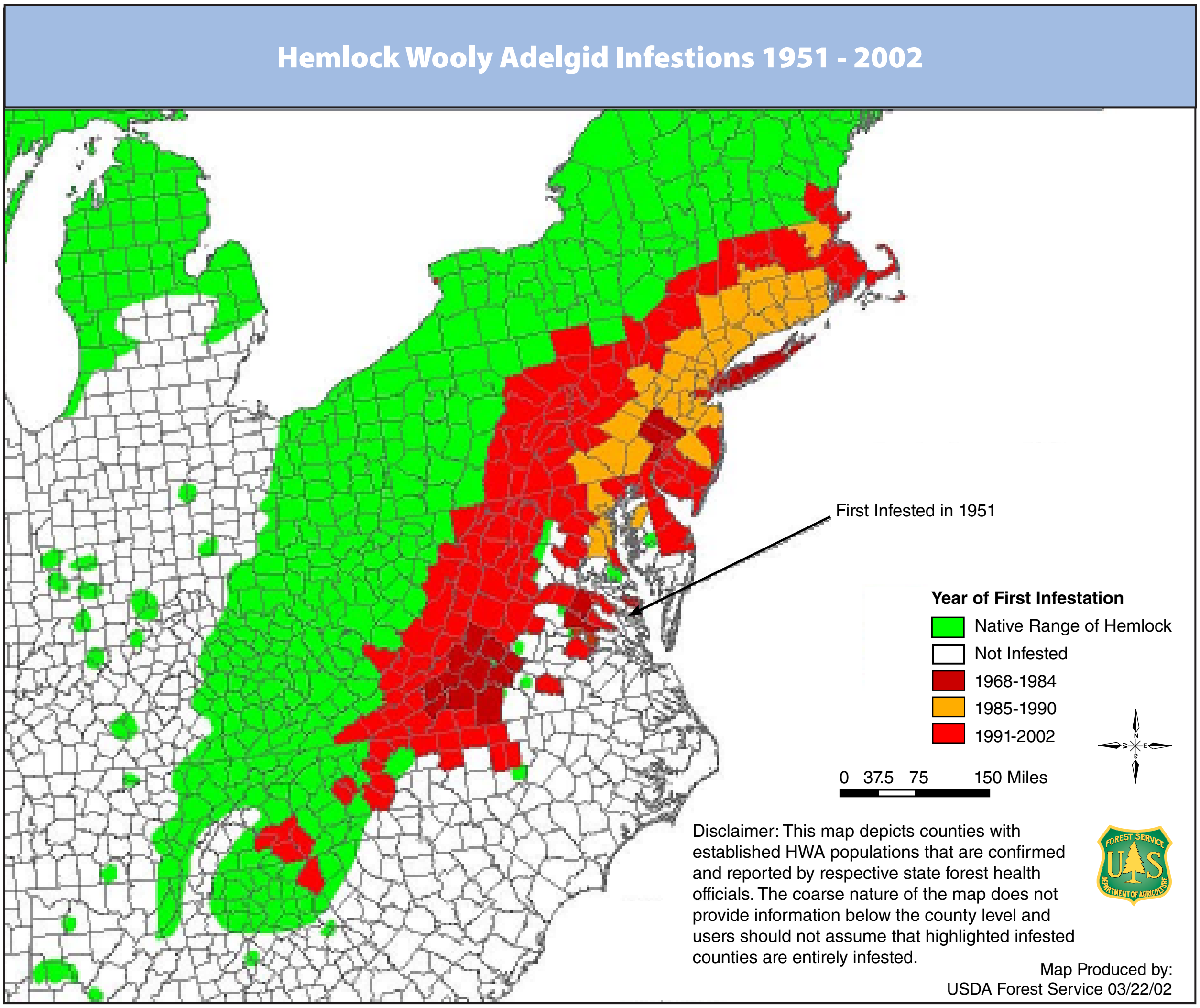


Figure 1-5. Hemlock wooly adelgid (*Adelges tsugae)* infestation in North America from 1951 to 2002 (Source: USDA Forest Service 2010). Wooly adelgid are sensitive to cold temperatures and experience significant overwintering mortality when exposed to cold conditions. Under climate change, this pest is expected to thrive with warmer winters, and has already experienced range expansion since it was discovered in 1951.

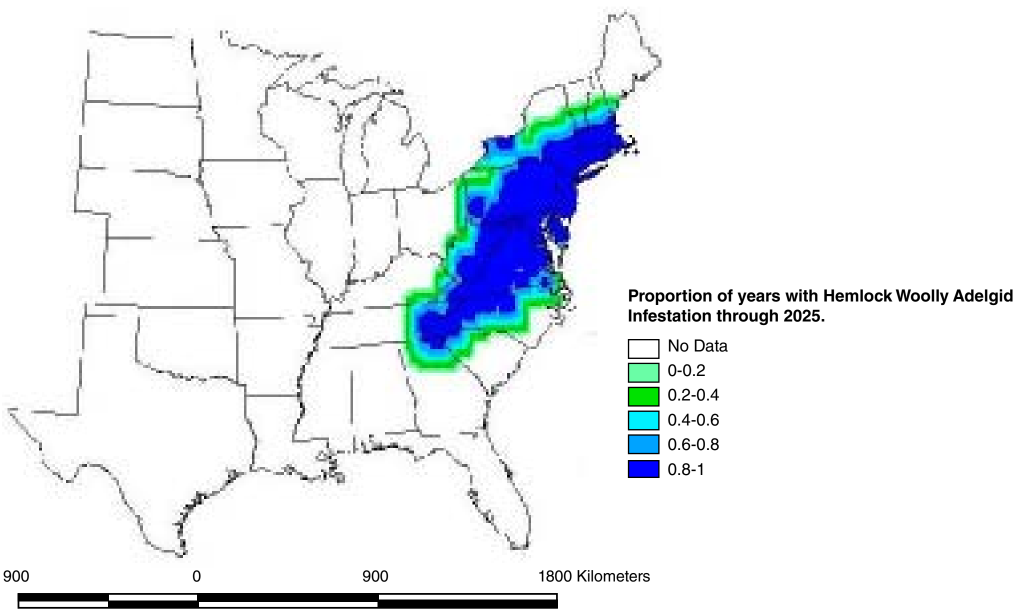
species there is evidence of Lepidoptera expansion of northern boundaries in Finland, Great Britain, and Europe, northern range expansion of 23 of 24 Odonata species in the United Kingdom, range expansions and contractions in songbirds, and colonization of an additional 77 lichen species in more northerly locations in the Netherlands. In montane regions, lowland birds are shifting to higher elevations in Monteverde National Park Costa Rica, and the treeline has shifted upslope in Siberia and the Canadian Rockies. Montane species adapted to cooler high elevation sites are becoming locally extinct in the lower elevations of their range, including Edith's checkerspot butterfly (*Euphydryas editha*, Mexico to Canada), Apollo butterfly (*Parnassius apollo,* France), and the pika (*Ochotona princeps*, in the Great Basin of the Western U.S.). Additionally, entire forest ecosystems and plant communities are expected to change as tree species shift their ranges poleward and upslope in response to climate change. Some common forest types such as oak-hickory may expand while others such as maple-beech-birch are expected to contract and spruce-fir forests may disappear altogether (Karl et al. 2009).

Pests, pathogens, and invasive species will also respond to climate change by shifting their distributions. Invasive species will have a competitive

Hemlock Woolly Adelgid Predicted Range Expansion

A spatial representation of the predicted future range expansion for hemlock woolly adelgid was created by estimating spread rates from historical records and using these estimates to predict future spread. Presence was based upon visual detection of life stages by pest management personnel. Historical records were available for 1951, 1971, 1980, 1990, 1995, 2001, and 2002. A GIS was used to calculate the minimum distance of each county to the area initially infested. The rate of spread was estimated as the slope of the least squares linear regression model describing the relationship between each county's distance from the initially infested area and the time until the pest was established in the county. Due to the visibly anisotropic spread of hemlock woolly adelgid (Souto et al., 1996), the minimum distance of each county to the area initially infested was measured separately in the east/west- and north/south-direction. Thus, two linear models of the distance of the county as a function of its time of first infestation were used to estimate two spread rates. Historical spread of hemlock woolly adelgid in the east/west direction was estimated at 3.6 km/year ± 0.2 km/year (r2 =0.60) and in the north/south direction was estimated at 5.8 km/year ± 0.28 km/year (r2=0.66).

Souto, D., Luther, T., Chianese, B., 1996. Past and current status of HWA in eastern and Carolina hemlock stands. In: Salom, S.M., Tignor, T.C., Reardon, R.C. (Eds.), Proceedings of the First Hemlock Woolly Adelgid Review, USDA For. Service, Morgantown, WV, pp. 9-15.



Map Produced by:
USDA Forest Service
Randall Morin
Northeastern Research Station

Figure 1-6. Hemlock wooly adelgid (*Adelges tsugae)* predicted range expansion in North America based on historic rates of spread (Source: USDA Forest Service 2010). Woooly adelgid have already experienced range expansion since 1951, and are expected to expand further based on historic rates of spread. Warmer winters associated with climate change may enhance wooly adelgid overwintering success.

advantage over many native species that are also shifting ranges because most invasive species have rapid dispersal abilities and may have the capacity to survive and tolerate a range of environmental conditions (Dukes and Mooney 1999). In British Columbia, warmer temperatures are implicated in expanded large mountain pine beetle (*Dendroctonus ponderosae*) outbreaks that are now occurring further north than they have previously been recorded (Logan et al. 2003). The hemlock woolly adelgid (*Adelges tsugae*) is an invasive non-native insect likely to expand as a result of climate change (Paradis et al. 2007). Hemlock wooly adelgid has had a catastrophic impact on the forest system of the eastern U.S. by decimating stands of eastern and Carolina hemlock (*Tsuga canadensis* and *T. caroliniana*). The adelgid is sensitive to cold temperatures and experiences greater overwintering mortality when exposed to colder conditions for longer periods of time (Shields and Cheah 2004, Paradis et al. 2007). Although the first known hemlock infestation was found in Virginia in 1951, this invasive pest has already spread to significant portions of the eastern U.S. since (USDA Forest Service 2010, Figure 1-5). Historic rates of spread indicate an outward expansion of the hemlock woody adelgid's range from its current known range. However, this estimation does not include the predicted impacts of increasing temperatures on its range (Figure 1-6).

The ability of native and non-native species to shift in response to climate changes will depend on a number of factors, including the species' ability to keep pace with climate change through dispersal, the availability of suitable habitat, the permeability of the landscape through which the species must move, the species' capacity to adapt to change, and the resulting interactions of the species within a new community. Coupled global climate models and global vegetation models suggest that keeping pace with climate change may require migration rates much faster than those observed during post-glacial times, potentially at rates of 1,000 meters per year or more (Malcolm et al. 2002). As the geographic range and timing of species migration changes, there is also potential for mismatches between species and the resources they require to survive. Furthermore, highways and expanding urban areas, as well as the often isolated distribution of protected areas, may prevent species from successfully migrating in response to climate change.

… it is regional changes in climate, rather than global changes, that are likely to be more relevant in the context of species and habitat responses to climate change

1.2.2 Climate Change Impacts on Phenology and Biotic Interactions

Species have evolved within an ecological context and are therefore tightly linked to the abiotic and biotic components of ecosystems. The influence of climate on the ecology of species includes direct constraints on the physiology of organisms, as well as indirect effects resulting from disruptions to food supply, changes in competitive interactions, or influences on behavior, along with many others (McCarty 2001, Walther et al. 2002, Parmesan 2006). Any one of these effects alone or in combination has the potential to impact reproduction and/or survival, and therefore the long-term viability of populations. There is now ample evidence for the ecological impacts of recent climate change on populations and species. It is also increasingly apparent that not all species respond in identical ways, creating the potential for mismatches in the timing of events or spatial associations within ecosystems. Regional differences in the magnitude of climate change may further complicate the population dynamics of certain species, such as long distance migrants, that depend on the environmental conditions of more than one area (Stenseth and Mysterud 2002).

Phenological events, such as the timing of flowering, the onset of breeding, or the timing of migration, have typically evolved through natural selection to match environmental conditions. These seasonal life cycle events are generally tied to environmental cues, and a growing number of studies have documented changes in phenology in response to recent climate change (e.g., see McCarty 2001, Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003, Parmesan 2006 for reviews). However, as local conditions drive phenological events, it is regional changes in climate, rather than global changes, that are likely to be more relevant in the context of species and habitat responses to climate change (Walther et al. 2002). Differences in the rate and magnitude of change across the globe will contribute to heterogeneity in ecological dynamics across systems, potentially disrupting interactions across trophic levels as well as co-evolved relationships such as pollination and seed dispersal.

Long-term data sets from Europe and North America document phenological changes across taxa, including timing of flowering and leaf out in plants, first appearance of butterflies, initiation of breeding in birds, timing of phytoplankton blooms, and choruses or spawning of amphibians (McCarty 2001, Parmesan 2006), which are generally associated with warmer temperatures and earlier onset of growing seasons in northern latitudes. Across species and regions, these observed advances in phenological timing range from a day or less to several weeks per decade (McCarty 2001, Table 1-1). However, not all species will have the capacity to respond rapidly to climate change, and this variability in response has the potential to disrupt correlations with other ecological factors. For example, population declines in the migratory pied flycatcher (*Ficedula hypoleuca*) in the Netherlands have been associated with a mismatch between the timing of breeding and their main food supply (Both et al. 2006). Populations have declined by 90% in areas in which the peak in caterpillar abundance in spring has started earlier than the birds' breeding date. The laying dates of resident great tits (*Parus major*) have not advanced in concert with the availability of insects and peak food demands for food and thus face a similar mismatch (Visser et al. 1998).

Shifts in the timing of emergence or arrival in response to climate change may also have repercussions on competitive interactions within and among populations of species. For example, Winkler et al. (2002) found that laying dates in tree swallows (*Tachycineta bicolor*) were more constricted in warmer years. Greater synchrony of hatching dates among nests in warmer years may result in increased competition for food resources to support young. In subalpine meadows in Colorado, timing of early snowmelt affected the composition of co-flowering plants, potentially influencing interactions among plant species as they compete for pollinators (Forrest et al. 2010). In southern Wisconsin, records of arrival dates for migratory birds and first bloom of spring flowers over a 61 year period show that roughly one-third of species appeared to have advanced timing of arrival or bloom, while one-third appeared not to have advanced, and the remaining date changes were statistically indeterminate (Bradley et al. 1999).

A great number of seasonal events are regulated by

Table 1-1. Observed changes in phenology attributed to recent climate change (drawn from studies reviewed in McCarty 2001).

Phenologic variable	Species observed	Change/period	Location	Reference
Flowering date	6 wildflower spp.	9.8 days/50 years	Northeastern U.S.	Oglesby and Smith (1995)
	36 plant species	8.2 days/61 years	Wisconsin	Bradley et al. (1999)
Spawning date	2 frog spp.	14-21 days/17 years	northern North America	Beebee (1995)
Breeding migration	3 newt spp.	35-49 days/17 years	northern North America	Beebee (1995)
Breeding date	20 bird spp.	8.8 days/25 years	United Kingdom	Crick et al. (1997)
	3 bird spp.	3-9 days/25 years	Germany	Winkel and Hudde (1997)
	Pied flycatcher	13 days/24 years	Wales	Slater (1999)
	Tree swallow	5-9 days/33 years	North America	Dunn and Winkler
	Great tit	11.9 days/27 years	England	McCleery and Perrins (1998)
	2 bird spp.	30 days/35 years	Hudson Bay region	MacInnes et al. (1990)
	Mexican jay	10.1 days/27 years	Arizona	Brown et al. (1999)
Migration date	4 bird spp.	11.9 days/50 years	England	Mason (1995)
	39 bird spp.	5.5 days/50 years	Northeastern U.S.	Oglesby and Smith (1995)
	American robin	14 days/19 years	Colorado	Inouye et al. (2000)
	19 bird spp.	4.4 days/61 years	Wisconsin	Bradley et al. (1999)
End of hibernation	Yellow-bellied marmot	23 days/23 years	Colorado	Inouye et al. (2000)

mechanisms other than spring temperature–such as photoperiod or winter conditions– and will thus fail to respond or respond in different ways to climate warming. For example, during warm springs, poor synchrony has been observed between oak (*Quercus robur*) bud burst and winter moth (*Operophtera brumata*) egg hatching (Visser and Holleman 2001), resulting in a mismatch between the caterpillars and their food supply. The mismatch is the result of different phenologic mechanisms; oak bud burst responds to spring temperatures whereas winter moth egg hatching is affected by the incidence of winter freezes. However, even for species for which temperature or precipitation is closely associated with the timing of phenologic events, genetic or other constraints may limit species' ability to respond. In a review of cases ranging from marine plankton to birds, Visser and Both (2005) found that the majority of species shifted either too much or too little in the timing of phenologic events, such as emergence, migration, or laying dates, compared to the shift in timing of food abundance.

We know little about the potential implications that shifts in phenology may have on life history characteristics influencing reproductive success. For example, Winkler et al. (2002) looked at the consequences of earlier egg-laying dates on clutch size in tree swallows. In birds, there is a strong negative relationship between laying date and clutch size, however mean clutch size for tree swallows has not increased with advanced laying dates. Examples such as these suggest that previously established relationships among abiotic factors and life history traits may not adequately capture the impacts of climate change on factors influencing population dynamics (Stenseth and Mysterud 2002) and quantifying responses of traits for single species may not go far enough in terms of understanding community dynamics (Berg et al. 2010). Berg et al. (2010) argue that the traditional approach for forecasting change in ecological community structure (i.e., modeling based solely on climate-species range relationships) will fail to accurately predict species changes because it ignores the potential role for biotic interactions (Box 1-1).

Box 1-1. Examples of mechanisms that may facilitate disruption of biotic interactions under climate change (drawn from studies reviewed in Berg et al. 2010).

Prey-predator	Differential impacts on reproductive rates of predators and prey could result in a temporal mismatch in abundance.
Plant-pollinator	Disruption in the correlation between flowering period and pollinator activity could result in a temporal mismatch.
Plant-pathogen	Dissimilarity in dispersal ability could result in a spatial mismatch beween a plant and pathogen.
Plant-herbivore	Higher development rate in insect herbivores could result in an increase in herbivory intensity.
Host-parasitoid	Dissimilarity in lethal temperatures could enhance survival in a parasitized host relative to the parasitoid.
Plant-mycorrhizae	Climate impacts could alter root growth and morphology, adversely affecting the plant-mycorrhizal association.
Plant-herbivore-predator	Disrupted correlations between environmental cues used by plant and herbivore could cause a temporal mismatch between abundance and food supply across trophic levels.

Recent modeling efforts have provided support for the importance of biotic interactions on individual species distributions at macroecological scales (Araújo and Luoto 2007, Heikkinen et al. 2007), but whether these results are generally representative of a wide range of species remains an open question. Associations between these factors may emerge based on life history traits or trophic status (Berg et al. 2010). For example, the ability of specialists to expand their ranges may be limited by the dispersal ability of host or prey species, whereas generalist species will not face such constraints.

Climate sensitivity may vary across trophic levels, with higher-level predator communities being more sensitive than producers (Voigt et al. 2003). This response may be due, at least in part, to differences in physiologic responses to climate change across trophic levels. For example, development rates of insects may be more sensitive to temperature than those of their plant food sources (Bale et al. 2002), resulting in increased herbivory intensity as a consequence of higher growth rates and reduced generation time in insect herbivores. In grasshoppers, changes in temperature influence resource acquisition, ultimately affecting the intensity of intraspecific competition (Laws and Belovsky 2010). As responses to climate change become increasingly apparent across biological systems (Parmesan and Yohe 2003, Root et al. 2003), it may well be the range and variability of species-specific responses that poses the greatest challenge to efforts to maintain ecological structure and function similar to that of present ecological systems.

1.2.3 Species and Ecosystem Vulnerability

Vulnerability refers to the degree to which an ecological community or individual species is likely to experience harm due to exposure to perturbations or stresses. Species or ecosystem vulnerability to climate change is a function of three variables: **exposure**, or the degree to which a system or species is exposed to climate change and variability, **sensitivity** to these changes, and the species or ecosystems' **adaptive capacity** to respond to these changes as well as the strategies practitioners implement to help the species or system adapt (IPCC 2007, Williams et al. 2008). Specific factors that influence the vulnerability of species or ecosystems to climate change may include biological and physiological traits that make a species particularly sensitive to climate changes, the adaptive capacity of the species, barriers to dispersal, high exposure or sensitivity to specific climate impacts because of distribution or biological factors, the pace and magnitude of climate change, or exposure to existing or future non-climate threats such as land use change. In a recent guide, Glick and Stein (2010) provide an in-depth review and guidance on the use of vulnerability assessments in conservation planning.

Exposure relates to short-term or long-term the degree of climate stress in a particular region. From a species or habitat perspective, exposure may include areas exposed to sea-level rise, or changes in precipitation and temperature. In some cases, local microhabitat buffering may reduce exposure. For example, some species may be buffered from climate changes by living in a thermally sheltered microhabitat under logs or in a cool ravine alongside a stream.

Sensitivity is a measure of how a species or ecosystem responds or changes in relation to climatic conditions. Species or ecosystems that are more sensitive to changes in climate may experience dramatic shifts in distribution or population size in response to only slight increases or decreases in temperature and precipitation. Sensitivity will be determined by intrinsic factors including ecological, genetic and physiological traits (Table 1-2).

The combination of exposure and sensitivity determine the potential impact of climate change on an ecosystem or species, which is then modified by the species' or ecosystem's adaptive capacity and the capacity of humans to manage, adapt and minimize climate change impacts (Williams et al. 2008). Adaptive capacity refers to the intrinsic ability of organisms to adapt to changing conditions. Species or ecosystems with a high degree of adaptive capacity to climate changes will be less impacted than species or ecosystems with relatively low adaptive capacity, even if they are sensitive to climate change. Ecological plasticity, or the ability individuals to modify their behavior, morphology, or physiology to changing conditions, generally increases the likelihood that a species will be able to respond to climate change impacts (Parmesan et al. 2005). In addition, evolutionary processes have the potential to influence responses to climate change, but require genetic change over multiple generations. Genetic change in response to recent, rapid climate change has been documented in a number of species, over differing time scales and to differing degrees (reviewed in Bradshaw and Holzapfel 2006). However, the majority of species will not likely have the capacity to adapt given the rate and magnitude of projected climate changes (Bradshaw and Holzapfel 2006, Williams et al. 2008). Evidence from the fossil record suggests that, despite evidence for local adaptation at specific sites, species as a whole tend to shift their geographical distributions in response to climate change, rather than undergoing major evolution at the species level that would allow conservation of the original range (Parmesan 2006).

Vulnerability assessments that are geared towards quantifying the relative exposure and sensitivity to climate changes as well as the adaptive capacity of species or ecosystems can help to direct and prioritize research and management efforts. Because vulnerability assessments can be time-intensive and expensive, selecting specific species or ecosystem targets can be challenging and will depend on the manager's needs or an organization's values. If only a subset of species or habitats can be chosen, these targets

Table 1-2. Physiological and life-history traits that influence species vulnerability in response to climate change disturbances (Source: Steffen et al. 2009, ©Commonwealth of Australia, used with permission).

Species least at risk	Species most at risk
• Physiological tolerance to broad range of factors such as tempertures, water availability and fire • High degree of phenotypic plasticity • High degree of genetic variability • Short generation times (rapid life cycles) and short time to sexual maturity • High fecundity • 'Generalist' requirements for food, nesting sites, etc. • Good dispersal capability • Broad geographic ranges	• Narrow range of physiological tolerance to factors such as temperature, water availability and fire • Low genetic variability • Long generation times and long time to sexual maturity • Specialized requirements for other species (e.g. for a disperser, prey species, pollinator or photosynthetic symbiont) or for a particular habitat that may itself be restricted (e.g. a particular soil type) • Poor dispersers • Narrow geographic ranges

can be selected to span variability in life history traits, conservation status, or other testable hypotheses that might inform future assessments. The vulnerability assessment process generally follows the series of steps outlined below (Turner et al. 2003, Schröter et al. 2005, Fuentes et al. 2010, Glick and Stein 2010):

1. **Define the study areas together with stakeholders** – Identify spatial and temporal scales appropriate to management objectives with stakeholders and recognize that the scale of the assessment needs to match the scale of decision-making. Consider how a conservation target (species or system) may respond differently at other scales. Select an assessment approach based on targets, user needs, and available resources.

2. **Gather data and identify the climatic processes that can affect the species or ecosystems of interest** – Review the literature, contact experts, and spend time with stakeholders to identify the main climate change impacts that affect the species or conservation targets of interest. Hypothesize how these impacts will affect the target. For example, in assessing the vulnerability of sea turtles to climate change, knowledge of nesting habitat requirements, physiological tolerances, and mechanisms of sex determination would allow the identification of important climate change factors affecting reproductive success. In this case, increased sand temperatures may alter hatchling sex ratios and survival, while sea level rise and increased storm severity may cause loss and/or alteration of nesting beaches and egg mortality.

3. **Select climate scenarios and data** – Given the uncertainty in the levels of future greenhouse gas emissions and resulting climate changes it is generally a good idea to use more than one climate change scenario to assess vulnerability. For example, practitioners may use projected climate changes based on a high future emissions scenario and a more moderate future emissions scenario with a lower degree of resulting climate changes. Scenarios should be selected and discussed with all stakeholders in order to assure transparency. The assumptions underlying any projection used in the vulnerability assessment should be outlined explicitly and communicated with stakeholders.

4. **Develop a "causal model" of vulnerability** – Stakeholders should work together to develop a simple model or flow chart that depicts the factors affecting the sensitivity and exposure of a target to climate change and how these factors contribute to vulnerability. These factors should include both climate change factors and ongoing stressors that affect a species vulnerability to climate change.

5. **Operationalize the vulnerability model** – Estimate overall vulnerability of the target based on the factors identified in the causal model and the climate change scenarios. Document levels of confidence or uncertainty in assessments.

6. **Use the vulnerability assessment to design adaptation strategies, prioritize response options, and identify areas of further research** – Vulnerability assessments pinpoint the factors affecting the vulnerability of a conservation target to climate change and help identify intervention

points for management actions. Understanding the factors that influence vulnerability for a particular species or system allows managers to design adaptation strategies directed at mitigating a particular impact. For example, increased water temperature is a primary factor contributing to vulnerability of a species. Management responses for species vulnerable to increased water temperatures might include restoring streamside vegetation to lower water temperatures or trans-locating the species to streams with cooler conditions. Vulnerability assessments also allow users to identify where information is lacking and where additional research or monitoring would be valuable to understanding how climate change impacts the species or system of interest.

Depending on the approach used, vulnerability assessments can be used to prioritize species based on relative vulnerability risk, develop adaptation options for sensitive species or habitats, identify future research needs, or help inform the conservation planning process. For a complete review of vulnerability assessment tools, approaches, and applications see Glick and Stein (2010).

Table 1-4. A summary of current approaches and tools used in climate change vulnerability assessment by fish and wildlife practitioners and conservation professionals (Source: Inkley et al. 2010 in Scanning the Conservation Horizon: A guide to climate change vulnerability assessments, Glick and Stein 2010); http://www.nwf.org/Global-Warming/Climate-Smart-Conservation/Safeguarding- Wildlife/Assessing-Vulnerability.aspx.

Table 7.1: Summary of Case Studies

	1. NatureServe Nevada Species Assessment	2. EPA Endangered Species Framework	3. Species Vulnerability Assessment for the Middle Rio Grande	4. State-level Habitat Assessment for Mass.	5. Coastal Habitats and Species	6. Integrated Framework for the Four Corners	7. Pacific Northwest Assessment
Location and Extent	Nevada, statewide	National	New Mexico, regional	Massachusetts, statewide	Chesapeake Bay Region (two studies)	Southwest, Four Corners region	Pacific Northwest, regional
Status	In progress	Completed	Completed	Completed	Completed	Phase 1 Completed	In progress
Targets	263 priority animal species (invertebrates and vertebrates)	Six threatened and endangered vertebrate species	Terrestrial vertebrate species occupying riparian habitats	20 habitats	5.1: Coastal wetland habitats 5.2: Marsh bird species of concern	Species and habitats identified as conservation priorities	Species and habitats
Climate Change Models?	Yes, downscaled climate data based on ClimateWizard	No (used published projections)	Yes, downscaled climate data based on ClimateWizard, and published projections	No (used published projections)	No (used published projections)	Yes, downscaled climate data based on ClimateWizard	Yes, downscaled climate data based on multiple model simulations
Other Models?	General characterization	General characterization, expert opinion	General characterization, expert opinion	General characterization, expert opinion	Habitat and ecosystem model (SLAMM)	General characterization, expert opinion	Climate niche, habitat, and hydrological models
Detail	Low	Moderate	Low	Moderate	Moderate	Low	High
Work/time	Low (application time per species = 30-45 minutes)	Moderate	Moderate	Moderate (1 year)	Low-Moderate (5.1: 1 year 5.2: 4 months)	Moderate (2.5 years)	High (3-4 years)
Cost	$160,000	$40,000	$66,000	$70,000	5.1: $40,000 5.2: $25,000	$200,000	$800,000
Lead	B. Young	H. Galbraith	D. Finch	H. Galbraith	5.1: P. Glick 5.2: M. Wilson	C. Enquist	J. Lawler
Citations	Young et al. (in press)	U.S. EPA 2009	USDA Forest Service, Rocky Mountain Research Station 2010	MDFW and Manomet Center for Conservation Sciences (in press)	5.1: Glick et al. 2008a, 2008b 5.2: Wilson and Watts 2009	Enquist and Gori 2008	Lawler et al. 2009, 2010

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Temperature, Precipitation, and Sea Level Rise in the Southeast under Climate Change: Future Projections and Impacts on Species and Habitats

Increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere generate complex dynamics that are reflected in changes across the globe, but are likely to be regional in their impact. Atmospheric concentrations of greenhouse gases will influence temperature and precipitation patterns as well as hydrology, and feed into the complex dynamics regulating biological systems. In this chapter, we discuss some of the regional projections of temperature, precipitation, and sea level rise in the Southeast under climate change, and we highlight the available research on potential impacts to terrestrial and aquatic species.

2.1 Projected Temperature Changes in the Southeast

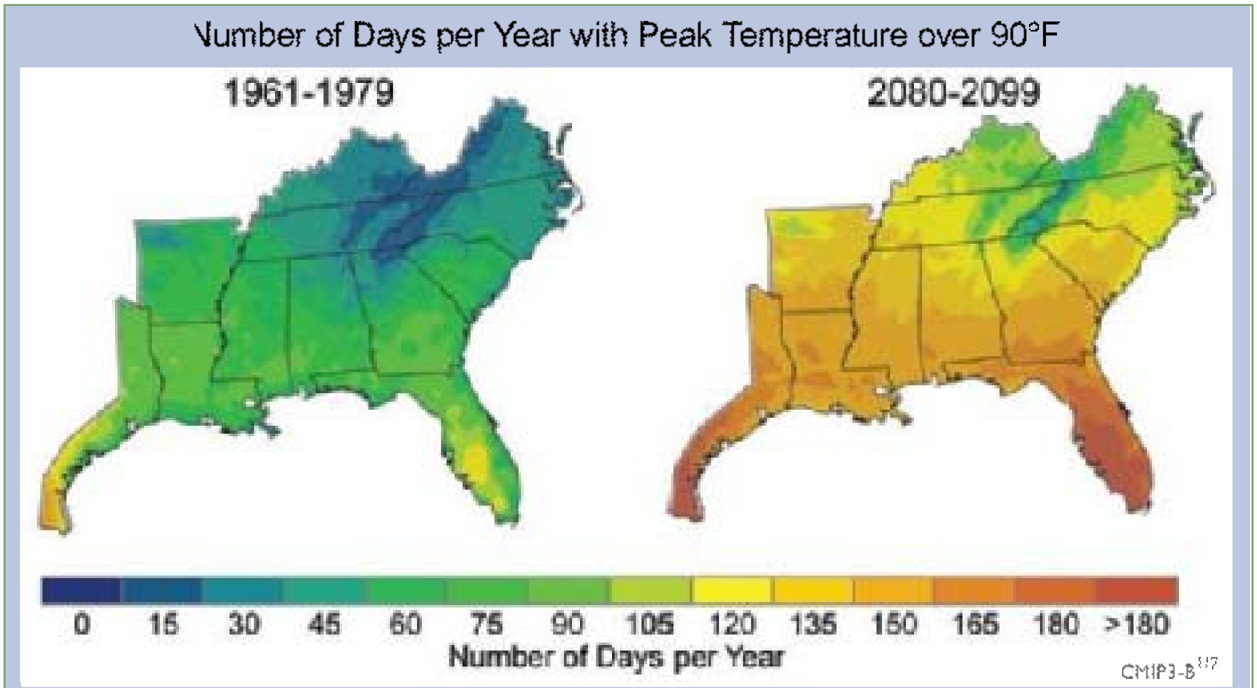
As reported by the U.S. Global Change Research Program (Karl et al. 2009), the annual average temperature across the Southeast region has risen by approximately 2°F since 1970, with the greatest increase during the winter months (Table 2-1). Freeze days have declined by 4-7 days per year for most of the region over this time period. Climate models project continued warming across the Southeast, with an increasing rate of warming toward the end of the century. Rates of warming are expected to be more than double those experienced in the Southeast since 1975. The greatest temperature increases are projected to come during already hot summer months, and the number of very hot days is projected to rise at a greater rate than the average temperature.

The greatest temperature increases are projected to come during already hot summer months, and the number of very hot days is projected to rise …

Table 2-1. Observed temperature changes in the Southeast summarized for two different time periods. Average temperature declined from 1901 to 1970 and then increased strongly from 1970 - 2008 (Source: Karl et al. 2009).

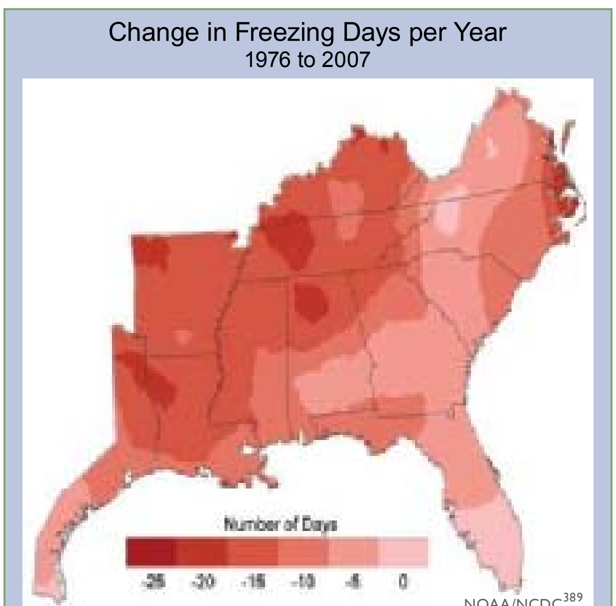
Average Change in Temperature in the Southeast		
	Temperature Change in °F	
	1901-2008	1970-2008
Annual	0.3	1.6
Winter	0.2	2.7
Spring	0.4	1.2
Summer	0.4	1.6
Fall	0.2	1.1

Different emissions scenarios lead to different projected temperature increases (Karl et al. 2009). Under a low emissions scenario, average temperatures in the region are projected to rise by about 4.5°F by the 2080s, while a higher emissions scenario yields about 9°F of average warming and a much higher heat index. For the same time period, the number of days per year with peak temperatures over 90°F is expected to rise significantly, especially under a higher emissions scenario (Figure 2-1). This increase in very hot days will have consequences for human health, drought, and wildfires. As temperatures rise, the number of days below freezing will also decrease (Figure 2-2). A reduction in freezing days can improve survival for disease vectors and pests, alter growing seasons, and reduce the amount of water available from snow pack for spring thaw.



The number of days per year with peak temperature over 90°F is expected to rise significantly, especially under a higher emissions scenario[5], as shown in the map above. By the end of the century, projections indicate that North Florida will have more than 165 days (nearly six months) per year over 90°F, up from roughly 60 days in the 1960s and 1970s. The increase in very hot days will have consequences for human health, drought, and wildfires.

Figure 2-1. Number of days per year in the Southeast with peak temperature above 90°F (Source: Karl et al. 2009).



Since the mid-1970s, the number of days per year in which the temperature falls below freezing has declined by four to seven days over much of the Southeast. Some areas, such as western Louisiana, have experienced more than 20 fewer freezing days. Climate models project continued warming across the region, with the greatest increases in temperature expected in summer, and the number of very hot days increasing at a greater rate than the average temperature.

Figure 2-2. Change in freezing days per year in the Southeast between 1976 and 2007 (Source: Karl et al. 2009).

2.1.1 Understanding the Potential Impacts of Temperature Shifts on Species and Habitats

Terrestrial systems

The impacts of rising temperatures on terrestrial species and habitats will depend on a number of other climate change factors. However, there are a few key trends in extreme temperatures as well as shifts in growing season that may have a direct physiological impact on species and habitats or an indirect impact on community relationships through competition. The temperature range under which plants grow normally is 0 to 40°C (Went 1953), but many plants have more specific temperature requirements beyond which significant damage can occur. Moderate temperature increases can speed up plant growth as well as processes such as decomposition and nutrient cycling (Karl et al. 2009) Some of the largest shifts in terrestrial systems are observed in the timing of the seasons. Many species are flowering an average of four to five days earlier than they did in previous decades (Wolfe et al. 2005, Fitter and Fitter 2002), and experiencing longer growing seasons (Myneni et al. 1997).

Increased temperatures may also cause shifts in the geographic distribution of species in places where temperature increases exceed physiological tolerances. In the northern hemisphere, shifts are expected to track temperatures, primarily along northward or elevational gradients (Parmesan 2006). Such range shifts are likely to result from population extinctions at southern latitudes or lower elevations and expansions at the northern range limits. This pattern has been observed in populations of Edith's checkerspot butterfly (*Euphydryas editha*), which occurs in the western U.S. (Parmesan 1996). Iverson and Prasad (2001) looked at projected climate warming on tree distributions for 80 species occurring in the U.S., and showed that almost half would shift their ecological optima at least 100 km to the north. Most of the species included in their study either expanded or contracted their range in response to climate warming.

In other cases, temperature may have significant effects on developmental pathways or behaviors influencing reproduction and survival. For example, sex determination in hard-shell turtles is largely temperature dependent (Bull 1980). A recent study on viviparous lizards occurring in Mexico linked local population extinction to loss of thermal niches (Sinervo et al. 2010). Their research suggests that high temperatures during the reproductive cycle affect foraging behavior and limit reproduction. Rising temperatures can also affect metabolic and growth rates in insects and other ectotherms (e.g., Dukes et al. 2009, Bickford et al. 2010), resulting in faster development and shorter lifecycles in some cases. Increased winter temperatures and frost-free days may also affect overwinter survival of some insects and pathogens (Dukes et al. 2009), resulting in increased population sizes that contribute to outbreaks.

Aquatic systems

Rapid changes in water temperature will have direct impacts on the physiology and metabolic rates of freshwater biota (Allan et al. 2005), which are dominated by cold-blooded organisms with no physiological ability to regulate their body temperature. Furthermore, the ability of freshwater organisms to move to new locations is constrained by the connectivity of streams and rivers within drainage basins. Eaton et al. (1995) reported maximum temperature tolerance estimates for 30 species of freshwater fishes occurring in the U.S. (Table 2-2). Temperature tolerance ranges are species specific, and the availability of cooler waters may become limiting to some species in their current range in a warmer climate.

Table 2-2. Maximum temperature tolerance estimates for 30 species of fish (Source: Eaton et al. 1995, © American Fisheries Society, used with permission). Temperature tolerance ranges are species specific, and in a warmer climate cooler waters may become limiting to some species in their current range.

Table 1. The 95th percentile weekly mean temperatures and standard errors calculated for the highest 5% of F/T dataset values (N) for each species

Species		95th percentile	Standard error	N
Black crappie	*Pomoxis nigromaculatus*	30.6	SE 0.31	146
Bluegill	*Lepomis macrochirus*	31.7	SE 0.08	495
Brook trout	*Salvelinus fontinalis*	22.3	SE 0.34	180
Brown bullhead	*Ictalurus nebulosus*	29.5	SE 0.78	85
Brown trout	*Salmo trutta*	24.1	SE 0.40	53
Carp	*Cyprinus carpio*	31.4	SE 0.06	714
Channel catfish	*Ictalurus punctatus*	31.6	SE 0.17	393
Chinook salmon	*Oncorhynchus tshawytscha*	24.0	SE 0.12	282
Chum salmon	*Oncorhynchus keta*	19.8	SE 0.18	70
Coho salmon	*Oncorhynchus kisutch*	23.4	SE 0.23	193
Cutthroat trout	*Oncorhynchus clarki*	23.2	SE 0.43	109
Flathead catfish	*Pylodictis olivaris*	32.5	SE 0.14	122
Freshwater drum	*Aplodinotus grunniens*	32.4	SE 0.25	213
Gizzard shad	*Dorosoma cepedianum*	31.5	SE 0.12	502
Golden shiner	*Notemigonus crysoleucas*	30.8	SE 0.27	134
Green sunfish	*Lepomus cyanellus*	31.7	SE 0.11	390
Largemouth bass	*Micropterus salmoides*	31.7	SE 0.11	391
Mountain whitefish	*Prosopium williamsoni*	23.2	SE 0.66	83
Northern pike	*Esox lucius*	28.0	SE 0.58	72
Pink salmon	*Oncorhynchus gorbuscha*	21.0	SE 1.01	76
Rainbow trout	*Oncorhynchus mykiss*	24.0	SE 0.14	442
Rock bass	*Ambloplites rupestris*	29.3	SE 0.40	121
Sauger	*Stizostedion canadense*	30.1	SE 0.33	106
Smallmouth bass	*Micropterus dolomieui*	29.5	SE 0.21	209
Smallmouth buffalo	*Ictiobus bubalus*	32.1	SE 0.16	236
Walleye	*Stizostedion vitreum*	29.0	SE 0.15	102
White bass	*Morone chrysops*	31.4	SE 0.06	249
White crappie	*Pomoxis annularis*	31.3	SE 0.09	215
White sucker	*Catostomus commersoni*	27.3	SE 0.37	433
Yellow perch	*Perca flavescens*	29.1	SE 0.74	64

Under warmer climatic conditions, the habitat available to cool water species is expected to decrease and the distributions of these species will become more spatially fragmented. Rahel et al. (1996) investigated potential habitat loss in relation to climate warming for salmonids occurring in streams of the North Platte River drainage in Wyoming. Under summer air temperature increases of 1.8-9°F, they estimated that 7-76% of habitat would be lost, depending on the approach and amount of warming. In addition, population fragmentation was expected to occur as cold water populations were restricted to increasingly higher elevations.

Eaton and Sheller (1996) looked at the effects of climate warming on 57 species of fishes in streams across the U.S., using temperature projections based on the Canadian Climate Center GCM (CCC GCM). They found a nearly 50% reduction in thermal habitat for cold and cool water species and a 14% decrease in habitat for warm water species. Overall, species with smaller ranges were projected to exhibit the largest habitat losses. Cold and cool water fish were least affected in locations that were higher in latitude or elevation. Additional studies on stream systems have confirmed significant effects on cold water fishes, but vary in their assessments of the impacts on cool and warm water fishes. For example, Mohseni et al. (2003) used a different approach to examine the impacts on climate change for the same set of 57 species used by Eaton and Sheller (1996). The results of their analysis projected a 36% decrease in cold water fish habitat and a northward shift in range. Changes in habitat for cool and warm water fishes was dependent on the assumptions for minimum temperature tolerance (32°F vs. 35.6°F) and ranged between a 12-15% decrease in habitat for cool water fishes and a 0-31% increase in habitat for warm water fishes. Maximum temperature tolerance was not expected to have a significant effect on warm water habitat due to evaporative cooling of streams (Mohseni et al. 2003).

Recognizing that both temperature and dissolved oxygen concentrations control the distribution of fish species in lakes, Stefan et al. (2001) simulated changes in both factors and examined impacts on fish habitat in North American lakes in response to projected climate warming. Using a doubled CO_2 concentration scenario under the CCC GCM, their results suggest that climate warming will reduce the geographic area in which lakes have suitable cold and cool water habitat by 45% and 30% respectively. Suitable habitat for coldwater fish was likely to be restricted to deep lakes along the northern border of the U.S. In the south central and southeastern states, summer kill of cool water fish was expected to be more prevalent. However, warm water fish were expected to benefit in all lake types (Stefan et al. 2001).

In rivers and streams with adequate dispersal corridors, species at the southern extent of their geographical distribution may shift their distributions northward into cooler habitats (Allan et al. 2005). For lakes, differences in surface area, depth, latitude, and elevation are all factors that will influence response to climate change. Water levels are likely to be reduced in regions that experience increased evapotranspiration brought about by higher temperatures and longer growing periods, unless offset by increased precipitation. As in streams, warmer air temperatures will raise water temperatures, especially in smaller and shallower lakes.

In ponds and lakes deep enough to exhibit summer thermal stratification, warm water habitat will increase in depth, potentially forcing cool water organisms into deeper waters (Allan et al. 2005). At the same time, bottom waters may become depleted of oxygen due to higher decomposition of algae and organic matter settling out of warmer, more productive surface waters. Cool water habitat may therefore be constrained by increased warm water volumes above and oxygen depletion below (Figure 2-3).

Large, deep lakes could see an increase in suitable habitat for warm water fishes in the summer, without exceeding the temperature tolerances of cool water fish in the cooler waters of the hypolimnion. Smaller, shallower lakes may experience enough loss of cooler bottom waters to reduce habitats for cool water fish. Changes in temperature caused by global climate change may also affect primary production and the nutrient concentration of inland waters (reviewed in Ficke et al. 2007). Increased productivity resulting from warmer temperatures can lead to oxygen depletion in bottom waters as algae and organic matter settle out of surface waters and decompose.

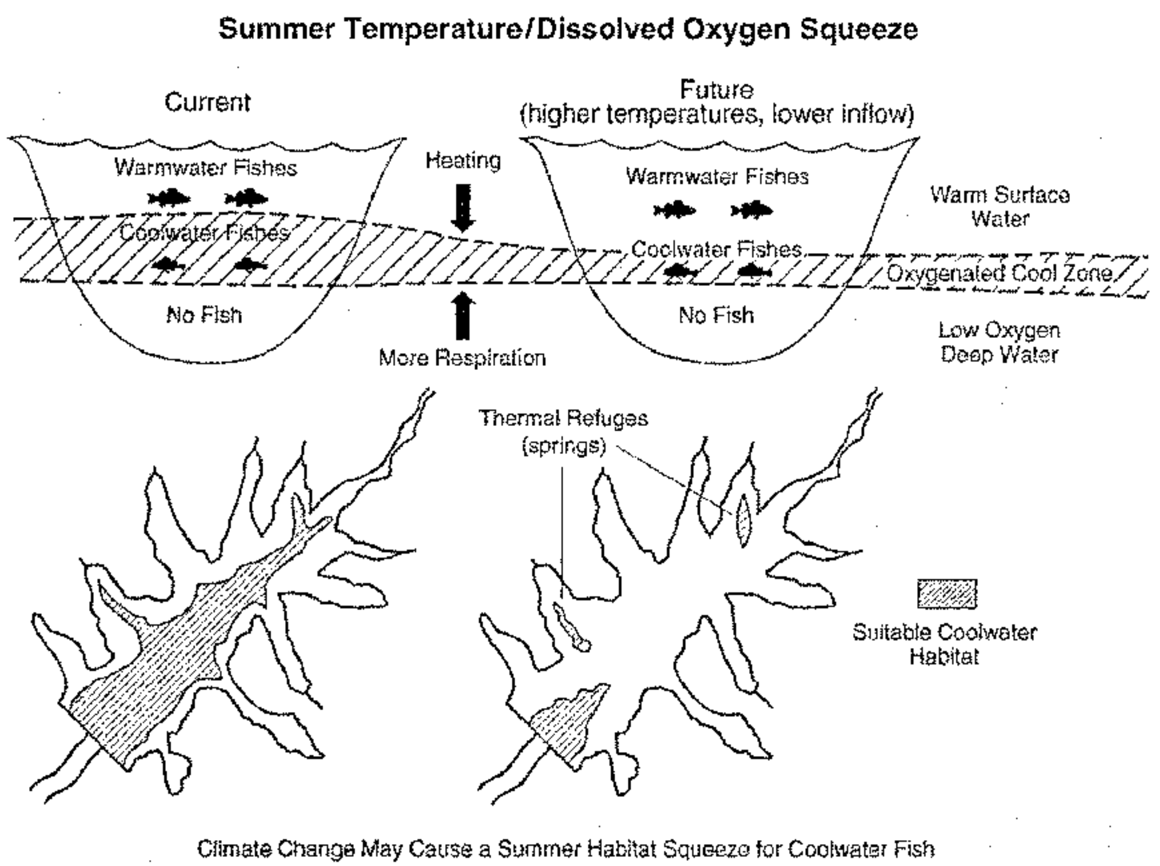


Figure 3. Potential increases in the severity of the summer temperature–dissolved oxygen squeeze with future climate change

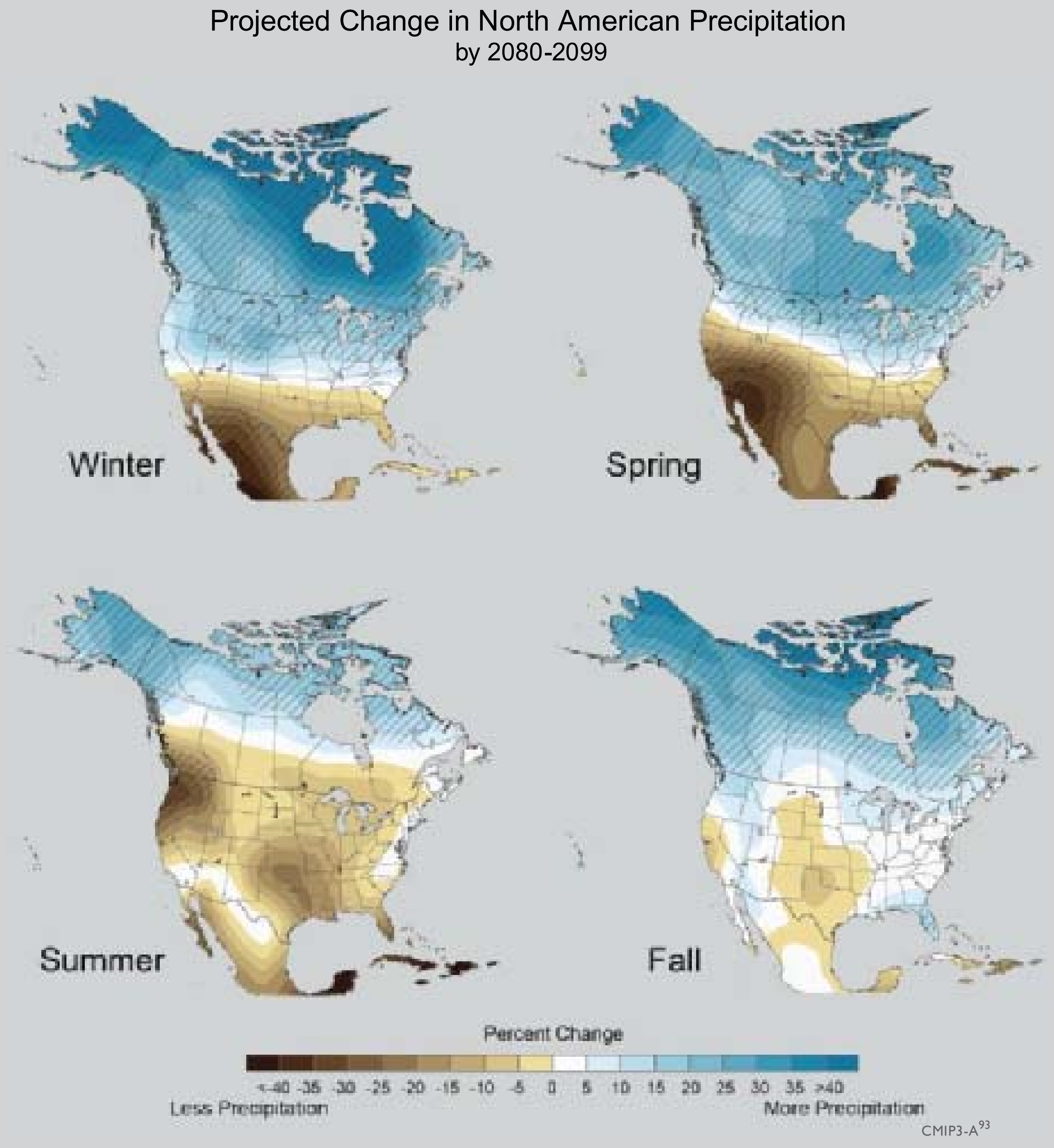
Figure 2-3. Increased air temperatures are expected to result in decreased cool water fish habitat as a result of higher water temperatures in surface waters and lower dissolved oxygen concentrations in deeper waters (Source: Mulholland et al. 1997, © Wiley Interscience, used with permission).

King et al. (1999) provided empirical links between growth and thermal habitat for species occurring in lakes in Ontario. Years with warmer temperatures resulted in an earlier onset of stratification, a warmer epilimnion, larger thermal gradient, and shallower thermocline. On average, these variables accounted for 44% of the variation in fish growth. However, responses were species specific. For example, smallmouth bass (*Micropterus dolomieui*) showed increased growth rates, presumably as a result of increased availability of preferred growth temperatures in shallow waters. Whereas, in the case of lake trout (*Salvelinus namaycush*), early stratification was suspected to promote earlier migration into deeper water and limit the length of spring feeding, thus reducing growth rates. These findings illustrate how climatic changes not only have the potential to directly influence the availability of thermal habitats, but also may indirectly place constraints on feeding habitat availability, with subsequent consequences on growth.

2.2 Projected Precipitation Changes in the Southeast

Unlike projections for temperature, where consistency among models in local warming is high, less agreement exists among models regarding projected changes in precipitation for many regions (Meehl et al. 2007). Confidence in model projections of precipitation may vary depending on region and season. For example, confidence in precipitation projects is higher for winter and spring than for summer and fall (Karl et al. 2009). However, changes in the Southeast appear more difficult to project with confidence than some other regions of the United States (Figure 2-4). The cross hatching in Figure 2-4 indicates regions in which two-thirds of models agree on the direction of the mean change. Notice that the Gulf Coast states will tend to have less rainfall in winter and spring compared with the more northern states in the region, but the projected change for the mid-Atlantic states is generally small and with less agreement among models (Karl et al. 2009). This is not to say that changes in precipitation have not already occurred in the Southeast. Across the region, average autumn precipitation has increased by 30 percent since 1901, while summer and winter precipitation has declined by approximately 10 percent during this same period (Karl et al. 2009, Figure 2-5).

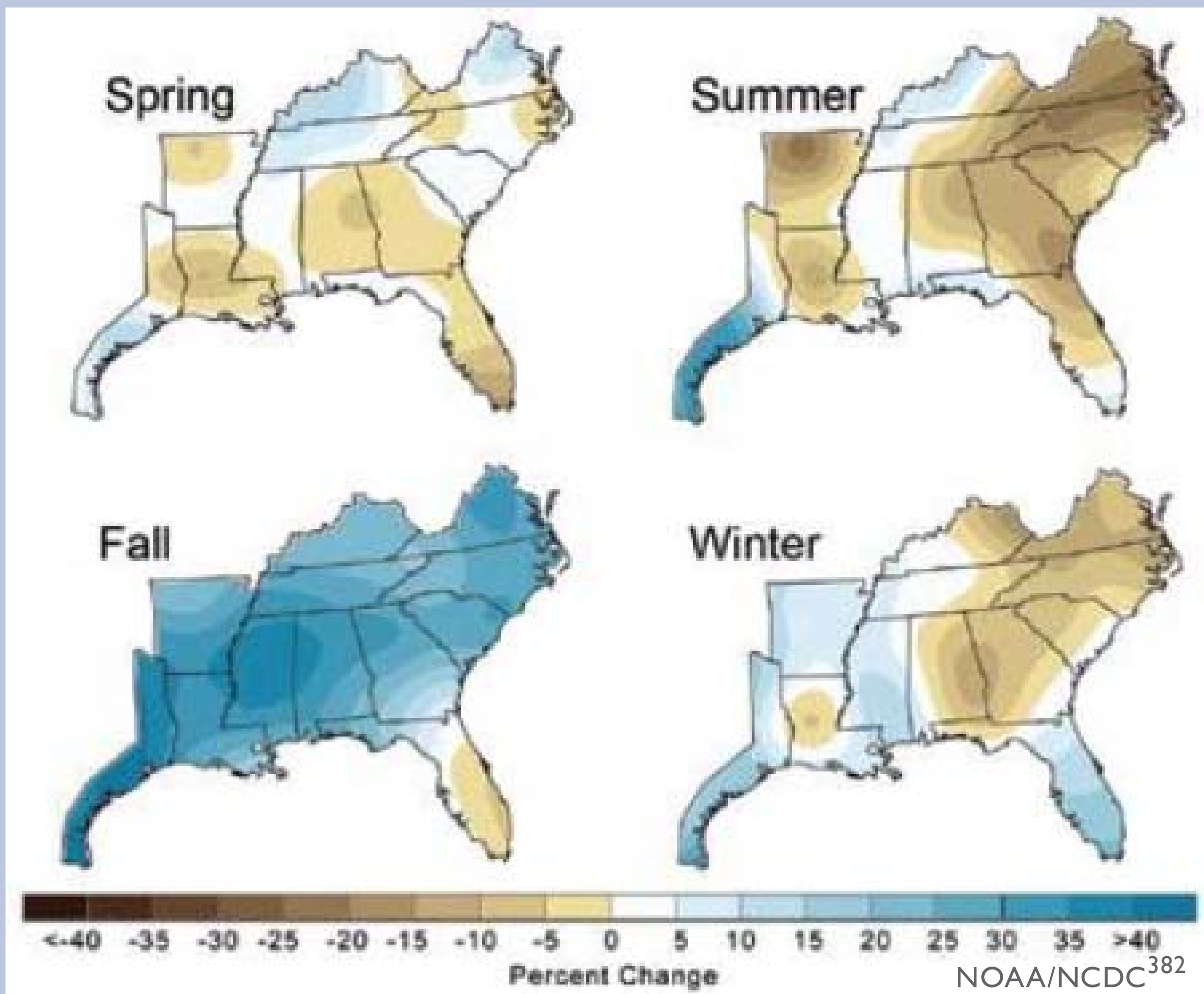
Unlike projections for temperature, where consistency among models in local warming is high, less agreement exists among models regarding projected changes in precipitation for many regions.



The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario.[91] For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

Figure 2-4. Multi-model changes in precipitation under a higher emissions scenario for the end of the century. Cross-hatches shows regions where at least two-thirds of models agree on the sign of the projected change (Source: Karl et al. 2009).

Observed Changes in Precipitation
1901 to 2007



While average fall precipitation in the Southeast increased by 30 percent since the early 1900s, summer and winter precipitation declined by nearly 10 percent in the eastern part of the region. Southern Florida has experienced a nearly 10 percent drop in precipitation in spring, summer, and fall. The percentage of the Southeast region in drought has increased over recent decades.

Figure 2-5. Observed changes in precipitation between 1901 and 2007 in the Southeast (Source: Karl et al. 2009).

In addition to the differences in the amount of precipitation, the occurrence of heavy downpours has increased in many parts of the region. For example, analyses of temporal trends over the past century have documented an increase in heavy rainfall events across the area, extending from central Texas to the Appalachian Mountains in Tennessee and North Carolina (Keim 1997). Increased frequency of extreme rainfall events will likely affect processes such as soil erosion, sedimentation, and stream dynamics. At the same time, many parts of the region are experiencing an increasing number of droughts. The areas of moderate to severe spring and summer drought have increased by 12 and 14 percent, respectively, since the mid-1970s (Karl et al. 2009). Continued rising temperatures will likely lead to further droughts in affected areas, as high temperatures increase evaporation of moisture from soils and plants. The projected increased variability in precipitation may have greater impacts than increases or decreases in magnitude.

Table 2-3. Observed precipitation changes in the Southeast summarized for two different periods (Source: Karl et al. 2009)

Average Change in Precipitation in the Southeast		
	Precipitation Change in %	
	1901-2008	1970-2008
Annual	6.0	-7.7
Winter	1.2	-9.6
Spring	1.7	-29.2
Summer	-4.0	3.6
Fall	27.4	0.1

2.2.1 Storms and Severe Weather Events

During hurricane season, tropical cyclones account for as much as 15% of the rainfall along portions of the Carolinas (Knight and Davis 2007). Changes in hurricane frequency and intensity would have impacts on precipitation patterns across the state. There has been much research into whether the significant increase in numbers of tropical storms and hurricanes in the Atlantic over the last three decades is due to increases in sea surface temperatures or to other factors related to multidecadal variability (Webster et al. 2005, Pielke et al. 2005). More support exists for a link between warmer sea surface temperatures and the observed increases in hurricane intensity (Emanuel 2005, Elsner et al. 2008). Globally, the number of category four and five hurricanes has almost doubled since 1975, and similar trends have been observed in the Atlantic basin (Webster et al. 2005). It remains unclear whether these observed patterns have exceeded the variability expected through non-anthropogenic causes. However, advances in modeling techniques have increased confidence concerning several aspects of cyclone-activity projections (reviewed in Knutson et al. 2010). A general convergence of frequency projections, in combination with fairly accurate hindcasting predictions, have begun to provide some confidence that globally the number of tropical cyclones is likely to decrease or remain unchanged under warming conditions. There is less certainty in projections for individual basins. Some increase in mean maximum wind speed of tropical cyclones is likely, although increases may not occur in all tropical regions, and rainfall rates are likely to increase. High resolution models for the western Atlantic suggest there will be fewer tropical cyclones in the basin overall, but significantly more intense hurricanes by the end of the twenty-first century (Bender et al. 2010). When storms do occur, rising sea levels will amplify the impacts of storm-surge incidence, particularly in sensitive coastal regions.

2.2.2 Hydrology

The hydrologic cycle describes the continuous circulation and conservation of water on, above, or below the surface of the Earth and is thus uniquely tied to changes in temperature *and* precipitation. Hydrologic patterns are driven by complex processes associated with precipitation, evaporation, and transpiration, which are typically incorporated into predictive models of future hydrologic system behavior. Because climate change may impact hydrological systems in a number of distinct but interrelated ways, this synthesis is treated separately from temperature and precipitation, with an understanding that projected changes in temperature and precipitation will be interrelated with impacts on hydrology. Changes in climate will have direct and indirect effects on the hydrological cycle and freshwater systems. A warmer climate increases the capacity of the atmosphere to hold moisture while also increasing evaporation from land and water surfaces, resulting in a more vigorous water cycle (Huntington 2006). Global increases in continental runoff from major rivers, increases in evapotranspiration (ET) inferred from hydrologic budgets and increased ocean salinity, and evidence for increase in water-vapor at the surface over most northern latitudes, all point to ongoing and future intensification of the hydrologic cycle (reviewed in Huntington 2006). Altered precipitation regimes will directly affect stream flows and groundwater recharge, but the net effect on water levels will depend on how increasing temperatures and CO_2 affect ET processes.

Praskievicz and Chang (2009) review hydrological modeling of basin-scale climate change impacts, as well as impacts of urban development and interactions with climate change. They note that a number of factors influence basin hydrological response to climate change. Latitude and whether a basin is located in a relatively humid or arid region will affect potential for flood risk and water stress. Humid mid-latitude regions may generally experience increased runoff, whereas arid regions may be more likely to experience a decrease in annual runoff. Elevation will influence hydrologic response to warming according to whether the basin is dominated by rainfall or snowmelt. Basins dominated by snowmelt are likely to exhibit increased winter runoff and earlier spring peaks. The geology of the basin will also be an important factor. Groundwater dominated systems, particularly those with deep aquifers may be less sensitive to changes in temperature in the short term whereas systems with shallow aquifers or those dominated by surface flows will respond more quickly. In addition to changes in mean hydrology, climate change will likely affect hydrological variability. Even in areas that see only slight changes in annual runoff, the frequency of very low or very high flows may change significantly.

There are several approaches to developing climate change scenarios for incorporation into hydrologic models (Praskievicz and Chang 2009). One approach is to modify the historical average temperature and precipitation by some fixed amount. A disadvantage of this approach is that these projections may or may not provide realistic reflections of current atmospheric changes. An alternative and increasingly common approach is to use projections based on IPCC emissions scenarios that have been coupled with global circulation models downscaled to appropriate scales. These projections are then used as inputs in a hydrologic model to examine projected changes in runoff and other variables.

Uncertainty associated with the choice of GCM, downscaling method, and choice of hydrological model can all impact projected changes to hydrology (Praskievicz and Chang 2009). Of these, the greatest source of uncertainty in the modeling chain appears to be the choice of GCM (Graham et al. 2007). However, fewer studies have addressed the range of outcomes obtained using different hydrologic models with a given climate scenario. Hydrologic models differ in their parameters and assumptions and their usefulness to various applications. Gleick (1986) identified six criteria for evaluating the applicability of hydrologic models for use with climate change projections (Box 2-1) and focused on water balance models as particularly useful for identify hydrologic consequences of changes in temperature, precipitation, and other climate variable. In addition, a number of other types of models have been applied to modeling hydrologic effects of climate change (Examples are shown in Table 2-4). One limitation of many of these models is that they do not incorporate physiological changes in plants or changes in plant communities resulting from increased temperature and atmospheric CO_2.

Box 2-1. Criteria for evaluating hydrologic models for use in climate change impact assessment (Gleick 1986).

- Accuracy of the hydrologic model
- Degree to which model accuracy depends on the climatic conditions used to develop and calibrate the model
- Availability of input data, including historical data
- Accuracy of the input data
- Model flexibility and ease of use
- Compatibility with existing general circulation models

Compared to surface waters, far fewer studies have assessed the potential impacts of climate change on groundwater. Indeed far less is known about groundwater recharge and levels even under current conditions. Groundwater systems will generally respond more slowly to climate change than surface water systems and, as compared to surface water, climate effects on groundwater may be more heavily influenced by changes in precipitation than temperature (Kundzewicz et al. 2007). However, in warm periods, temperature effects are likely to be more pronounced (Kundzewicz et al. 2007). Recharge rates are determined by precipitation minus the combined effects of evapotranspiration and surface runoff. Warmer temperatures and longer growing seasons are expected to increase evaporative demand (Allan et al. 2005). As with surface water, groundwater recharge will be affected by changes in the frequency and magnitude of intense precipitation events as well as total precipitation amounts.

Several studies document generally increasing stream flow in the eastern and southeastern regions of the United States over the last century (Lins and Slack 2005, Mauget 2003) consistent with trends in precipitation. This overall pattern was observed in the South-Atlantic Gulf, but the region showed more variability than other regions of the U.S. For example, a number of stations documented low stream flow, particularly in Georgia (Lins and Slack 2005). While precipitation is a major driver of runoff, increases and decreases in precipitation do not necessarily correspond to equal increases and decreases in runoff (Karl et al. 2009). Rose (2009) found a high degree of elasticity in the rainfall-runoff relationship in the southeastern U.S. in that small deviations in rainfall amounts resulted in proportionally greater deviations in runoff. These differences were largely driven by differences in elevation and watershed relief. For example, the runoff/rainfall ratio for the Blue Ridge region was more than twice that of the Coastal Plains or Piedmont regions in North Carolina, indicating that stream flow in areas with high topographic relief might be more susceptible to changes in precipitation regimes. Furthermore, the relationship between rainfall and runoff was more tightly correlated in the Blue Ridge than the Coastal Plains or Piedmont (Rose 2009).

Milly et al. (2005) looked at global runoff projections (2041-2060) using a set of models from the IPCC Fourth Assessment Report (2007). The results for the United States are replotted in Lettenmaier et al. (2008) and show general agreement among a majority of model runs for slight increases (2-5%) in runoff in the Southeast (Figure 2-6). However, these

Table 2-4. Studies that have modeled the impacts of climate change on hydrology at the basin-scale (A) and examples specific to the Southeast (B).

A. Basin-scale models (expanded from studies reviewed in Praskievicz and Chang 2009)

Author(s) Study basin	GCM(s)	Study period	Hydrological model	Results
Frei et al. (2002) New York (Catskills)	HadCM2; CGCMa1	2020s 2050s 2080s	Thornthwaite conceptual water balance model1	By 2080s: Increase of 12% in runoff under HadCM2; Decrease of 30% in runoff under CGCMa1
Loukas et al. (2002) British Columbia	CGCMa1	2080-2100	UBC Water-shed Model1	Rainfall-dominated basin: increased fall/winter runoff, decreased spring/summer runoff; Snowmelt-dominated basin: earlier spring peak, increased winter runoff
Eckhard and Ulbrich (2003) Central Europe	Ensemble of 5 models	2090s	SWAT-G3	Increased winter runoff; earlier spring peak; decreased summer runoff and groundwater recharge. Small effects on mean annual groundwater recharge and streamflow.
Christensen and Lettenmeier (2006) Colorado River Basin	Ensemble of 11 models	2010-2039 2040-2069 2070-2099	VIC3	Runoff essentially unchanged in first time period, decreased runoff in later time periods. Average total basin reservoir storage generally declined.
Jha et al. (2004) Upper Mississippi Basin	HadCM2	2040-2049	SWAT3	51% increase in surface runoff; 43% increase in groundwater recharge; 50% increase in total water yield
Jha et al. (2004) Upper Mississippi Basin	HadCM2	2040-2049	SWAT3	South of the Baltic Basin: reduced river flow from the south; North: increased river flow
Thodsen (2007) Denmark	HIRHAM RCM	2071-2100	NAM2	River discharges increased 12% on average. Monthly river discharges increased from December to August and decreased in September and October
Bae et al (2007) South Korea	ECHO-G; NCAR/	1960-2100	PRMS1	Northern regions: increased runoff; Southern regions: decreased runoff. Monthly variation: decreased runoff in spring and summer; increased runoff in fall and winter.

Table 2-4 *(continued)*. Studies modeling impacts of climate change on hydrology at the basin-scale (A) and examples specific to the Southeast (B).

B. Examples from the Southeast

Author(s) Study basin	GCM(s)	Study period	Hydrological model	Results
Qi et al. (2009) North Carolina (Coastal Plain)	HadCMSul2; CGC1	2100	PRMS1	Increasing streamflow and ET under HadC-MSul2; Decreasing streamflow and ET under CGC1
Sun et al. (2000) North Carolina (Coastal Plain)	HadCM2	2100	PnET-II[2]	Increased drainage of 6%, increased ET of 8.7%, increased and forest productivity of 2.5%
Amatya et al. (2006) North Carolina (Coastal Plain)	CGC1; HadCM2	2001-2025	DRAINWAT[3]	Decreased drainage outflow and increased ET under CGC1; Outflow unchanged but increased ET under HadCM2
Tu (2009) Massachusetts	CGCM3.1	2005-2024	AVGWLF[4]	Increased streamflow in late fall and winter, decreased streamflow in summer and early fall. Lower impact on annual streamflow
Lu et al. (2006) South Carolina (Coastal Plain)	Fixed scenarios (incr. temperature 2°C; incr. precipi-tation 10%)	2003, 2004	MIKE SHE[3]	Decreased water table and streamflow under warmer temperatures and increased precipitation
Lu et al (2009) Florida (Flatwoods)	Fixed scenarios (incr. temperature 2°C; incr. precipi-tation 10%)	1992-1996	MIKE SHE[3]	Decreased water table levels especially during dry periods. PET increased under higher temperature scenario

projections are not based on downscaled models and, as a result, do not capture spatial variability at finer scales. Relatively few studies have dealt specifically with projected hydrologic trends in the southeastern United States and this remains an area in need of future research. Both spatial and seasonal variability will greatly affect local systems, the latter of which will not be captured in projections of annual averages. An earlier study (Cruise et al. 1999) used downscaled data from the Hadley Center GCM and a simple regionalized stochastic stream flow model to examine the impacts of climate change on water quality in the southeastern United States. Although, their hydrologic model relied on a number of simplified assumptions and is therefore of limited application, their results illustrate the potential variability across wet and dry season stream flow conditions that are not captured in projections of annual averages.

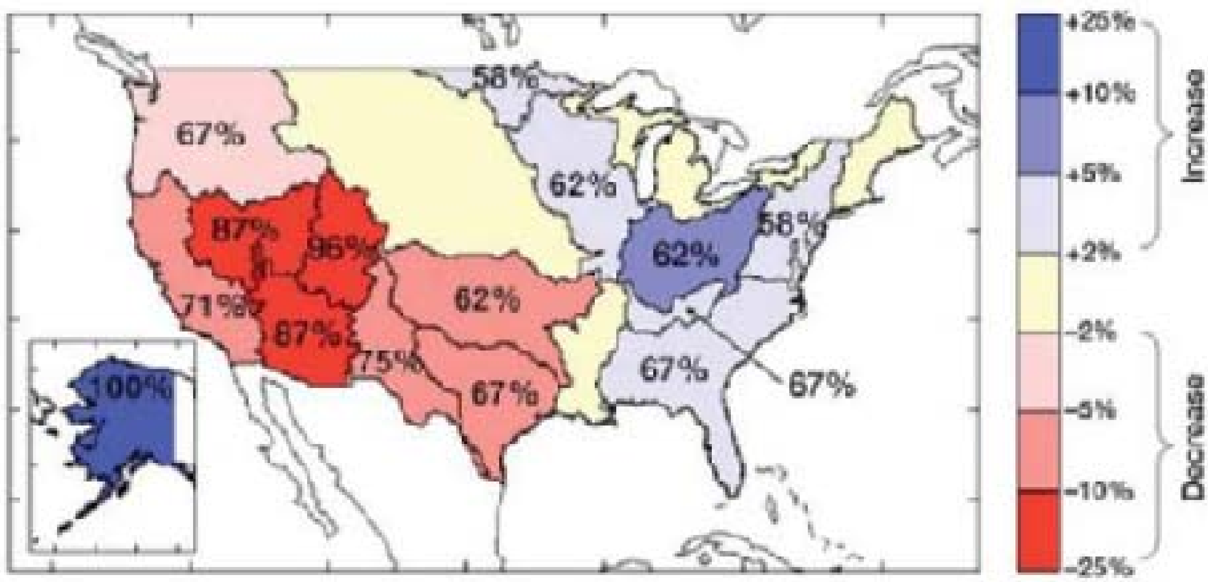


Figure 4.10 *Median changes in runoff interpolated to USGS water resources regions from Milly et al. (2005) from 24 pairs of GCM simulations for 2041-2060 relative to 1901-1970. Percentages are fraction of 24 runs for which differences had same sign as the 24-run median. Results replotted from Milly et al. (2005) by Dr. P.C.D. Milly, USGS.*

Figure 2-6. Mid-century projected changes in runoff for U.S. regions (Source: Lettenmaier et al. 2008).

A handful of studies have modeled hydrologic response to climate change in the Southeast using scenarios based on GCMs or other projections. The scenarios used in these studies consistently project warming by the end of the 21st century (although vary in magnitude) but differ in the projected changes in precipitation patterns, with some scenarios projecting decreases and others projecting increases in annual precipitation. A regional assessment of the effects of climate change on forest productivity and hydrology suggested that climate change could significantly alter stream flow across many forested areas in the southern U.S. (McNulty et al. 1997). The studies reviewed here (see Box 2-2) are limited to forested systems in the coastal plain. However, a common finding was that hydrologic regimes are likely to be much more sensitive to changes in precipitation than to changes in temperature.

Box 2-2. Hydrological models applied at watershed and regional scales in the southeast.

Sun et al. (2000) looked at climate change impacts on the hydrology and productivity of loblolly pines using PnET-IIS on a flat lower coastal plain in North Carolina. The PnET-IIS model closely integrates forest hydrology with biological processes, however, like most other models reviewed here, it does not consider biological responses such as stomata conductance and water use efficiency to changes in temperature and carbon dioxide concentrations. Under a climate scenario projecting warmer temperatures and increased precipitation (HadCM2), forest productivity, evapotranspiration, and drainage were all projected to increase, suggesting that overall water yield will track trends in precipitation patterns.

Amatya et al. (2006) used DRAINWAT to reassess climate change impacts on drainage and shallow groundwater tables in a loblolly pine plantation in North Carolina. Unlike the PnET-IIS model, DRAINWAT is based on a model developed for use with poorly drained soils. Amataya et al. (2006) examined two future climatic scenarios representing warmer/wetter (HadCM2) and hotter/drier (CGC1) regimes projected over a 25-year period. The results of both climate scenarios indicated that the change in air temperature would have a less significant impact than the change in precipitation on the hydrology of the system. In both scenarios, evapotranspiration increased. However, there was little effect on the drainage outflows under the HadCM2 climate scenario (5% increased precipitation). Under the CGC1 scenario (12% decreased precipitation) decreased outflow was the result of reduced rain and deeper predicted water table depths. Even under these conditions, water was not limited enough to significantly reduce forest productivity.

Lu et al. (2006) applied the MIKE SHE model to a coastal plain watershed in South Carolina. The MIKE SHE model simulates the full hydrologic cycle characteristics of forest ecosystems, including evapotranspiration and vertical soil water movement in the unsaturated zone to the groundwater. They looked at response to increased air temperature or decreased precipitation independently using fixed scenarios rather than input from GCMs. Warmer temperatures (2°C) or decreased precipitation (10%) resulted in reduced groundwater recharge and thus a lower water table. Similarly, projected stream flow decreased in response to warmer temperatures or reduced precipitation. However, stream flow was much more sensitive to changes in precipitation than temperature. Qi et al. (2009) found similar results using the USGS Precipitation Runoff Modeling system model with downscaled GCMs to examine the potential impacts of climate on the monthly stream flow of a river basin on the lower coastal plain of eastern North Carolina. Simulated stream flow response was more sensitive to changes in precipitation than to air temperature using scenarios based on the HadCM2 and CGC1.

2.2.3 Additional Considerations for Aquatic Systems

The general effects of climate change on freshwater systems will likely include increased water temperatures, decreased dissolved oxygen levels, and increased toxicity of pollutants thereby altering the availability and quality of habitat for aquatic biota (reviews in Mulholland et al. 1997, Allan et al. 2005, Ficke et al. 2007). Meyer et al. (1999) identified characteristics of aquatic ecosystems that are particularly sensitive to climate change (Table 2-5). These highlight the range of impacts climate change poses to the biota of freshwater systems–ranging from loss of habitat and the resulting shifts in species composition to changes in nutrient cycling that affect oxygen and nutrient availability–and the indirect effects of synergies with other stressors.

Changes in global climate affect primary production and the nutrient concentration of inland waters (reviewed in Ficke et al. 2007). Increased productivity resulting from warmer temperatures can lead to oxygen depletion in bottom waters as algae and organic matter settle out of surface waters and decompose. Water quality is also likely to be influenced by climate-induced changes, with potential consequences for aquatic organisms (reviewed in Murdoch et al. 2000). Warming of surface waters and longer growing seasons have the potential to increase primary production, organic matter decomposition, and nutrient cycling (Mulholland et al. 1997), particularly in systems with sufficient nutrient and oxygen supplies. Productivity will be affected by changes in the hydrologic cycle that impact nutrient loading and residence times. For example, more frequent storm events may flush nutrients and sediment into surface waters. In addition, warmer water temperatures may increase productivity as a result of increased metabolic rates. During drier climatic periods, decreased stream flow may increase the residence time and concentrations of nutrients and pollutants in surface waters. However, in oxygen poor systems, decreased oxygen holding capacity associated with warmer water temperatures may actually exacerbate low oxygen availability and limit productivity.

Table 2-5. Some properties of aquatic ecosystems that are particularly sensitive to climate change (Source: Meyer et al. 2002, © Wiley Interscience, used with permission).

Lakes	Streams	Wetlands
Mixing Regime	Flow Regime	Altered Water Balance Leading to Wetland Losses
Nutrient and DOC Inputs	Sediment Transport / Channel Alterations	Fire Frequency
Habitats Meeting Temperature and Oxygen Requirements	Nutrient Loading and Rates of Nutrient Cycling	Altered Rates of Exchanges of Greenhouse Gases
Productivity	Fragmentation and Isolation of Cold Water Habitats	Vegetation Species Composition
Top Predator Changes Leading to Trophic Cascades	Altered Rxchanges with the Riparian Zone	Reproductive Success of Many Animal Species
Abundance of Cold- and Warm-Water Fish Species	Life History Characteristics of Many Aquatic Insects	Sensitivity to Invasion by Tropical Exotic Species

2.2.4 Understanding the Potential Impacts of Precipitation and Hydrologic Shifts on Species and Habitats

Terrestrial systens

Precipitation patterns have direct effects on evapotranspiration and water availability, which are key determinants of the distribution of plant diversity (Kreft and Jetz 2007) and vegetation types (Stephenson 1990). Although most landscape-scale shifts in vegetation are assumed to have occurred over relatively long time scales in the past, rapid changes in future climate are expected to produce major shifts in vegetation (e.g., Saxon et al. 2005). Such rapid responses to altered moisture regimes are not unprecedented. For example in northern New Mexico in the 1950s, the boundary between semiarid ponderosa pine forest and piñon-juniper woodland shifted extensively and rapidly through mortality of ponderosa pines in response to severe drought, with lasting effects (Allen and Breshears 1998). Among pines found in the southeastern United States, longleaf pine may be more tolerant of a range of conditions (NWF 2009), including very dry periods during the growing season, than loblolly and slash pine (Iverson et al. 1999).

Aquatic systems

Among aquatic systems, wetlands will be particularly sensitive to even relatively small changes in precipitation. Wetlands that depend primarily on precipitation as a water source will be among the habitats most vulnerable. Winter (2000) assessed the vulnerability of wetlands to changes in climate relative to their position within the hydrologic landscape. He suggested that wetlands located in mountainous regions would be some of the most vulnerable to climate change due to their location within relatively small watersheds and dependence on precipitation inputs. For the organisms that are dependent on these ecological systems for specific portions of their life cycles, changes in precipitation patterns throughout the year can be as significant, if not more so, than changes in total or mean precipitation (Virginia Burkett and Kusler 2000). A number of amphibian species, for example, are sensitive to the amount and timing of precipitation for successful reproduction. Analysis of population trends over a 26-year period in South Carolina showed that declines in four species were associated with insufficient rainfall and a shortened hydroperiod at breeding sites (Daszak et al. 2005).

Wetlands associated with surface water, such as riparian wetlands, will be dependent on the hydrologic impacts of climate change on the stream flow. Those wetlands located in broad basins of interior drainage often depend on stream flow originating from precipitation in the contiguous uplands, with much smaller contributions from ground water and precipitation. They will therefore be highly dependent on precipitation regimes in the contiguous uplands and will also be more vulnerable to shifts in hydrology. Wetlands in coastal areas can be moderately vulnerable to climate change depending on their reliance on precipitation and flooding from streams. However, direct loss of area due to sea level rise is very likely to be the greatest threat to wetlands in coastal landscapes.

A number of aquatic species will be sensitive to changes in hydrology and timing of flooding and drying events. For example, fish kills associated with low dissolved oxygen levels and nutrient enrichment may be impacted by climate change. Strong storm events can flush excess nutrients into waterways, increasing productivity and temporarily causing low oxygen conditions. Warmer water temperatures are likely to exacerbate these situations through decreased oxygen carrying capacity and increased oxygen demand, potentially increasing the frequency of fish kills. Freshwater mussel assemblages are especially vulnerable to stream drying, particularly in streams without refugia such as that provided by wood debris (Golladay et al. 2004).

2.3 Sea Level Rise

Rising seas are perhaps one of the most immediate, and possibly devastating, impacts of climate change in coastal areas. The potential consequences of sea level rise include submerged wetlands, eroded beaches, flooded coastal areas, increased salinity in freshwater aquifers and estuaries, and damage to both human property and coastal ecosystems. Using tide gauge records from around the world, scientists have been able to reconstruct global sea levels since 1700 and then analyze shifts in levels and associated rates of change (e.g., Jevrejeva et al. 2008). Although there are some differences in the estimates of the magnitude and rates of change based on underlying model assumptions and available data, the IPCC suggests that current sea level rise (SLR) has occurred at a mean rate of 1.8 mm per year for the past century (Bindoff et al. 2007). Recent satellite altimetry measurements suggest that this rate may be increasing, with a mean rate of 2.8 to 3.1 mm per year from 1993 – 2003 (Bindoff et al. 2007).

Warming temperatures contribute to global sea level rise (SLR) through two mechanisms as temperature rises: (1) ocean water expands and increases in volume and (2) land reservoirs of ice (in glaciers and ice flows) melt and contribute additional water to the oceans. Observations suggest that both ocean warming and ice mel are contributing to increasing rates of average global sea level rise (Bindoff et al. 2007). The average temperature of the global ocean has increased to depths of at least 3,000 meters, and observations show that the ocean has been absorbing more than 80 percent of the heat added to the climate system (Williams et al. 2009). This warming causes seawater to expand and sea levels to rise. In addition, mountain glaciers and snow cover have declined on average in both hemispheres, and losses from the Greenland and Antarctic ice sheets have very likely contributed to global sea level rise between 1993 and 2003 (Williams et al. 2009).

Photo: Alligator River National Wildlife Refuge, beyondseasonsend.org

Land subsidence, both natural and human-caused, is the gradual downward settling of the Earth's surface (Williams et al. 2009). Groundwater removal, drainage of organic soils, and underground mining can all contribute to subsidence, leading to significant damage and increasing risk from flooding due to sea level rise. Subsidence is also caused by a variety of natural factors including tectonic processes, sediment loading and compaction, and the extraction of subsurface fluids such as oil and water. Both local subsidence and global mean SLR determine the relative sea level rise experienced at a particular location. On the Atlantic coast of North America, the Earth's crust is actually relaxing vertically, or sinking downward (Engelhart et al. 2009). Relative SLR is therefore measured with respect to a specific vertical point or line used as a reference in a particular location and can be measured directly by coastal tide gauges, which record both the movement of land to which the gauge is attached and the changes in global sea level rise. Relative SLR is already evident in many coastal regions and will increase significantly during this century (Bindoff et al. 2007), Williams et al. 2009), further magnifying the effects of global SLR resulting from thermal expansion and melting.

2.3.1 Future Global Projections

Results of climate models suggest that mean sea level rise during this century will significantly exceed rates experienced over the past century. Based on temperature increases projected in the IPCC report of 2 - 11.5°F of warming over the next century, global sea levels could rise from 0.18 meters to 0.59 meters, with an additional increase of up to 0.2 meters based on melting ice sheets (Meehl et al. 2007). Since publication of the Fourth IPCC report, these estimates have been called conservative (e.g., Velicogna and Wahr 2006, Bamber et al. 2009). The IPCC projections include a conservative contribution from the Greenland and Antarctic ice sheets and glaciers at the rates observed for 1993-2003 (Meehl et al. 2007). However, scientists have been warning of accelerations in the ice sheets and near-coastal thinning for several years (Rignot and Thomas 2002, Thomas et al. 2004, Rignot and Kanagaratnam 2006, Csatho et al. 2008). In particular, Rignot and Kanagaratnam (2006) detected a doubling in mass loss in the Greenland ice sheet between 1996 and 2005 using satellite radar interferometry and found that the contribution of Greenland's melting ice to sea level rise increased from 0.23±0.08 mm/yr in 1996 to 0.57±0.1 mm/yr in 2005. Several studies have projected up to 1.4 meters of sea level rise by 2100 when ice sheet contributions are included (e.g., Rahmstorf et al. 2007, Pfeffer et al. 2008).

As sea level rises, storms will reach higher elevations leading to more extensive inundation (FitzGerald et al. 2008). The combination of sea level rise and storm surge will lead to a greater frequency of flood waters overtopping levees, breaking over seawalls, and breaching barriers. These threats may be magnified with climate change, as storms that lead to coastal storm surges are likely to become more intense and bring heavy precipitation and higher wind speeds (Williams et al. 2009). Recent studies suggest that hurricanes in the Altantic Ocean have increased in intensity over the past half century (Kunkel et al. 2008).

2.3.2 Understanding the Potential Impacts of Sea Level Rise on Species and Habitats

Coastal habitats, including tidal marshes, submerged aquatic vegetation, estuarine beaches, tidal flats, freshwater tidal forest systems, marsh and barrier islands, cliffs, and other coastal habitats are all at risk to losing area to inundation under sea level rise. Additionally, these communities face impacts from changes in tidal range, saltwater intrusion, erosion and increases in the frequency and duration of flooding. Shoreline habitats are complex and dynamic environments shaped by physical processes, sediment transport and deposition, geology, and changes in sea level (Gutierrez et al. 2009). Although it is widely recognized that sea level rise alters coastal landforms, predicting precisely how changes in the landscape will occur in response to sea level rise is a complex endeavor. Gesch et al. (2009) identify a number of impacts that coastal regions will face in response to sea level rise (Box 2-3).

Box 2-3. Responses of a coastal regions to sea level rise (Gesch et al. 2009)

- Land loss resulting from inundation of low lying lands
- Land loss due to erosion
- Barrier island migration, breaching and segmentation
- Wetland accretion and migration
- Wetland drowning (deterioration and conversion to open water)
- Expansion of estuaries
- Saltwater intrusion
- Increased frequency of storm flooding

Photo: Shoreline erosion in North Carolina, coastal.geology.edu/NCCOHAZ

Along much of the U.S. coast, shoreline changes are related to changes in the shape of the landscape at the water's edge. These changes do not occur as a direct result of sea level rise but rather in response to waves and currents, sediment availability, coastal storms, and human activity, as well as the underlying geology. The complex and dynamic factors contributing to shoreline development make predictions of how shorelines will change in the future (and the relative contribution of sea level rise) difficult and uncertain. While current impact assessments often focus on the vulnerability of certain coastal landscapes to inundation due to sea level rise, these models do not incorporate the processes (e.g., barrier island migration) or the environmental changes (e.g., marsh deterioration) which may occur (Gutierrez et al. 2009) and may therefore fail to capture the full extent of impact required for local planning purposes.

Barrier islands are expected to be disproportionately affected by the impacts of sea level rise. These islands act as an energy buffer, protecting the back-barrier estuarine system from high-energy waves. Because barrier islands occur in areas of large wave energy they are exposed to overwash produced by storms. Overwash acts to erode dunes into the island interior, and sediment deposition from overwash then builds the island's elevation (Gutierrez et al. 2009). As sea level rises, three main processes will affect barrier islands. First, higher sea levels may cause storm overwash to occur more frequently, potential leading to greater erosion and overwash. Second, tidal inlet formation and migration will change future shoreline positions of barrier islands. Third, barrier island shoreline changes may accelerate with rising sea level and stronger storms. Given the dynamic nature of barrier islands, these factors have the potential to leading irreversible changes (Gutierrez et al. 2009), such as landward migration, changes in barrier island size or increases in tidal inlets. Narrow, low elevation barrier islands are most susceptible to increased overwash and may be the first to cross these thresholds. The future of these barrier islands depends in part on the ability of salt marshes in barrier lagoons and estuaries to build vertically at a pace equal to the rise in sea level (Gutierrez et al. 2009). However, assessments of shoreline changes on barrier islands indicate that barriers have already thinned in some areas of the country over the last century (Gutierrez et al. 2009).

Coastal wetlands are also highly vulnerable to the impacts of sea level rise. Tidal wetlands build vertically through the accumulation of mineral sediments and organic matter controlled by a number of processes (Figure 2-7, Cahoon et al. 2009). Mineral sedimentation represents the balance between sediment import and export, which varies among geomorphic settings and different tidal and wave energy regimes. Predicting marsh sustainability with given rates of projected sea level rise depends on an understanding of the complex factors that influence wetland development, some of which are themselves influenced by climate change. In addition to the environmental drivers identified in Figure 2-7, wetland development is also influenced by barriers to migration, such as human development and topog-

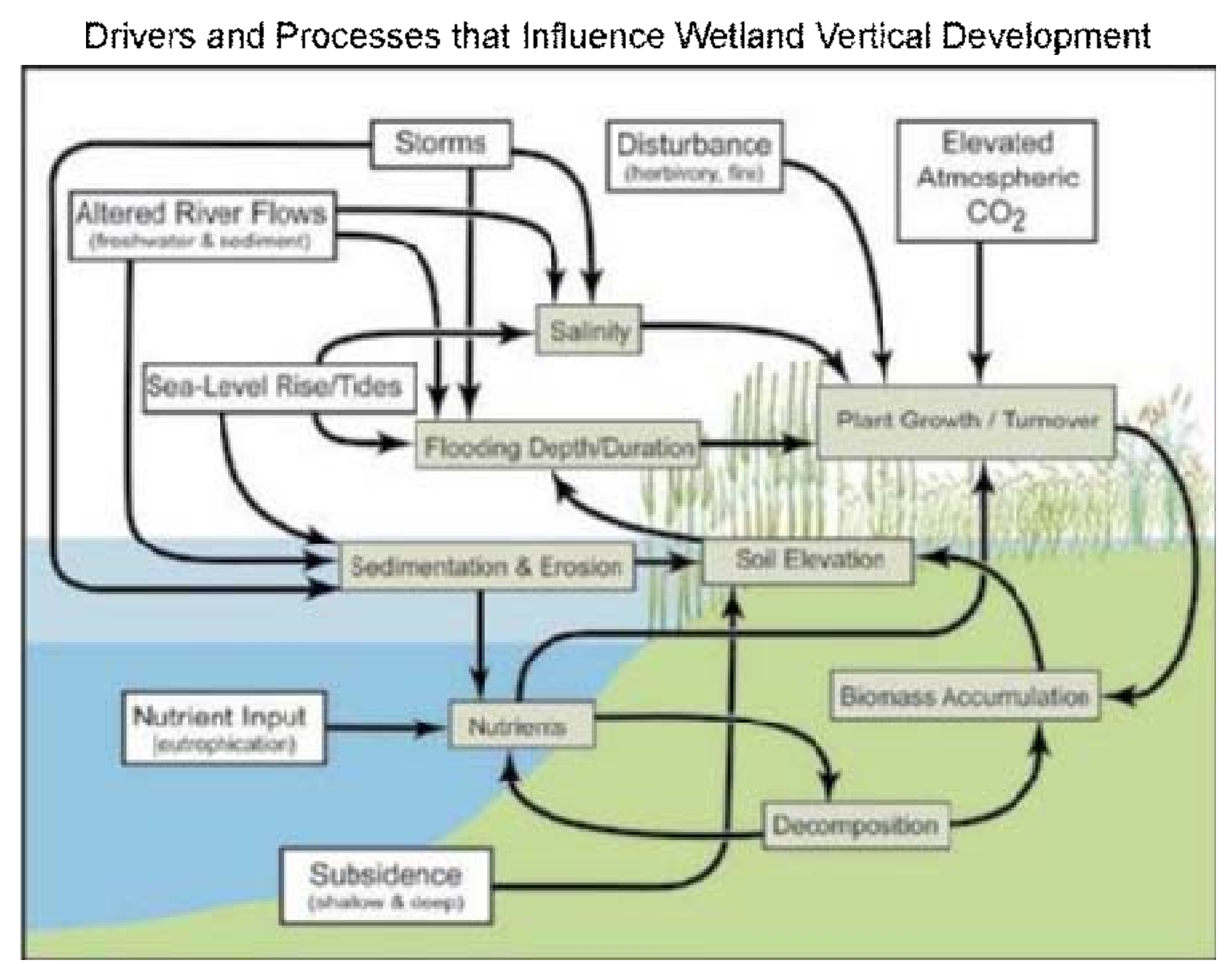


Figure 4.2 A conceptual diagram illustrating how environmental drivers (white boxes) and accretionary processes (grey boxes) influence vertical wetland development.

Figure 2-7: Drivers and processes that influence wetland vertical development (Source: Calhoon et al. 2009). The sustainability of coastal wetlands under sea level rise will be affected by differences in the rate and magnitude of acccretion.

raphy–drivers that may become increasingly important factors for wetland migration under sea level rise. The relative role of each driver in controlling the vertical development of wetlands depends varies with geomorphic setting (Cahoon et al. 2009).

Habitat loss due to sea level rise is expected to have a significant impact on nesting areas, spawning grounds, migratory paths, and foraging areas for a number of species (Daniels et al. 1993). Species that rely primarily on habitats in low-lying areas for some portion of their life history are expected to be particularly at risk. For example, Galbraith et al. (2002) modeled the impact of sea level rise on five internationally important sites for shorebird migration and overwintering. Although they used a conservative global warming estimate, the results of the study suggested a significant loss of tidal flat habitat across all sites. However, the magnitude of loss was dependent on local characteristics (Galbraith et al. 2002). Given the scale of habitat loss, the authors suggested that major reductions of shorebirds could occur, and could be excerbated if other synergistic threats (e.g., shoreline hardening, subsidence) were considered.

Habitat loss due to sea level rise is expected to have a significant impact on nesting areas, spawning grounds, migratory paths, and foraging areas for a number of species.

Species that are already endangered or threatened are of particular concern. For example, many endangered sea turtles in the Southeast nest on barrier islands that could be inundated under even conservative estimates of sea level rise (Daniels et al. 1993). Wave overwash in the early 1980s destroyed 3-35% of all loggerhead sea turtle nests on barrier islands in South Carolina (Hopkins and Murphy 1989 in Daniels et al. 1993). In addition to sea turtles, Daniels et al. (1993) suggest that other endangered or threatened species, such as the wood stork *(Mycteria americana)* and the American alligator (*Alligator mississippiensis*), will be negatively impacted not just by the reduction in marsh size and nesting sites, but the decline in recruitment success of larval and juvenile fish within tidal creeks (Thomas et al. 1991 in Daniels et al. 1993). Thus, species with a variety of life history characteristics may be at risk because of loss of nesting habitat, food sources, and breeding locations due to rising seas.

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Projected Impacts of Climate Change in North Carolina

Although regional studies provide a useful framework for assessing the impacts of climate change on fish and wildlife across the Southeast, state-specific information will be critical for updating the North Carolina Wildlife Action Plan (NC WAP) (NCWRC 2005). Fortunately, a number of climate modeling and scenario tools are available to project potential shifts in temperature and precipitation in the state. In this chapter, we apply climate modeling scenarios to map state-specific projected temperature and precipitation changes. We also provide a review of recent studies on projected sea-level-rise for the coast of North Carolina. In each section, we use the information from the projections to identify a broad subset of species and habitats in North Carolina that may be particularly susceptible to climate change impacts in the state.

3.1 Temperature Change Projections for North Carolina

Climate Wizard (Zganjar et al. 2009) is a useful mapping tool that can be used to derive temperature projections for North Carolina for the middle and end of this century. This user-friendly tool allows users to access past changes in climate, as well as project future changes in rainfall and precipitation in a given area based on available climate models statistically downscaled to a 12 km^2 resolution (Maurer et al. 2007). The projections presented in this section are based on multi-model ensemble averages of 16 global circulation models (GCMs) using the high emissions scenario (A2) from the IPCC. Estimates of mean temperature departures are provided for mid-century (2040 – 2069) and end of century (2070-2099).

Based on projections using Climate Wizard, average yearly temperatures across the state are expected to increase 3.5 to 4.7°F by mid century. The areas of highest temperature increase will be in the north and west of the state and in many of the mountainous regions. Coastal areas are also projected to experience significant yearly average temperature increases, but to a lesser degree than inland areas. By the end of the century, projections show increases in annual average temperatures of 5 to 6°F, again with the greatest increases in the north and west portions of the state (Figure 3-1).

In addition to changes in average annual temperature, seasonal, monthly, and maximum/ minimum daily temperatures can sometimes provide more meaningful projections for assessing the impact of temperature changes on species and ecosystems. Climate Wizard can easily be used to complete this type of analysis. Figure 3-2 shows projected change in temperature in North Carolina by season for the end of the century. The largest increase in temperature (7.8°F) is projected to occur in the summer months between June and August, while the lowest increases in temperature are projected to occur during the fall and winter. Other temperature related variables, such as number of frost free days or length of the growing season are also biologically important. Although, Climate Wizard does not provide these outputs directly, many climate modelers are interested in working with state agencies and other partners to identify the data and information needs required to facilitate climate change adaptation for wildlife. University researchers as well as many of the federal initiatives are identified in Appendix E.

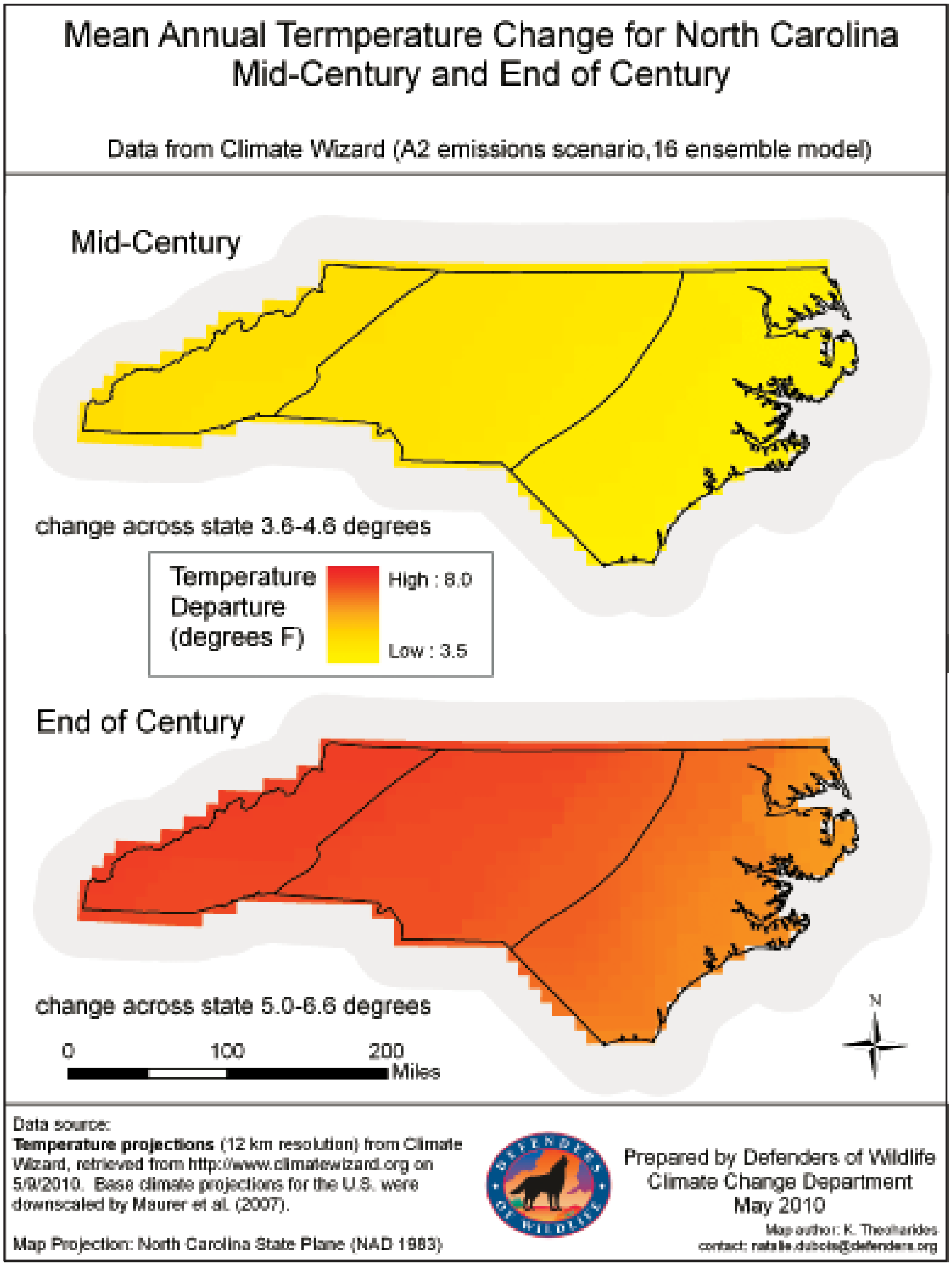


Figure 3-1. Projected change in mean annual temperature for North Carolina by mid and end of the century. Projections are based on a high emissions scenario (A2) and the ensemble average of 16 GCMs statistically downscaled to 12 km.

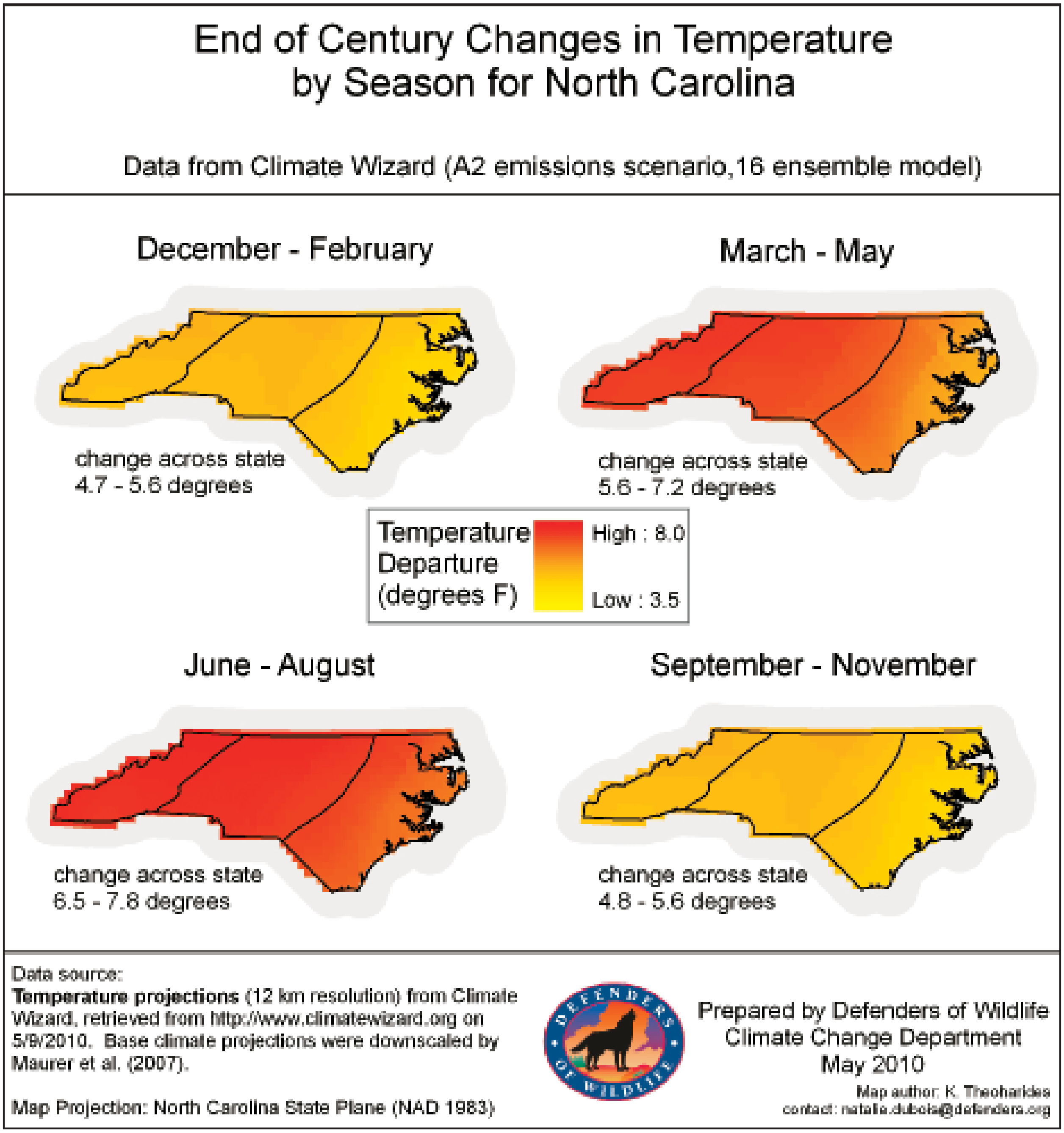


Figure 3-2. End of century projected changes in temperature shown by season for North Carolina. Projections are based on a high emissions scenario (A2) and the ensemble average of 16 GCMs statistically downscaled to 12 km.

3.1.1 Potential Impacts of Temperature Shifts on Species and Habitats in North Carolina

In North Carolina, a number of important species may be impacted by increasing temperatures. Shifts in the timing of seasons may cause asynchrony in species interactions or trophic mismatches. Warmer and dryer years may alter the timing of insect emergence or the time of blooming (reviewed in Parmesan 2006). High elevation communities may be particularly at risk given projected climate warming in the region. Spruce-fir forests are projected to move northward as physiological tolerances are exceeded across its southern range, which is limited by summer heat and drought (Figure 3-3, Iverson and Prasad 2001). Research from Iverson and Prasad (2001), suggests that spruce-fir habitat could be easily extirpated from the eastern U.S. as temperatures increase. In addition, changes in seasonal temperatures may allow pest species to survive during warmer winters and thus exacerbate the threat of insect outbreaks (Logan et al. 2003). An increase in insect outbreaks may make spruce-fir habitats in North Carolina particularly vulnerable to the effects of climate change. Spruce-fir habitats provide critical habitat for a number of priority birds, including a subspecies of brown creeper (*Certhia americana*) and northern saw-whet owl (*Aegolius acadicus),* that may be endemic to the high peaks of the Southern Blue Ridge Ecoregion (NCWRC 2005).

… changes in seasonal temperatures may allow pest species to survive during warmer winters and thus exacerbate the threat of insect outbreaks. An increase in insect outbreaks may make spruce-fir habitats in North Carolina particularly vulnerable to the effects of climate change.

Reptiles and amphibians can also be very sensitive to changes in temperature. An ectotherms' life history traits, behavior and physiology are all strongly influenced by environmental temperature (Standora and Spotila 1985, Janzen 1994). For example, in a study on Eastern red-spotted newt (*Notophthalmus viridescens),* Rohr and Madison (2003) found that elevated dehydration risk may compromise antipredator behavior and exacerbate amphibian population declines. Although they spend the majority of their lives at sea, marine turtles have a terrestrial component of their life cycle, returning to land each year to nest. Sand temperature during egg incubation is a critical factor in embryo development, hatching success, and hatchling sex ratios (Figure 3-4). Increases in sand temperature may therefore affect reproductive success and hatchling development, as well as the sex ratios of offspring produced (Hawkes et al. 2009). Increased water and air temperatures may also lead to earlier onset of egg-laying and range expansion northward. For example, warmer temperatures in past interglacial periods have facilitated the expansion of loggerhead sea turtles (*Caretta caretta)* into higher latitudes (Bowen et al. 1994), and leatherback sea turtle (*Dermochelys coriacea)* nests are now being recorded at their most northerly locations in a decade of monitoring (Rabon et al. 2003). Loggerhead sea turtles have shown earlier nesting by 12 to 18 days in response to 1.8 °F of warming (Hawkes et al. 2007). Both loggerhead and leatherback sea turtles are identified as priority species in North Carolina and are internationally classified as endangered and critically endangered respectively (Marine Turtle Specialist Group 1996, Sarti Martinez 2000).

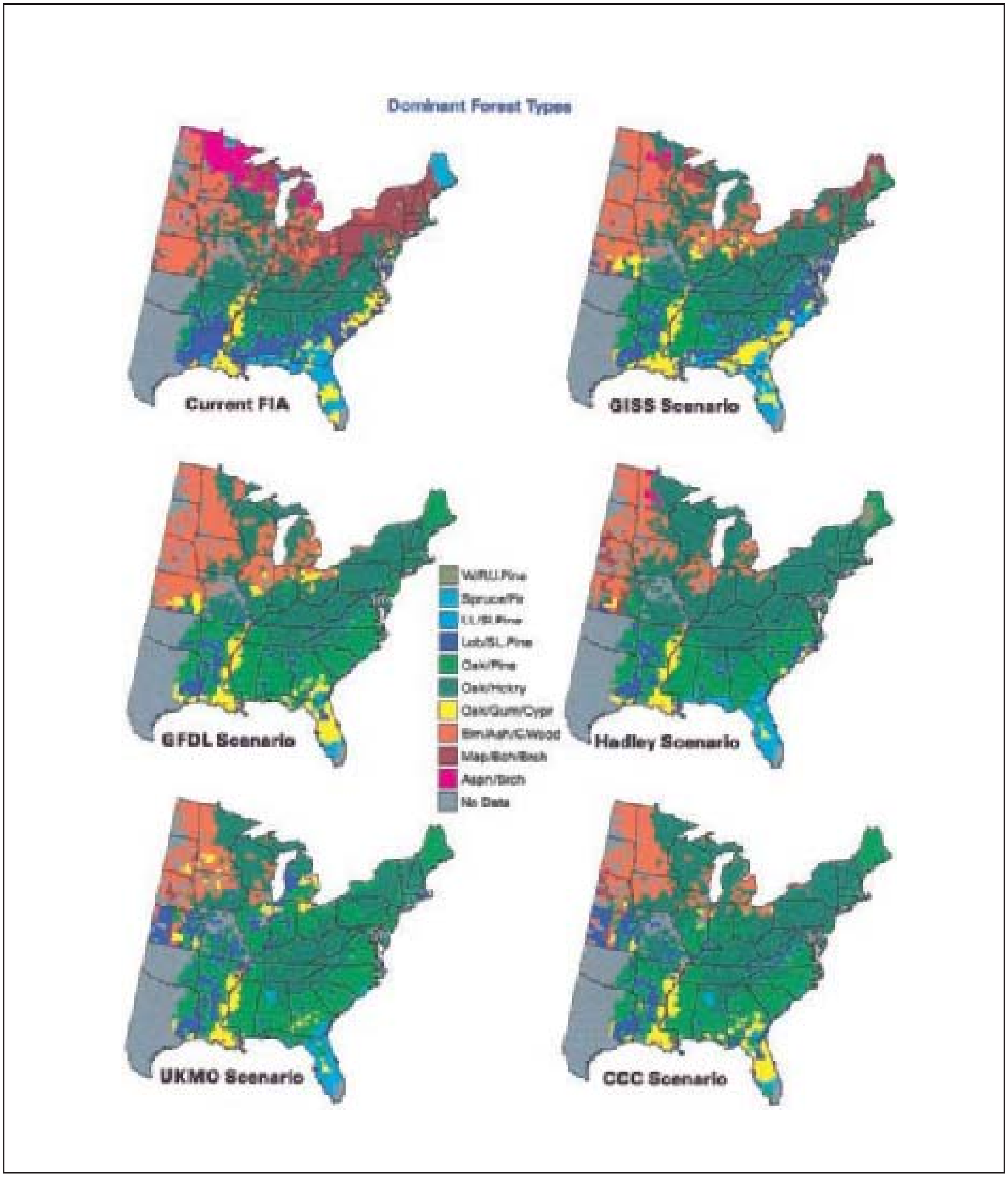


Figure 3-3. Current forest types as determined from forest inventory data and potential future forest types under five scenarios of climate change. (Source: Iverson and Prasad 2001, © Springer, used with permission).

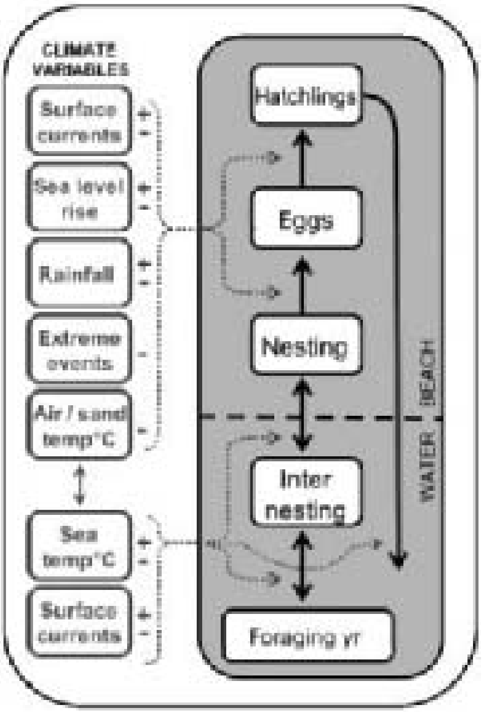


Fig. 3. Breeding and nesting phase of marine turtles. Dotted grey arrows represent the potential climate variables and their indirect effects, + or – indicate likely direction of effect

Figure 3-4. Climatic factors affecting sea turtles during nesting and breeding (Source: Hawkes et al. 2009, © Inter-Research, used with permission). Increases in sand temperature due to climate change may affect reproductive success and hatchling development, as well as the sex ratios of offspring produced (Hawkes et al. 2009).

Marine turtles typically incubate successfully only between 77 and 95°F (Ackerman 1997 in Hawkes et al. 1997). In general, the higher end of this temperature range produces female embryos while lower temperatures result in male turtles (e.g., Hays et al. 2003). An equal number of males and females are produced at the 'pivotal temperature' which, for loggerhead turtles, occurs between 82.4 to 87.8°F (Mrosovsky 1988). Projected future increases in temperature could result in biased sex ratios towards females, although behavioral changes, such as choosing shaded nesting sites, nesting earlier, or nesting later in the season, could maintain mixed sex ratios (Hawkes et al. 2009). Whether marine turtles will be able to adapt either behaviorally or physiologically to increased temperatures for incubation, remains unclear.

Aquatic habitats and species are expected to be significantly impacted by warming climate trends. The Southeast has the highest aquatic species diversity in the entire United States, including significant taxonomic diversity of fishes, mollusks, and crayfish (NC WAP). A significant proportion of these groups are already known to be at risk in North Carolina, with 83 fish species, 43 mussel species, 21 crayfish species, and 10 snail species identified as priorities for conservation in the NC WAP. Major threats identified in the NC WAP include pollution, hydrologic alteration, physical habitat manipulation, and introduction of non-indigenous species, many of which are likely to be exacerbated by climate change. In the Piedmont and Mountains, a number of river basins are already extensively modified by dams (Figure 3-5) and impoundments, further limiting species ability to move to more suitable habitats under changing climatic conditions.

Photo: Cheoah Dam, www.learnnc.org/lp/multimedia/7836

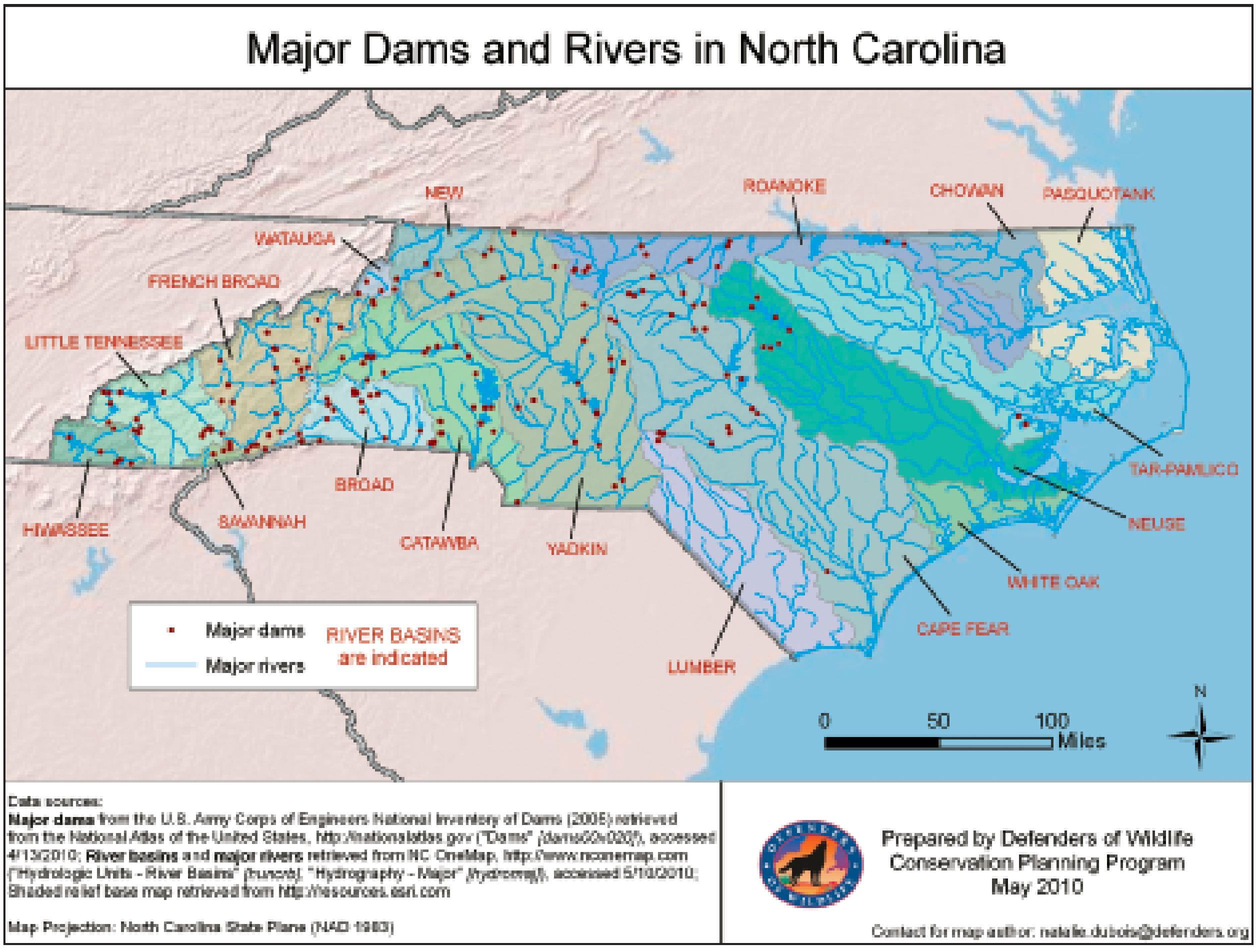


Figure 3-5. Dams and major rivers in North Carolina. Existing threats to aquatic habitats and species, such as hydrological alteration, may be exacerbated by climate change.

As the availability of cool water habitat contracts, priority species that inhabit cooler headwaters, such as Johnny darter (*Etheostoma nigrum*), striped shiner (*Luxulis chrysocephalus*), and slippershell mussel (*Alasmidonta viridis*) may be more at risk. Recreationally important fisheries, for example those stocked in cold and cool water hatcheries in the state, such as walleye (*Sander vitreus*), muskellunge (*Esox masquinongy*), and trout species, are also likely to be affected. Box 3-1 includes a detailed assessment of temperature impacts on brook trout (*Salvelinus fontinalis)*. Sessile organisms unable to move to more suitable habitats, such as temperature-sensitive mussel species, may be particularly at risk. For example, Appalachian elktoe (*Alasmidonta raveneliana*) populations are already restricted to scattered pockets of suitable habitat consisting of cool, clean well-oxygenated water (NatureServe 2009).

Sessile organisms unable to move to more suitable habitats, such as temperature-sensitive mussel species, may be particularly at risk.

Box 3-1. A detailed assessment of the potential impact of climate change on brook trout

Brook trout (Salvelinus fontinalis), sometimes called the Eastern brook trout, are one of the most popular gamefish in the Northeast (Crossman and Scott 1973 in Roberts 2000), and the only trout species native to North Carolina (Southern Division American Fisheries Society Trout Committee (SDAFSTC) 2005). Because brook trout are coldwater fish, they are extremely sensitive to changes in stream temperature, particularly in their southern and lower elevation ranges. The upper thermal tolerance for brook trout is 72.3°F (Eaton and Sheller 1996) and maximal weight gain in juveniles occurs at temperatures less than 65°F (McCormick et al. 1972). As of 2002, only 24% of potential stream locations nationwide were cool enough to support brook trout (O'Neal 2002). In addition, average summer stream temperatures at sites across the U.S. are projected to rise 0.7-1.4°F by 2030, 1.3-3.2°F by 2060, and 2.2-4.9°F by 2090 (O'Neal 2002), potentially shrinking the already much-diminished available habitat for brook trout by 26-41% by 2090 under the higher emissions scenarios. Although this study focused on the impacts of climate change on water temperature, other potential climate change effects may have a significant impact on the amount and quality of available trout habitat, including the magnitude or timing of precipitation, evaporation rates, or stream flow changes. Additional secondary effects of climate change, such as the impact of warming waters on food supply, water quality, pesticide toxicity or disease, may impact the viability and persistence of brook trout in North Carolina, although further research is clearly needed. Brook trout may also face demographic threats as populations become ever more confined to the highest elevation and coldest streams. The loss of this widely popular recreational species from North Carolina waters could have a significant impact on local and regional economies (Responsive Management 2009).

3.2 Precipitation Change Projections for North Carolina

Climate Wizard (Zganjar et al. 2009) can also be used to derive middle and end of century precipitation projections for North Carolina. Unlike the temperature projections shown in the previous section, which vary in the magnitude but not the direction of effect among models, precipitation projections provide divergent results in the direction (wetter or drier) of change. One way to visualize this is to look at the range of projections generated by the ensemble models (Figure 3-6). The lowest 20% of projected values from the ensemble suggest less precipitation across the state; whereas the highest 20% of projected values from the ensemble suggest more precipitation, although there appears to be less variability in some seasons than others. Although the seasonal ensemble averages suggest that coastal areas may be drier in the spring and wetter in the fall and winter, with less variability in the western portion of the state (Figure 3-7), caution should be used in interpreting results from ensembles for which there is high disagreement among the input models. Seasonal averages are also likely to be less biologically relevant to many organisms, which are often more influenced by increased variability and changes in the timing and amount of precipitation during particular time periods, rather than changes in the magnitude of seasonal averages.

The guidance provided by Climate Wizard cautions that projections should be used for making climate decisions only in areas with high model agreement (Zganjar et al. 2009), which is often not the case when assessing future projected precipitation.

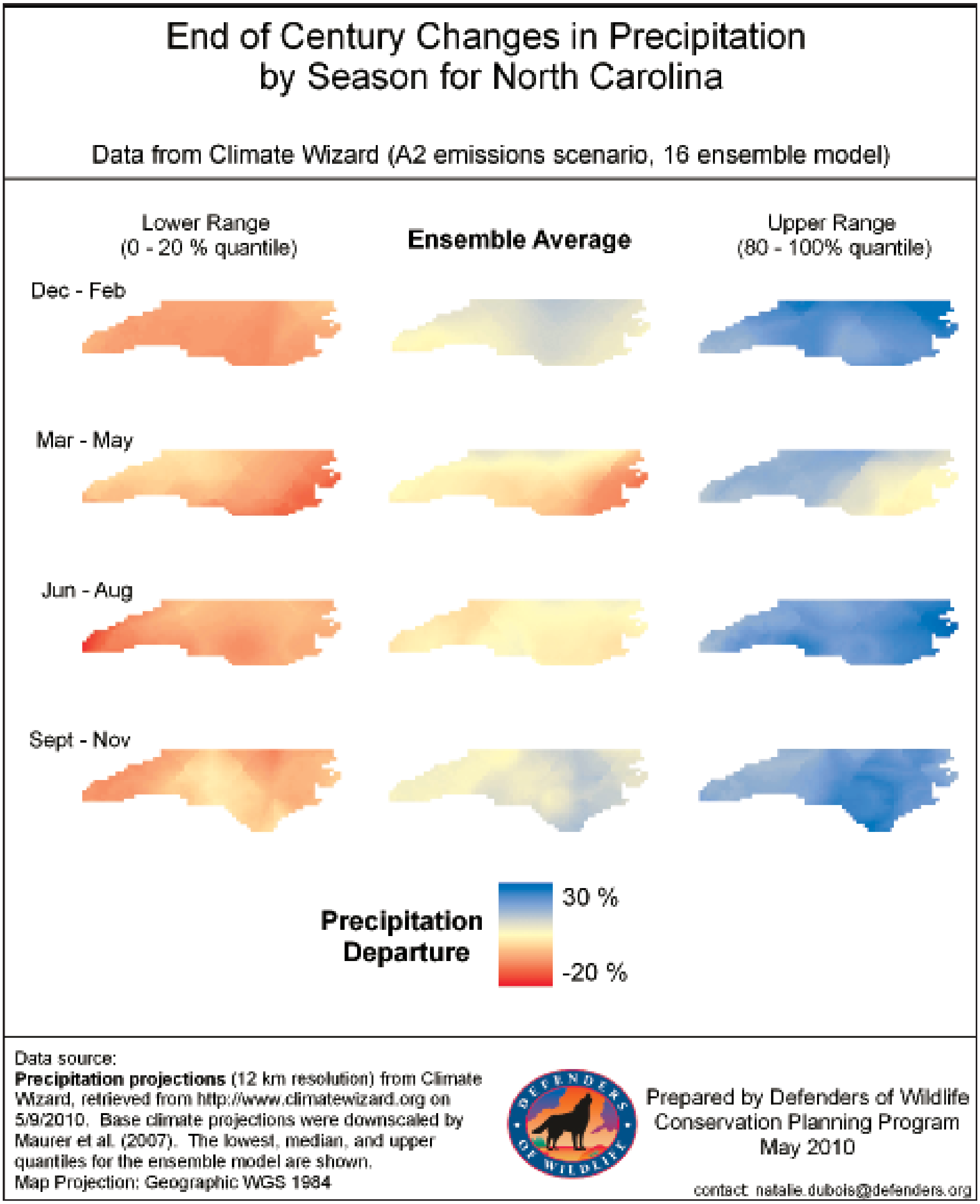


Figure 3-6. End of century precipitation projections by season for North Carolina illustrating the divergence among projections from models included in the ensemble. Projections are based on a high emissions scenario (A2). The lowest (0-20%), average, and upper (80-100%) quantiles are shown for the ensemble of 16 GCMs statistically downscaled to 12 km^2.

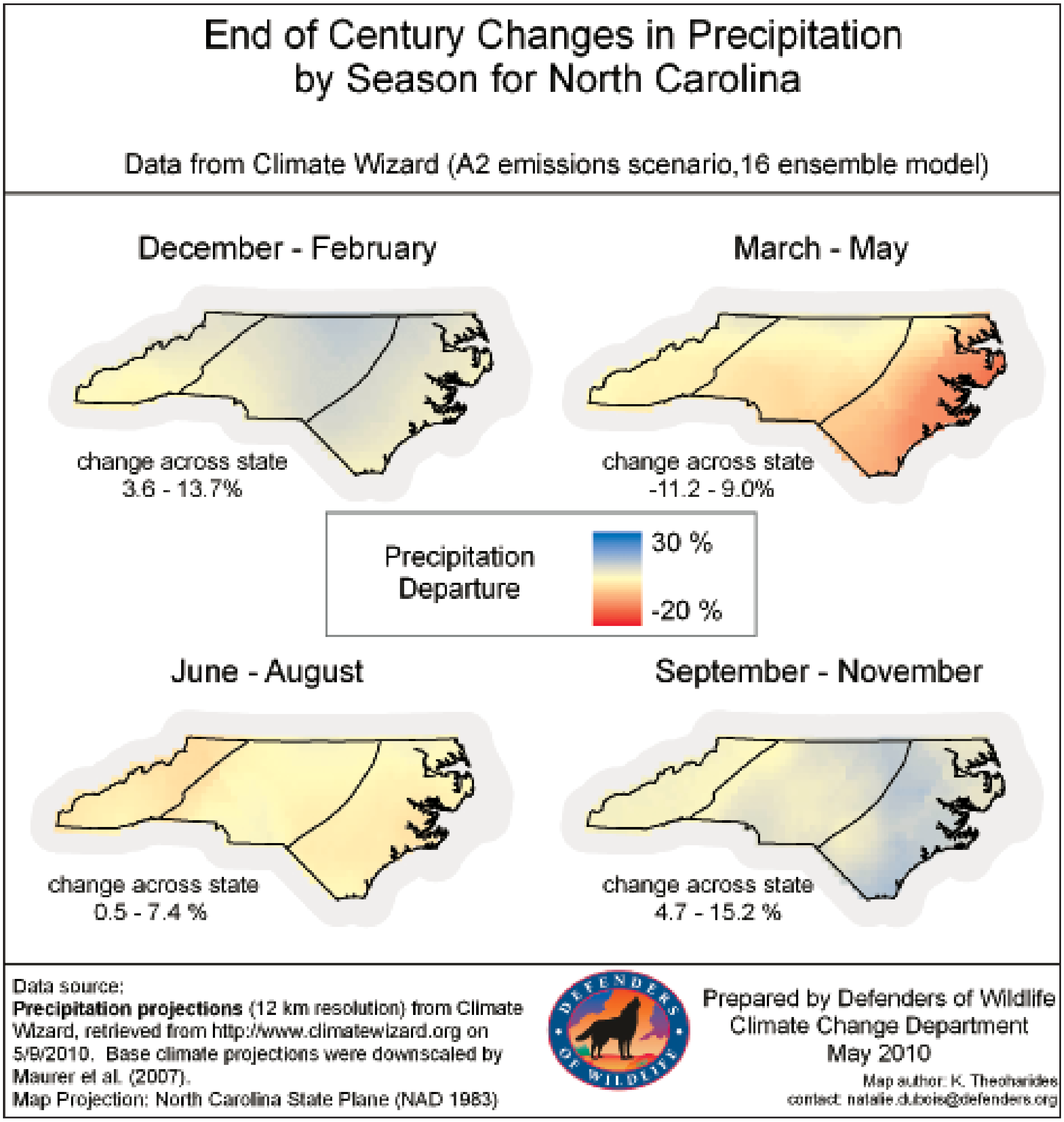


Figure 3-7. End of century precipitation projections for North Carolina based on the ensemble average of 16 models. Projections are based on a high emissions scenario (A2) and the ensemble average of 16 GCMs statistically downscaled to 12 km^2.

The analysis of model projections reviewed by the U.S. Global Change Research Program gives similar results. Most climate models agree that, at a continental scale, northern latitudes are likely to see increases in precipitation and southern areas will see decreases in precipitation, but there is less confidence in where this transition will occur (Karl et al. 2009). North Carolina falls in this transition area, but it is important to note that even if increases in precipitation occur, these may not offset increased evaporation and water loss resulting from higher temperatures projected to occur in the state. As a result, the frequency, duration, and intensity of droughts are likely to continue to increase (Karl et al. 2009).

3.2.1 Potential Impacts of Precipitation and Hydrology Shifts on Species and Habitats in North Carolina

Bogs, wetlands and flood plain communities are among those most likely to be impacted by even moderate changes to precipitation regimes. In North Carolina, many of these communities are already threatened by extensive land conversion and other modifications that alter hydrologic regimes (NC WAP). Changes in precipitation have the potential to exacerbate these issues through seasonal shifts in precipitation patterns as well as changes in the frequency of high-intensity events. For example, willow flycatchers (*Empidonax trailii*), a SGCN species in the NC WAP, are sensitive to flooding of nest sites during the breeding period from June to August (NatureServe 2009).

Small pools and wetlands that occur in depressions and are flooded for only a portion of the year are also important sites for breeding amphibians, in particular ambystomid salamanders. These habitat types may be found associated with bogs, small wetlands and floodplain forests across the state. Several ambystomids are identified as priority species

Photo: www.thinkstock.com

in North Carolina, and are sensitive to the timing of vernal pool formation and precipitation cues for breeding. For example, spotted salamanders (*Ambystoma maculatum*) begin their migration to breeding areas in response to rain and warming temperatures in the spring (Grace and Church 2003 in NatureServe 2009). Marbled salamanders (*A. opercum*) rely on breeding sites that lack standing water in the fall but are inundated by fall rains and hold standing water through spring. For marbled salamanders, timing of larval hatch is dependent on when the pond-basin nesting area is flooded (NatureServe 2009). Pechmann et al. (1991) reported that breeding populations of mole salamander (*A. talpoideum*), eastern tiger salamander (*A. trigrinum tigrinum*) and ornate chorus frog (*Pseudacris ornata*) in South Carolina were reduced during years of drought due to low numbers of breeding females and recruitment failures associated with inadequate pond hydroperiod. Timing of heavy rains is also associated with egg laying (NatureServe 2009) in species such as barking treefrog (*Hyla gratiosa*) and southern chorus frog (*Pseudacris nigrita*), a subspecies of which is identified as a priority species in North Carolina.

A number of aquatic species will be sensitive to changes in hydrology and timing of flooding and drying events. For example, several darters are associated with fast flowing waters. Priority species include longhead darter (*Percina macrocephala*) and olive darter (*P. squamata*), both of which prefer waters with moderate to high gradients. The former may already have been extirpated from the state (NatureServe 2009). Others species, such as Carolina darter (*Etheostoma collis*), prefer habitats characterized by low velocity currents. Some species are particularly sensitive to changes in stream flow (NatureServe 2009). For example beds in flowing areas of creeks appear to be essential habitat for the Cape Fear shiner (*Notropis mekistocholas*), a federally listed species limited to a single river basin. In the Little Tennessee River Basin, hydrologic regime had a significant effect on fish species assemblage over a ten-year period (1983-1992) that had some of the highest and lowest flows over the previous 58 year period (Grossman et al. 1998).

Virtually all river drainages in North Carolina are already impacted by erosion and sedimentation from timberlands, agricultural areas, and urban development activities (NC WAP). Seasonal increases in runoff under climate change have the potential to further increase nutrient and sediment loads impacting species such as shortnose sturgeon (*Acipenser brevirostrum*), which utilizes silt free cobble or boulder bottom for spawning (NatureServe 2009). In Virginia, siltation was identified as a primary cause of decline for Roanoke bass (*Ambloplites cavifrons*) in the Upper Roanoke River Drainage (Burkhead and Jenkins 1991 in NatureServe 2009). Examples of other priority fish species that may be particularly sensitive to increased sedimentation include spotfin chub (*Cyprinella monacha*), lake chubsucker (*Erimyzon sucetta*), Carolina darter (*Eheostoma collis*), and Cape Fear shiner (*Notropis mekistocholas*). Zamor and Grossman (2007) found that even low to moder-

Photo: National Park Service, www.nps.gov

Table 3-1. Fish kill events in river basins in North Carolina (Source: Street et. al 2005, © North Carolina Department of Environment and Natural Resources, used with permission)

River basin	Year						
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**Total**
Neuse	14	12	8	16	23	37	110
Cape Fear	21	16	23	14	12	5	91
Tar-Pamlico	3	6	5	11	14	23	62
Pasquotank	10	2	8	2	0	1	23
White Oak	3	3	1	3	3	3	16
Lumber	4	3	5	0	2	0	14
Chowan	2	2	1	1	0	1	7
Roanoke	2	0	1	0	0	0	3
Total	**59**	**44**	**52**	**47**	**54**	**70**	**326**

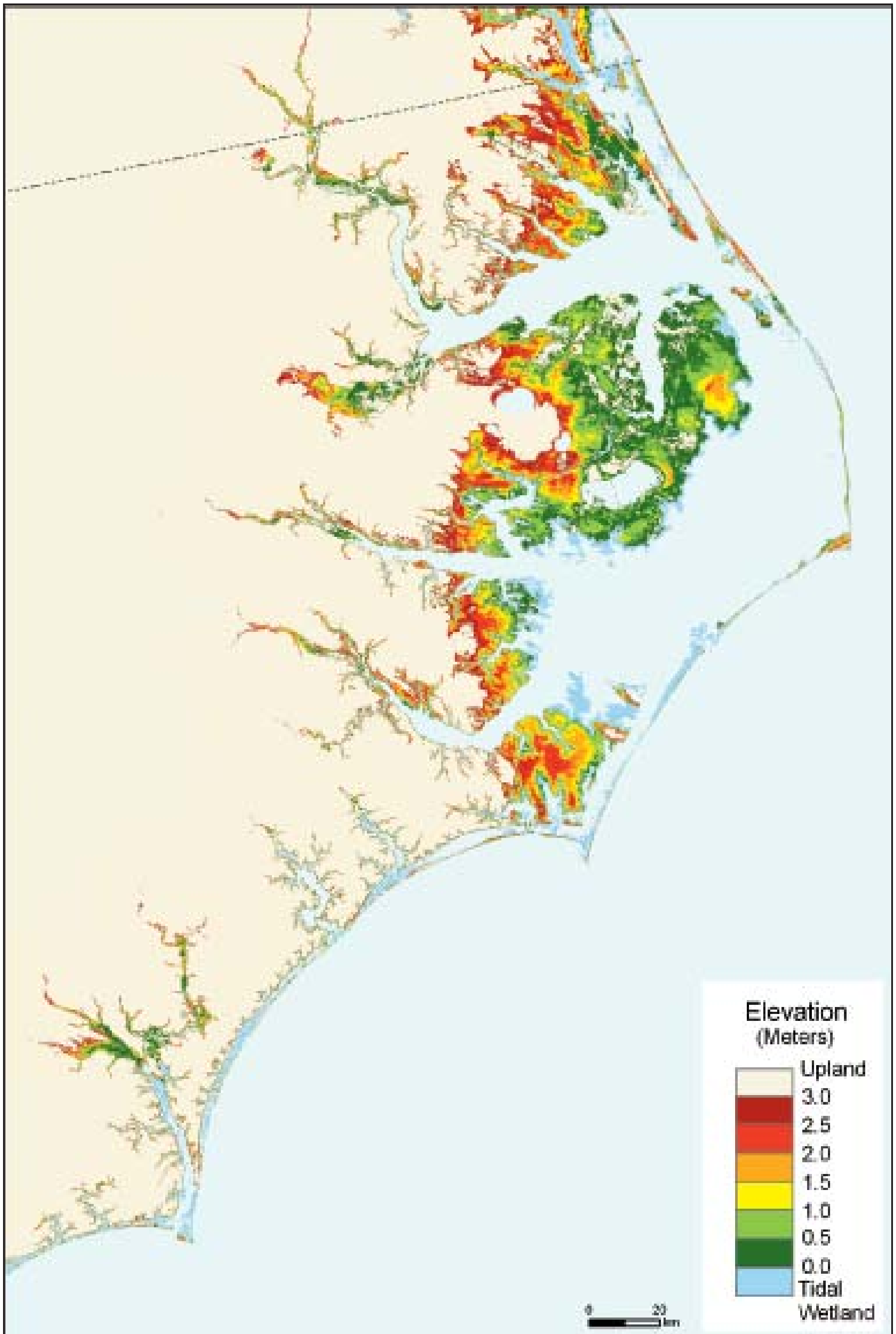
ate levels of turbidity affected foraging success in the rosyside dace (*Clinostomus funduloides*) collected from the Little Tennessee River Basin. Interactions between turbidity, velocity and interspecific competition with the yellowfin shiner (*Notropis lutipinnis*), which has recently invaded the Little Tennessee Basin, have also been shown to affect foraging behavior in this species (Hazelton and Grossman 2009). In addition, mussels are particularly vulnerable to silt and sedimentation (reviewed in Watters 1999) as are a number of crayfish species such as Broad River stream crayfish (*Cambarus lenati*) and Broad River spiny crayfish (*C. spicatus*) (Simmons and Fraley 2010), two priority species occurring in western North Carolina.

In 1996-2001 fish kills were concentrated in the Neuse, Cape Fear, and Tar-Pamlico River Basins (Street et al. 2005). Small schooling fish may be some of the most affected in estuarine waters, but other fish observed in fish kill events in North Carolina include sunfish, minnows, killifish, suckers, and darters (Table 3-1, Street et al. 2005). Species from these groups are well-represented in the priority species identified in the North Carolina Wildlife Action Plan. Other freshwater taxa may also be vulnerable, for example, Edisto crayfish (*Procambarus ancylus*) is thought to be particularly sensitive to disturbances affecting dissolved oxygen concentrations (NatureServe 2009).

3.3 Sea Level Rise Projections for North Carolina

Conservative estimates from the IPCC show that Coastal North Carolina has over 5900 km^2 of land below one meter of elevation (over 1 million acres) (the third largest low-lying region in the U.S. after Louisiana and Florida). Over 1.4 million acres of land in North Carolina are below 1.5 meters (Titus and Richman 2001). North Carolina is fortunate to have access to LiDAR data for the state, which provides high quality elevation data with an accuracy of 20 cm and is a valuable tool in the assessment of vulnerability of low lying areas to sea level rise (Figure 3-8).

A recent report put out by the North Carolina Coastal Resources Commission (NCCRC) Science Panel on Coastal Hazards (2010) synthesizes the best available science on SLR as it relates specifically to North



Elevations of Land Close to Sea Level
Elevations are above spring high water, which is the average high tide during new and full moons, and approximately the inland boundary of tidal wetlands. This map is a general graphical representation of elevations in the area depicted, not designed to estimate the precise elevations at specific locations. Actual elevations at specific locations may be 30 cm above or below the elevation shown.
Source: J.G. Titus and J Wang. 2008. "Maps of Lands Close to Sea Level along the Mid-Atlantic Coast". US Environmental Protection Agency.

Figure 3-8
Coastal elevations for North Carolina based on data from Titus and Wang (2008). Elevation values used in these data are relative to spring high water elevations and are higher than the mean tide level or mean sea level (Source: http://maps.risingsea.net/).available with a vertical accuracy of 20cm.)

Carolina and summarizes the results of four studies that provide data on the rates of relative sea level rise in (Box 3-2). The data analyzed in the report indicates that relative sea level rise varies as a function of latitude, with higher rates in the north as a result of local geology and differences in crustal subsidence and uplift (NCCRC 2010). The first three studies listed in Box 3-2 utilize geological data and provide the basis for understanding the potential for future changes in the rate of sea level rise.

Based on these studies, the panel made projections for relative sea level rise in North Carolina through 2100 based on differing rates of sea level rise acceleration (Figure 3-9). The initial rate of rise was set at 4.27 mm per year (Zervas 2004) with a minimum rise of 0.50 meters to a maximum of 1.4 meters by 2100. Delayed positive feedback may result in an underestimation of the contribution from land use resulting in a total sea level rise above 1.4 meters (NCCRC 2010). Given the uncertainty and potential increase in ice sheets melting and contributing to sea level rise the panel concluded that 2 meters of sea level rise, by 2100 is unlikely, but still possible, and could occur only with rapidly accelerated and very high rates of warming and ice sheet melting (NCCRC 2010).

Box 3-2. Four studies summarized in the North Carolina Sea-Level Rise Assessment Report that provide data on relative sea level rise in North Carolina (Source: NC Coastal Resources Commission 2010).

Study 1: Horton et al. (2009) developed a sea-level database for North Carolina from new, published and unpublished geological data that cover the past 12,000 years. During this period, long-term average rates of SLR varied from approximately 5 mm per year (19 inches/century) until approximately 3,500 y BP (y BP = years before present, where "present" is AD 1950), to about 1 mm per year (4 inches/century) from 3,500 y BP until today.

Study 2: Kemp (2009 thesis) presented continuous, high resolution constructions of SLR in North Carolina for the past 2,000 years using geological data from Sand Point (Roanoke Island) and Tump Point (Cedar Island). The rate of RSL rise was close to 1mm per year (4 inches/century) for most of this period. The rate almost doubled to 1.7mm per year (6.7 inches/century) for about 350 years during the Medieval Warm Period (AD 1000 to 1350), and then returned to 1.0 mm/yr for the next few centuries. The rate then increased in the 20th century to about 3.2 mm per year (12.6 inches/century).

Study 3: Kemp et al. (2009) concentrated on the RSL records at Sand Point and Tump Point since AD 1500. They noted that the 20th century rate of RSL rise of 3.0 to 3.3 mm per year (13 inches/century) is in agreement with local tide gauges (Fig. 1) and instrumental records from the north-west Atlantic (Woodworth et al., 2008).

Study 4: Zervas (2004) documented the MSL trends for eight water level stations in North Carolina (Table 1). The intervals of time represented by the data vary from station to station and dredging has resulted in variation in the trends of different tidal datums. These factors led Kemp et al. (2009, Study 3) to average North Carolina tide gauge records. The highest rates (up to 16.8 inches/century) are in the northern portion of the state.

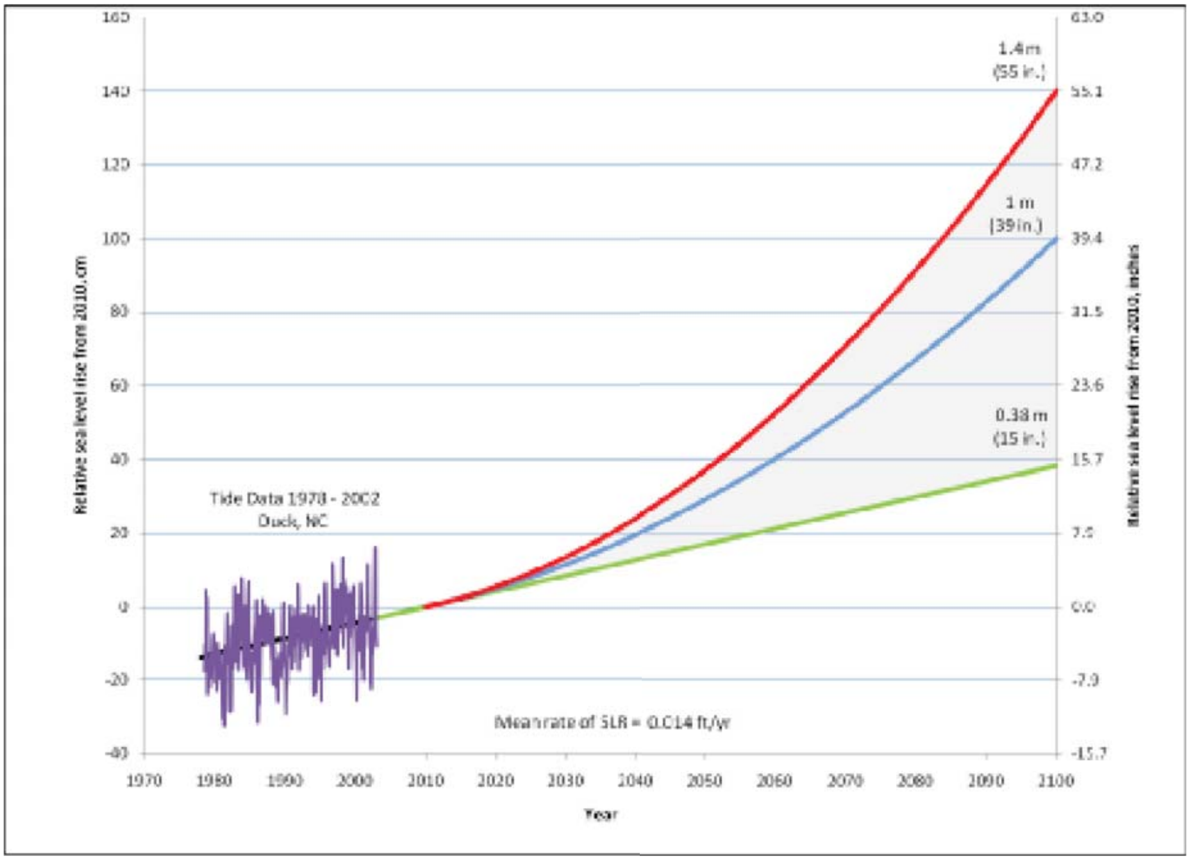


Figure 2. This chart illustrates the magnitude of SLR resulting from differing rates of acceleration. The most likely scenario for 2100 AD is a rise of 0.4 meter to 1.4 meters (15 inches to 55 inches) above present.

Figure 3-9. An analysis of rates of sea-level rise (SLR) under different scenarios of climate warming and ice sheet melting. The resulting magnitude of sea level rise differs depending on the rate of acceleration. According to the NC Coastal Resources Commission's Science Panel on Coastal Hazards, the most likely scenario is a rise of 0.4 meters to 1.4 meters above present by the end of the century (Source: NCCRC 2010).

3.3.1 Potential Impacts of Sea Level Rise on Species and Habitats in North Carolina

Storms, wave energy, rising sea levels, and other natural and human activities have led to significant shifts in the North Carolina coast line (Feldman et al. 2009). These dynamic coast lines both retreat and accrete, with long-term erosion rates (19402 – 1998) estimated at an average of 0.8 m per year (NC DCM 2003 in Feldman et al. 2009). In areas where data are available, average erosion rates have been shown to vary by as much as 4 – 8 m depending on location, time period, or accretion rates (see Everts et al. 1983). Although erosion already plays an important role in defining the North Carolina coastline, impacts will likely be magnified by sea level rise and greater storm surges. For example, Leatherman et al. 2000 found a 1 m sea level rise would result in a shore retreat of an average of 88 m statewide, in addition to erosion caused by existing wave energy, storms, or human activities (in Feldman et al. 2009).

North Carolina's coast is primarily composed on wave-dominated barrier islands consisting of long, thin stretches of sand that buffer shallow estuaries or lagoons and are bisected by widely-space tidal inlets (Gutierrez et al. 2009, Figure 3-10). These barrier islands act as an energy buffer, protecting the interior coastal estuarine system from high-energy waves. Overwash, breaching, and storm surge, are already

Coastal Landform Types Along U.S. Mid-Atlantic Coast

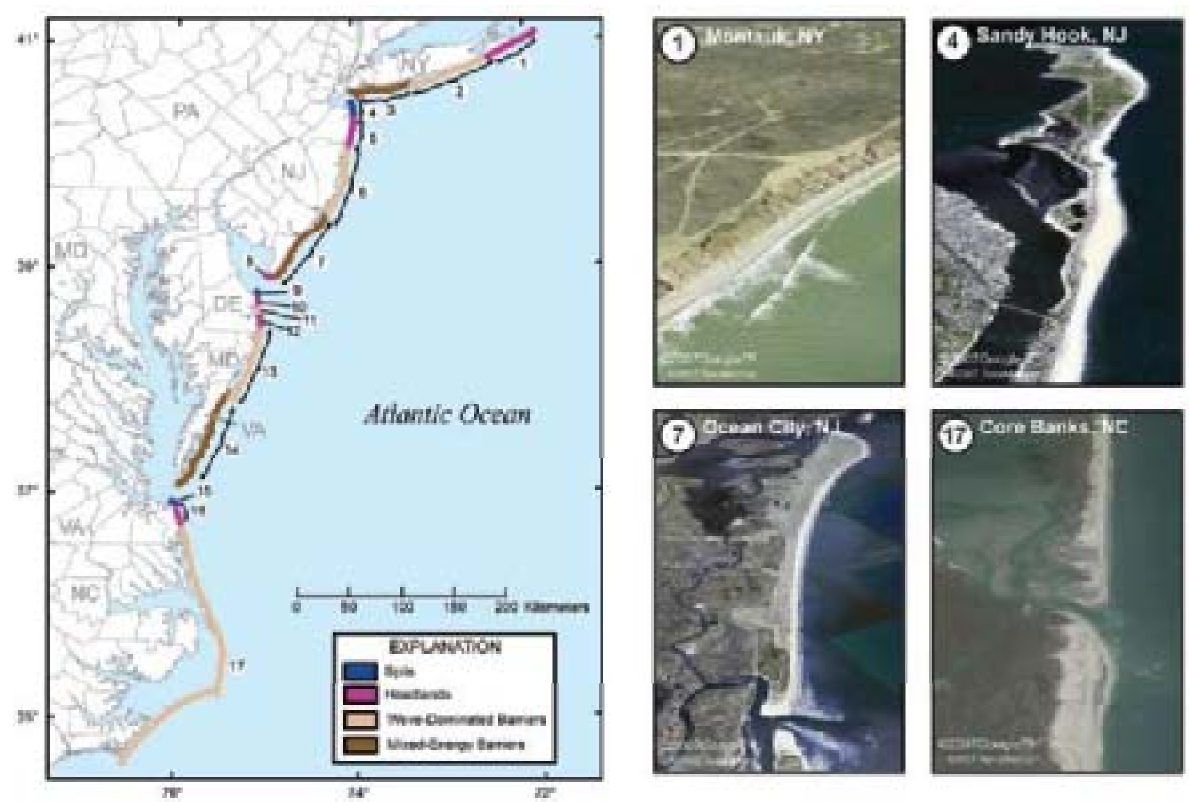


Figure 3.1 Map of the mid-Atlantic coast of the United States showing the occurrence of the four coastal landform types**.** Numbers on the map designate distinct portions of the coast divided by landform type and refer to the discussions in Sections 3.5 and 3.7. Numbers on the photographs refer to specific sections of the coast that are depicted on the map. Images from Google Earth (Gutierrez *et al.*, 2007).

Potential Mid-Atlantic Landform Responses to Sea-Level Rise

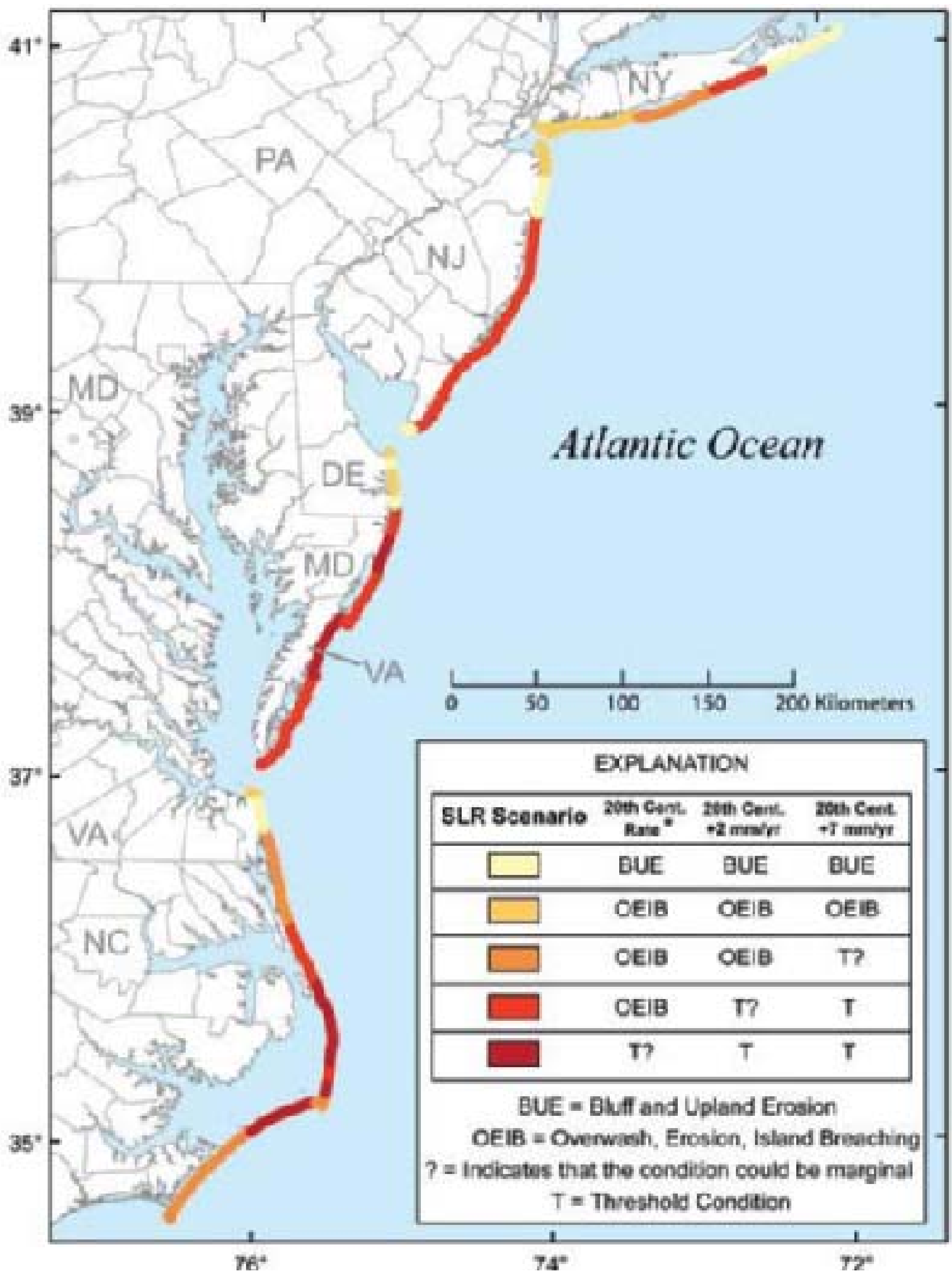


Figure 3.2 Map showing the potential sea-level rise responses (in millimeters [mm] per year [yr]) for each coastal compartment. Colored portions of the coastline indicate the potential response for a given sea-level rise scenario according to the inset table. The color scheme was created using ColorBrewer by Cindy Brewer and Mark Harrower. After Gutierrez *et. al.* (2007).

Figure 3-11. Much of North Carolina's coastline will be susceptible to overwash, erosion, and island breaching under current rates of sea level rise (Source: Gutierrez et al. 2009).

a cause of barrier migration on the Core Banks in North Carolina (Riggs and Ames 2003, Gutierrez et al. 2009) (Figure 3-11). Maritime forests and shrub communities have been identified as highly sensitive habitats in the NC WAP. These habitats are mainly found along barrier islands and the mainland coast on stabilized upper dunes and flats protected from salt spray. These habitats are important breeding and migration stopover points for many migratory birds, and key breeding areas for declining populations of the eastern painted buntings, as well as for several snake species (NC WAP). All of the barrier island maritime forest/shrub communities occur in very dynamic environments and will be susceptible to sea level rise.

Coastal wetlands are also highly vulnerable to sea level rise, and loss of this habitat has the potential to adversely affect a number of priority species listed in the NC WAP. Estimates suggest there are between 3.1 and 3.9 million acres of wetland in coastal North Carolina, including marshes, swamps, forested wetlands, pocosins, and other wetland habitats (Street et al. 2005). Vertical accretion rates in North Carolina have been able to keep up with the rate of sea level rise (Feldman et al. 2009), however there are some wetlands that have been unable to vertically accrete at a pace to match current rates of sea level rise. Feldman et al. (2009) suggest that North Carolina's lower coastal plain fringe wetlands may not survive with the 10 mm per year of relative sea level rise scenario described by Day et al. (2005) for the Mississippi Delta region. Pocosin wetlands generally accrete at a rate of approximately one to two mm per year when in their natural state (Craft and Richardson 1998 and Moorhead and Brinson 1995 in Feldman et al. 2009). Human altered drainage patterns appear to be limiting their vertical accretion, which, in combination with saltwater intrusion, could cause subsidence and conversion to open water (Pearsall and Poulter 2005). As sea level rises further and waters with higher salt content reach the Albemarle-Pamlico peninsula, the ability of peat-based wetlands to keep up is unlikely (Box 3-3, Feldman et al. 2009). Higher scenarios of sea level rise may lead to an increase in inlets and segmentation or disintegration of barrier islands leading, potentially resulting in a change from a non-tidal to a tidal regime with increased salinity. These changes would fundamentally alter the structure of current ecosystems and would lead to increased erosion and impacts on wetlands (Riggs and Ames 2003).

Photo: North Carolina Devision of Coastal Management

Coastal wetlands are also highly vulnerable to sea level rise, and loss of this habitat has the potential to adversely affect a number of priority species listed in the NC WAP.

Box 3-3. Vulnerability of the Albemarle-Pamlico Peninsula to sea level rise and stakeholder response (Source: Feldman et al. 2009, see original report for citations).

BOX A1.8: Vulnerability of the Albemarle–Pamlico Peninsula and Emerging Stakeholder Response

Vulnerability to sea-level rise on the diverse Albemarle–Pamlico Peninsula is very high: about two-thirds of the peninsula is less than 1.5 meters (m) (5 feet [ft]) above sea level (Heath, 1975), and approximately 30 percent is less than 1 m (3 ft) above sea level (Poulter, 2005). Shoreline retreat rates in parts of the peninsula are already high, up to about 8 m (25 ft) per year (Riggs and Ames, 2003). The ecosystems of the Albemarle–Pamlico Peninsula have long been recognized for their biological and ecological value. The peninsula is home to four national wildlife refuges, the first of which was established in 1932. In all, about one-third of the peninsula has been set aside for conservation purposes.

The Albemarle–Pamlico Peninsula is among North Carolina's poorest areas. Four of its five counties are classified as economically distressed by the state, with high unemployment rates and low average household incomes (NC Department of Commerce, 2008). However, now that undeveloped waterfront property on the Outer Banks is very expensive and scarce, developers have discovered the small fishing villages on the peninsula and begun acquiring property in several areas—including Columbia (Tyrrell County), Engelhard (Hyde County), and Bath (Beaufort County). The peninsula is being marketed as the "Inner Banks" (Washington County, 2008). Communities across the peninsula are planning infrastructure, including wastewater treatment facilities and desalination plants for drinking water, to enable new development. Columbia and Plymouth (Washington County) have become demonstration sites in the North Carolina Rural Economic Development Center's STEP (Small Towns Economic Prosperity) Program, which is designed to support revitalization and provide information vital to developing public policies that support long-term investment in small towns (NC REDC, 2006).

There are already signs that sea-level rise is causing ecosystems on the Albemarle–Pamlico Peninsula to change. For example, at the Buckridge Coastal Reserve, a 7,547-hectare (ha) (18,650-acre [ac]) area owned by the North Carolina Division of Coastal Management, dieback is occurring in several areas of Atlantic white cedar. Other parts of the cedar community are beginning to show signs of stress. Initial investigations suggest the dieback is associated with altered hydrologic conditions, due to canals and ditches serving as conduits that bring salt and brackish water into the peat soils where cedar usually grows. Storms have pushed estuarine water into areas that are naturally fresh, affecting water chemistry, peatland soils, and vegetation intolerant of saline conditions (Poulter and Pederson, 2006). There is growing awareness on the part of residents and local officials about potential vulnerabilities across the landscape (Poulter, *et al.*, 2009). Some farmers acknowledge that saltwater intrusion and sea-level rise are affecting their fields (Moorhead and Brinson, 1995). Researchers at North Carolina State University are using Hyde County farms to experiment with the development of new varieties of salt-tolerant soybeans (Lee *et al.*, 2004). Hyde County is building a dike around Swan Quarter, the county seat (Hyde County, 2008).

A variety of evidence has suggested to some stakeholders that the risks to the Albemarle–Pamlico Peninsula merit special management responses. In fact, because so much of the landscape across the peninsula has been transformed by humans, some have expressed concern that the ecosystem may be less resilient and less likely to be able to adapt when exposed to mounting stresses (Pearsall *et al.*, 2005). Thus far, no comprehensive long-term response to the effects of sea-level rise on the Peninsula has been proposed. In 2007, The Nature Conservancy, U.S. Fish and Wildlife Service, National Audubon Society, Environmental Defense, Ducks Unlimited, the North Carolina Coastal Federation, and others began working to build an Albemarle–Pamlico Conservation and Communities Collaborative (AP3C) to develop a long-term strategic vision for the peninsula. Although this initiative is only in its infancy, sea-level rise will be one of the first and most important issues the partnership will address (TNC, 2008).

The Nature Conservancy and other stakeholders have already identified several adaptive responses to sea-level rise on the Peninsula. Many of these approaches require community participation in conservation efforts, land protection, and adaptive management (Pearsall and Poulter, 2005). Specific management strategies that The Nature Conservancy and others have recommended include: plugging drainage ditches and installing tide gates in agricultural fields so that sea water does not flow inland through them, establishing cypress trees where land has been cleared in areas that are expected to become wetlands in the future, reestablishing brackish marshes in hospitable areas that are likely to become wetlands in the future, creating conservation corridors that run from the shoreline inland to facilitate habitat migration, reducing habitat fragmentation, banning or restricting hardened structures along the estuarine shoreline, and establishing oyster reefs and submerged aquatic vegetation beds offshore to help buffer shorelines (Pearsall and DeBlieu, 2005; Pearsall and Poulter, 2005).

Table 3-2. Bird Species of Greatest Conservation Need threatened by sea level rise. Species that occur only in coastal habitats in the Mid-Atlantic Coastal Plain Ecoregion or those species that depend on coastal habitats for at least part of their life cycle are highlighted as these species may experience greater impacts than species that occur in both coastal and interior habitats.

Scientific Name	Common Name	State Status (Federal Status)	Habitat type: Tidal swamp forest and wetlands	Habitat type: Maritime forest/shrub	Habitat type: Estuarine communities	Habitat type: Beach and dune habitats
Ammodramus caudacutus	Saltmarsh Sharp-Tailed Sparrow		X		X	
Ammodramus nelsoni	Nelson's Sharp-tailed Sparrow		X		X	
Anhinga anhinga	Anhinga	SR	X			
Asio flammeus	Short-eared Owl		X		X	
Botaurus lentiginosus	American Bittern	SR	X		X	
Calidris alba	Sanderling				X	X
Calidris canutus	Red Knot				X	X
Charadrius melodus	Piping Plover	T(T)			X	X
Charadrius wilsonia	Wilson's Plover	SR			X	X
Chordeiles minor	Common Nighthawk					X
Circus cyaneus	Northern Harrier	SR	X		X	
Cisthothorus platensis	Sedge Wren		X		X	
Coturnicops noveboracensis	Yellow Rail	SR	X		X	
Egretta caerulea	Little Blue Heron	SC	X		X	
Egretta thula	Snowy Egret	SC	X		X	
Egretta tricolor	Tricolored Heron	SC			X	
Elanoides forficatus	Swallow-tailed Kite		X			
Falco peregrinus	Peregrine Falcon	E			X	X
Gallinula chloropus	Common Moorhen		X			
Haematopus palliatus	American oystercatcher	SR			X	X
Haliaeetus leucocephalus	Bald Eagle	T(T)	X		X	
Himantopus mexicanus	Black-necked Stilt	SR	X		X	
Ixobrychus exilis	Least Bittern		X		X	
Laterrallus jamaicensis	Black Rail	SR	X		X	
Mycteria americana	Wood Stork	E(E)	X		X	
Nyctanassa violacea	Yellow-crowned Night-heron		X		X	
Passerina ciris	Eastern Painted Bunting			X		
Pelecanus occidentalis	Brown Pelican	SR			X	X
Plegadis falcinellus	Glossy Ibis	SC	X		X	
Porzana carolina	Sora		X		X	
Rallus elegans	King Rail		X		X	
Rallus limicola	Virginia Rail		X		X	
Rynchops niger	Black Skimmer	SC			X	X
Sterna antillarum	Least Tern	SC			X	X
Sterna caspia	Caspian Tern	SR			X	X
Sterna hirundo	Common Term	SC			X	X
Sterna nilotica	Gull-billed tern	T			X	X

North Carolina's coastal marsh habitat usually develops on the mainland side of barrier islands and sounds, and in the lower reaches of rivers. These communities are important habitat year-round for a variety of rails, bitterns, and wading birds. Other birds that use coastal wetlands during some stage of their life cycle include the piping plover *(Charadrius melodus,* see Box 3-3), Wilson's plover *(Charadrius wilsonia)*, American oystercatcher (*Haematopus palliates),* black skimmer *(Rynchops niger),* gull-billed tern *(Gelochelidon nilotica)*, bald eagle *(Haliaeetus leucocephalus)*, peregrine falcon *(Falco peregrines)*, and woodstork *(Mycetria americana)*. Endangered or threatened sea turtles and diamond-backed terrapins also use these habitats for nesting. In addition, many commercially important species such as young blue crabs *(Callinectes sapidus)*, various shrimp species, and southern flounder *(Paralichthys lethostigma)* use tidal salt marsh habitat at various stages of their life (Street et al. 2005). With the rates of sea level rise projected in the future, apecies associated with coastal habitats, including many species identified in the NC WAP, will be threatened by direct loss of habitat to sea level rise (Tables 3-2, 3-3, 3-4, and 3-5).

Photo: Wood Stork (Mycteria americana)*, www.thinkstock.com*

Table 3-3. Mammal Species of Greatest Conservation Need threatened by sea level rise. Species that occur only in coastal habitats in the Mid-Atlantic Coastal Plain Ecoregion or those species that depend on coastal habitats for at least part of their life cycle are highlighted as these species may experience greater impacts than species that occur in both coastal and interior habitats.

Scientific Name	Common Name	State Status (Federal Status)	Habitat type: Tidal swamp forest and wetlands	Habitat type: Maritime forest/shrub	Habitat type: Estuarine communities	Habitat type: Beach and dune habitats
Condylura cristata	Star-nosed mole	SC	X			
Cryptotis parva	Least Shrew		X		X	
Peromyscus leucopus easti	White-footed Mouse	SC		X		X
Sylvilagus palustris	Marsh Rabbit		X		X	
Trichechus manatus	Manatee	E(E)			X	

Table 3-4. Amphibian Species of Greatest Conservation Need threatened by sea level rise. Species that occur only in coastal habitats in the Mid-Atlantic Coastal Plain Ecoregion are highlighted as these species may experience greater impacts than species that occur in both coastal and interior habitats.

Scientific Name	Common Name	State Status (Federal Status)	Habitat type: Tidal swamp forest and wetlands	Habitat type: Maritime forest/shrub	Habitat type: Estuarine communities	Habitat type: Beach and dune habitats
Bufo quercicus	Oak Toad	SR		X		
Desmognathus auriculatus	Southern Dusky Salamander			X		
Scaphiopus holbrookii	Eastern Spadefoot			X		

Photo: U.S. Fish and Wildlife Service

Table 3-5: Reptile Species of Greatest Conservation Need threatened by sea level rise. Species that occur only in coastal habitats in the Mid-Atlantic Coastal Plain Ecoregion are highlighted as these species may experience greater impacts than species that occur in both coastal and interior habitats.

Scientific Name	Common Name	State Status (Federal Status)	Habitat type: Tidal swamp forest and wetlands	Habitat type: Maritime forest/shrub	Habitat type: Estuarine communities	Habitat type: Beach and dune habitats
Alligator mississippiensis	American Alligator	T(T)	X			
Caretta caretta	Loggerhead Sea Turtle	T(T)			X	X
Cemophora coccinea copei	Northern Scarletsnake			X		
Chelonia mydas	Green Sea Turtle	T(T)			X	X
Dermochelys coriacea	Leatherback Sea Turtle	E(E)				X
Eretmochelys imbricata imbricata	Atlantic Hawksbill Sea Turtle	E(E)			X	
Farancia abacura abacura	Eastern mudsnake		X			
Farancia erytrogramma erytrogramma	Common Rainbow Snake		X			
Heterodon simus	Southern Hog-nosed Snake	SC		X		
Kinosternon baurri	Striped Mud Turtle		X			
Lampropeltis getula getula	Eastern kingsnake			X	X	
Lampropeltis getula sticticeps	Outer Banks Kingsnake	SC		X	X	
Lepidochelys kempii	Kemp's Ridley Sea Turtle	E(E)			X	X
Malaclemys terrapin	Diamond-backed Terrapin	SC			X	X
Masticophis flagellum	Eastern Coachwhip	SR				
Micrurus fulvius	Eastern Coral Snake	E				
Nerodia sipedon williamengelsi	Carolina Watersnake	SC				
Thamnophis sauritus sauritus	Common Ribbonsnake					

Table 3-6. Quantification by county of the amount of North Carolina's shoreline along the Atlantic Ocean, the Pamlico and Albemarle sounds, and the back barrier sounds by likelihood of shore protection (Modified from: Clark et al. 2010, http://risingsea.net/ERL).

Table 2. Shoreline Length by Major Water Body and Likelihood of Shore Protection (miles)*

North Carolina

	Likelihood of Shore Protection			No Protection	Nontidal Wetlands	Outside Study Area	Totals
County	Almost Certain	Likely	Unlikely				
Atlantic Ocean		53	26	106	0	0	303
Brunswick	34	0	1	5	0	0	40
Carteret	25	0	0.3	43	0	0	68.3
Currituck	9	1	10	2	0	0	22
Dare	24	25	0.2	37	0	0	86.2
Hyde	0	4	0	11	0	0	15
New Hanover	11	4	9	4	0	0	28
Onslow	5	18	0.6	4	0	0	27.6
Pender	10	0	4	0	0	0	14
Albemarle Sound	30	2	18	0	41	0	91
Bertie	0.2	0	3	0	2	0	5.2
Camden	1	0	5	0	0	0	6
Chowan	7	1	2	0	8	0	18
Currituck	2	0	2	0	0	0	4
Dare	3	0	0	0	0.3	0	3.3
Pasquotank	0.9	0.1	5	0	0.1	0	6.1
Perquimans	5	0.8	0.7	0	2	0	8.5
Tyrell	4	0	0.3	0	16	0	20.3
Washington	8	0	0	0	13	0	21
Alligator River	0.4	0	0	0	65	0	65.4
Dare	<0.1	0	<0.1	0	27	0	27
Hyde	0	0	0	0	9	0	9
Tyrell	0.4	0	<0.1	0	29	0	29.4
Cape Fear River	8	10	13	<0.1	15	0	46
Brunswick	5	3	7	<0.1	8	0	23
New Hanover	4	8	6	<0.1	7	0	25
Chowan River	11	0.7	9	0	23	0	43.7
Bertie	4	0.7	7	0	4	0	15.7
Chowan	8	0	0.6	0	15	0	23.6
Gates	0	0	0.2	0	0.4	0	0.6
Hertford	0	0	0.7	0	4	0	4.7
Little River	4	2	1	9	0	0	16
Pasquotank	3	0.6	0.9	4	0	0	8.5
Perquimans	1	1	0.1	5	0	0	7.1

Table 3-6. *Continued*

County	Likelihood of Shore Protection: Almost Certain	Likely	Unlikely	No Protection	Nontidal Wetlands	Outside Study Area	Totals
Neuse River	35	11	10	2	22	0	80
Carteret	0	5	1	0	0.8	0	6.8
Craven	21	3	5	2	12	0	43
Pamlico	14	2	4	0	10	0	30
North River	2	0.4	32	0	0	0	34.4
Camden	0	0	12	0	0	0	12
Currituck	2	0.4	20	0	0	0	22.4
Pamlico River	32	16	5	4	13	0	70
Beaufort	32	16	3	4	8	0	63
Pamlico	0	0	2	0	5	0	7
Pamlico Sound							
Dare	0.1	2	2	0	0	0	4.1
Pasquotank River	19	3	10	0	0	0	32
Camden	9	2	6	0	0	0	17
Pasquotank	10	1	4	0	0	0	15
Perquimans River							
Perquimans	9	7	0.2	19	0	0	35.2
Back Barrier Bays	199	99	117	98	159	0	672
Brunswick	60	5	8	8	5	0	86
Carteret	49	13	15	51	7	0	135
Currituck	13	3	43	1	20	0	80
Dare	42	27	0.6	24	50	0	143.6
Hyde	1	12	8	5	57	0	83
New Hanover	12	11	17	4	0.9	0	44.9
Onslow	8	24	7	4	8	0	51
Pamlico	0	0	1	0	8	0	9
Pender	12	2	17	0	1	0	32
North Carolina Total *	1,458	772	1,655	445	2,921	15	7,267

*Note: * Includes tributaries to major water bodies.*

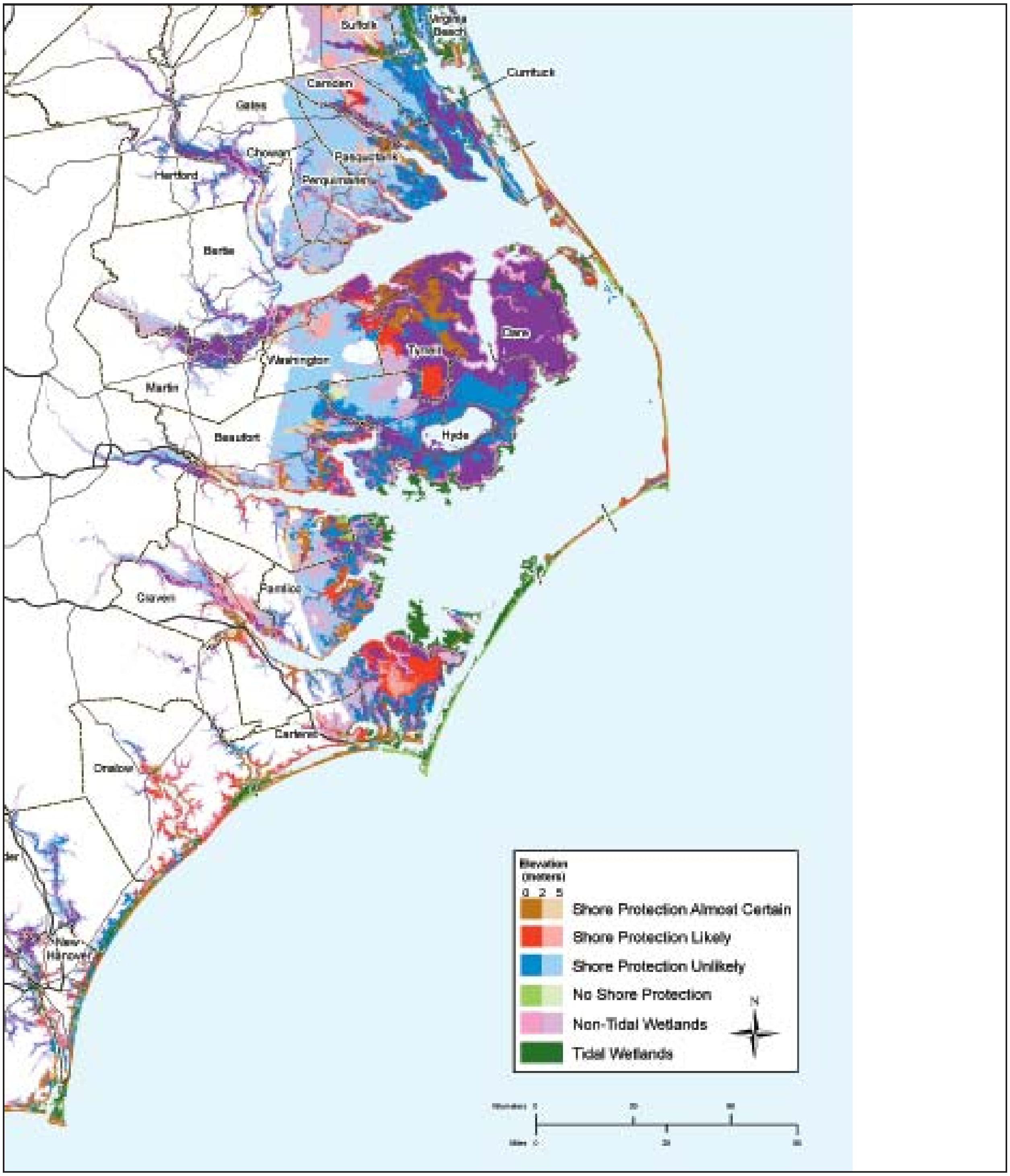


Figure 3-12. Likelihood of shore hardening to protect public and private property from the impacts of sea level rise in North Carolina. For each shore protection category, the darker shades represent lands that are either less than 7 feet above spring high water, or within 1000 feet of the shore. The lighter shades show the rest of the study area. This map is based on data published between 1999 and 2003 and site-specific changes suggested by planners in 2002 and 2003 (Source: Clark et al. 2010, http://risingsea.net/ERL, used with permission).

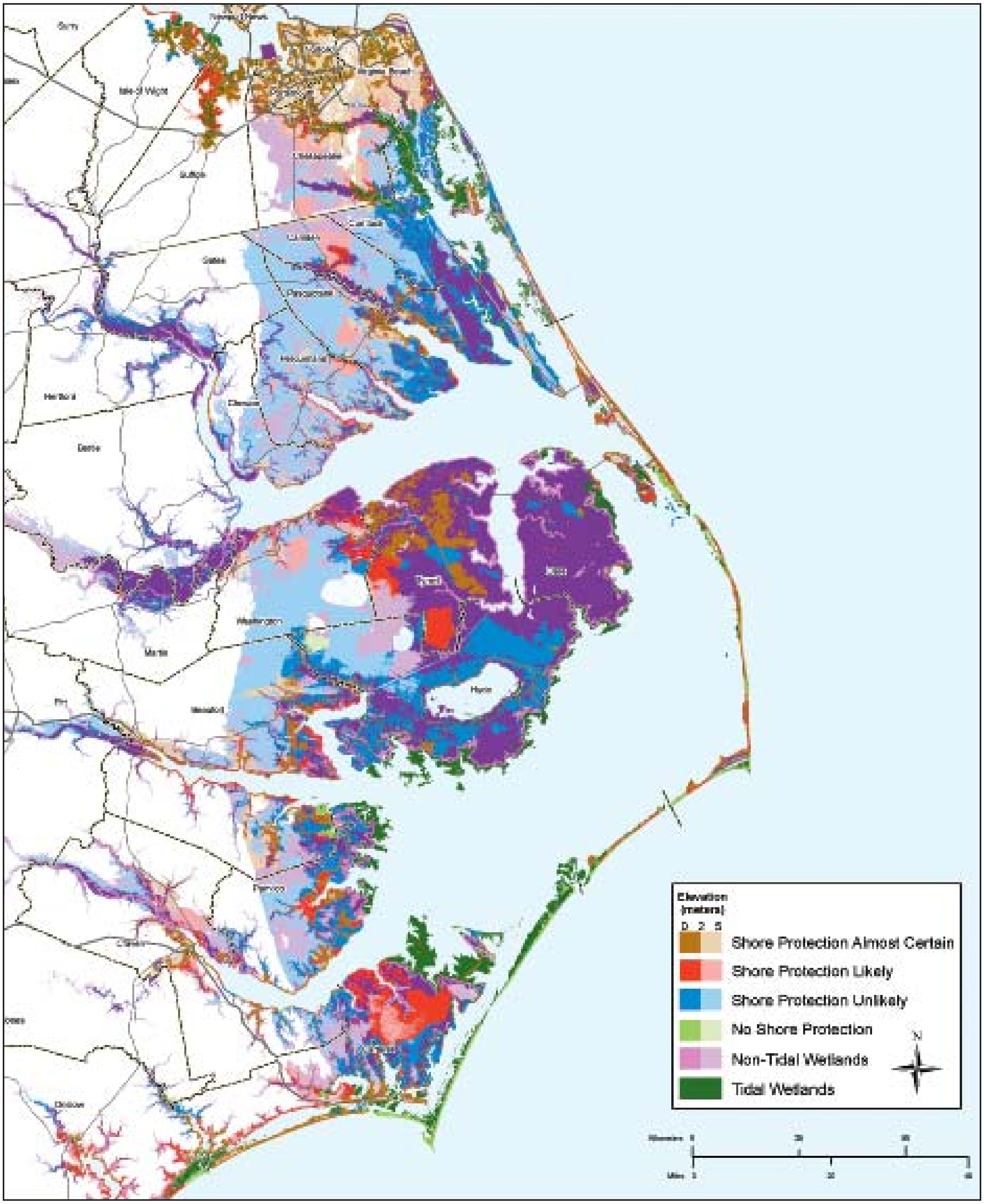


Figure 3-13: Dare County (Mainland and Roanoke Island): Likelihood of Shore Protection. For each shore protection category, the darker shades represent lands that are either less than 7 feet above spring high water, or within 1000 feet of the shore. The lighter shades show the rest of the study area. This map is based on data published between 1999 and 2003 and site-specific changes suggested by planners in 2002 and 2003 (Source: Clark et al. 2010, http://risingsea.net/ERL).

Impacts of Human Adaptation on Species and Habitats

In addition to the direct impacts of habitat loss resulting from sea level rise, ecosystems and species may also be impacted by human adaptation strategies implemented in response to SLR. Under the existing nationwide permit for shore protection, almost any owner of a small or medium-sized lot is allowed to erect shore protection structures that prevent ecosystems, such as tidal marshes, from migrating inland. Although it is currently difficult to predict where such future armoring will take place, a recent study attempted to quantify the potential for future armoring in the mid-Atlantic region using a survey approach (Titus et al. 2009). Based on 131 state and local land use plans, Titus et al. (2009) estimated that almost 60% of the land below one meter along the coastline of the Atlantic will be hardened to protect public and private property from the impacts of sea level rise (Figure 3-12, Table 3-6). Currently, 28% of dry land within 1 meter above tidal wetlands is developed and most likely will continue to be armored, while an additional 14% of lands within 1 meter above tidal wetlands have some existing development or are expected to be developed in the future. By contrast, only 3 % of land area within 1 meter above tidal wetlands is set aside for conservation or in some type of protected status.

Shoreline protection or armoring resulting from the threat of sea level rise is likely to threaten coastal wetlands by preventing inland migration of wetlands in response to SLR. In order to maintain wetland areas under SLR wetlands will need to migrate inland, which may be difficult given that less than 10% of coastal lands are currently protected and is likely impossible in areas where armoring has occurred (Titus et al. 2009). In North Carolina, some of the areas more likely to be armored include barrier islands near Nags Head, areas along the southern coast southeast of Wilmington, and areas on the Albermarle Peninsula (Figure 3-13, Titus et al. 2009).

Photo: Bulkheading, www.vims.edu

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Synergistic Threats to Species and Habitat

Human-induced climate change threatens species and habitats already impacted by other serious stressors such as habitat loss and degradation, introduction of non-native species, overexploitation, and many others. For numerous terrestrial species, habitat destruction and degradation have been ranked as a primary threat, often followed by competition with, or predation by, non-native species (e.g., Flather et al. 1998, Wilcove et al. 1998). Analyses focused on aquatic systems also identify habitat destruction and degradation (Williams et al. 1989), as well as agricultural pollution, non-native species, and altered hydrologic regimes as primary threats to species and habitats (Richter et al. 1997). In many cases, these extrinsic factors continue to be primary drivers of biodiversity loss. However synergies among stressors are likely to amplify the dynamics of extinction (Brook et al. 2008).

Climate change is already beginning to exacerbate the impacts of these existing threats and, as a result, estimates of extinction risk for vulnerable species may be much more severe than previously recognized (Brook et al. 2008). For example, species attempting to shift their ranges in response to changing climatic conditions are now faced with trying to move through heavily modified landscapes (Honnay et al. 2002). Current protected areas only capture a narrow range of environmental conditions across the wide range of habitat types. With climate change, protected areas may no longer capture temperature, precipitation, or hydrologic conditions within historic ranges (Pyke 2004). Additionally, new bioclimatic conditions and altered composition of ecological communities may facilitate invasions by non-native species, further stressing resident species (Dukes and Mooney 1999). In this chapter, we examine several synergistic threats to species and habitats, including land use change, demand for land intensive alternative energy sources, and spread of invasive species, as well as how climate change may amplify the impact of these stressors on wildlife in North Carolina.

4.1 Land Use Change

Conversion of land to urban development produces some of the greatest rates of local extinction among the many anthropogenic activities that cause habitat loss. Unlike other types of habitat conversion, conversion to urban development is often more permanent than conversion to other land uses. According to the U.S. Census Bureau, population size in North Carolina increased 21.4% between 1990 and 2000, increasing population density from 136.1 to 165.2 people per square mile (USCB 2004). Projections suggest that roughly half the state or greater will be settled at a density of urban, suburban, or sprawling exurban (rural communities beyond the suburbs that serve as commuter towns) by 2030 (Conservation Trust for North Carolina 2007). Across the United States, the rate of urban land use is accelerating faster than the rate at which land is being protected as national parks, state parks, or privately by land trusts such as The Nature Conservancy (McKinney 2002). The impact of urbanization is observed along the urban to rural gradient, affecting both species richness and species composition (McKinney 2002). Additionally, a large percentage of imperiled plants and animals are affected by other land uses, such as agriculture, extractive land uses, water and infrastructure development, and outdoor recreation (Wilcove et al. 1998).

The USGS Land Cover Trends Project (USGS 2010) uses a probability sampling approach to measure national land change on an ecoregion (EPA Level III) basis for the time period spanning 1973 to 2000. For each sample block, satellite images are used to

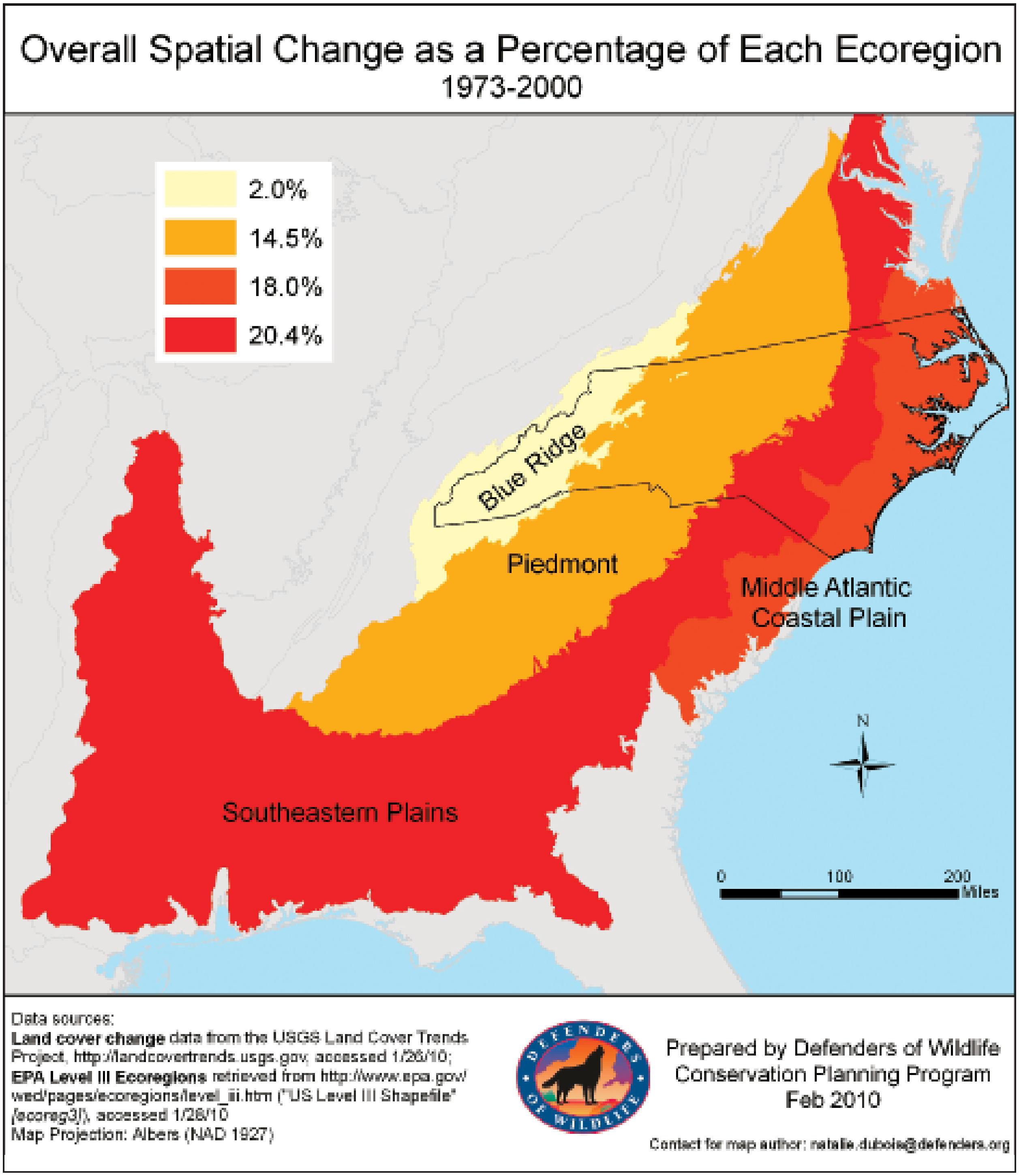

Figure 4-1. The four ecoregions (EPA Level III) covering portions of North Carolina are shown. Colors indicate the percent of area within each ecoregion that experienced a change in land cover at least once during four time periods occurring between 1973 to 2000 (Data: USGS Land Cover Trends Project, USGS 2010).

interpret land cover change for four separate time periods (ending in 1980, 1986, 1992, and 2000) as well as across the entire study period. Across the eastern U.S., 12.5% of land area was converted from one land cover category to another at least once during the study period (Loveland and Acevedo 2010). However this figure masks high amounts of geographic variability across the landscape. The southeastern ecoregions experienced greater than average land change (18.9%) but with enormous heterogeneity across regions. For example, overall land use change in the ecoregions occurring in North Carolina ranged from 2% in the Blue Ridge Mountains to 20% in the Southeastern Plains (Figure 4-1).

Across the region, land cover change during this time period was dominated by changes in forest. In the Southeastern Plains, Middle Atlantic Coastal Plain, and Piedmont, the primary land cover transitions were from forest to mechanically disturbed and from mechanically disturbed back to forest (Auch 2008, Napton 2008, Sohl 2010), which are consistent with large-scale planting and cutting rotations associated with the timber industry. In 1999, planted pine stands occupied 15% of the South's commercial forest land, up from 1% of commercial forest land in 1952, with the remainder consisting of natural stands of pine, hardwood, and mixed forest (Conner and Hartsell 2002). This change is illustrated in the Middle Atlantic Coastal Plain, where only 59.5% of forest persisted throughout the study period, one of the lowest percentages of all eastern ecoregions (Auch 2008). Changes in forest cover for each ecoregion are provided in Table 4-1.

Photo: C.J. Peters

In the Blue Ridge Mountains, where 98% of land cover remained stable across the study period, the leading land cover conversion was forest to developed use (Taylor and Kurtz 2008). Increasing population pressures across the region have corresponded to increases in developed areas (Table 4-2). For example, in the Piedmont and Southeastern Plains, approximately 2.7 million acres were converted from forest and agricultural land to developed uses (Auch 2008, Napton 2008). In the Piedmont Ecoregion, 70% of the land that was converted to developed uses was forested. Unlike land cover transitions associated with planting and cutting rotations, these developed areas rarely revert to non-developed cover types.

Table 4-1. Changes in forest cover between 1973 and 2000 for the four ecoregions (EPA Level III) occurring in North Carolina (Data: USGS National Land Cover Trends Project). Percentage of total area is indicated in parentheses.

Ecoregion	Acres (1973)		Acres (2000)		Percentage change
Middle Atlantic Coastal Plain	7,861,400	(35.5%)	7,112,200	(32.1%)	-9.5%
Southeastern Plains	44,071,700	(53.1%)	43,053,400	(51.8%)	-7.3%
Piedmont	24,469,400	(59.8%)	22,524,100	(55.1%)	-7.9%
Blue Ridge Mountains	9,394,200	(79.5%)	9,245,900	(78.3%)	-1.6%

Table 4-2. Changes in developed area between 1973 and 2000 for the four ecoregions (EPA Level III) occurring in North Carolina (Data: USGS National Land Cover Trends Project). Percentage of total area is indicated in parentheses.

Ecoregion	Acres (1973)		Acres (2000)		Percentage change
Middle Atlantic Coastal Plain	1,433,200	(6.5%)	1,988,500	(9.0%)	38.7%
Southeastern Plains	7,461,600	(9.0%)	8,543,400	(10.3%)	14.4%
Piedmont	4,866,000	(11.9%)	6,703,500	(16.4%)	37.8%
Blue Ridge Mountains	715,600	(6.1%)	846,600	(7.2%)	18.3%

4.1.1 Applying Land Cover/Land Use Data at the State and Local Scale

Investments in remote sensing and advances in spatial technology have made land use and land cover datasets increasingly available for use in the public sector. While it remains true that the resolution of the available data can present challenges for land use planning, particularly at local scales, these data sets are particularly useful in capturing changes over time (assuming data from multiple time points are available). It is important to keep in mind that for any metric capturing change over time, the magnitude of change will depend on the time period and geographic area under consideration, as well as the definition of land use types used in the data model. Here we review some of the more commonly used data sets and provide a few examples that apply to North Carolina. These and other data resources are also listed in Appendix A.

Both the National Land Cover Database (NLCD) and NOAA's Coastal Change Analysis Program (CCAP) provide data on land use and land cover for portions of the state of North Carolina (Appendix A). NLCD provides data from 1992 and 2001, as well as a retrofitted change product to allow comparison between the time periods (differences in methodologies between the two periods make direct comparison impossible). The CCAP provides data from 1996, 2001, and 2006, but is limited geographically to estuarine drainage area boundaries and thus maps only a portion of North Carolina. Both data sets use a modification of the Anderson classification system (Anderson et al. 1976), which has relatively coarse category definitions (e.g., deciduous forest, cultivated crops, open water). The USGS National Gap Analysis Program (GAP) recently released a national land cover map (based on 2001 satellite data) and an online map viewer (http://www.gap.uidaho.edu/landcover.html). These maps utilize the NatureServe Ecological Systems Classification, which provides a consistent, detailed classification of vegetative types across the U.S. The National GAP land cover map contains 551 cover classes (82 of which occur in North Carolina). The 2001 land cover map is similar to the 1992 North Carolina Gap Land Cover which was crosswalked to the North Carolina Wildlife Action Plan (NC WAP, NCWRC 2005) habitat classes. A crosswalk from the 2001 land cover to those same NC WAP habitat classes is available. These regional and state data sets can be obtained from the Southeast GAP Program (http://www.basic.ncsu.edu/segap).

Across the state of North Carolina, both the NLCD and CCAP data sets show an approximately 6% increase in urban/developed areas within the preceding decades (Tables 4-3, 4-4). However, within some areas, the rate of development has been much higher. For example, Pitt County saw an increase of almost 9% in developed area between 1996 and

Table 4-3. Land cover change in the state of North Carolina for the period 1992-2001 derived from the National Land cover Database (NLCD) 1992/2001 Retrofit Land Cover Change Product (Fry et al. 2009). Percentage of total area is indicated in parentheses.

Land Cover Class	Acres 1992		Acres 2001		Percent Change
Open Water	2,078,836	(1.5%)	2,177,307	(1.5%)	4.7%
Urban	12,680,568	(8.9%)	13,422,270	(9.5%)	5.8%
Barren	471,946	(0.3%)	575,423	(0.4%)	21.9%
Forest	67,826,462	(47.8%)	64,437,680	(45.4%)	-5.0%
Grassland/Shrub	9,181,576	(6.5%)	11,575,851	(8.2%)	26.1%
Agriculture	32,476,851	(22.9%)	32,746,512	(23.1%)	0.8%
Wetlands	17,067,268	(12.0%)	16,848,464	(11.9%)	-1.3%

Changes by class from 1992 to 2001

Class	Acres	Class	Acres
Urban-unchanged	2,808,110	Forest to Open Water	11,849
Barren-unchanged	101,161	Forest to Urban	137,602
Forest-unchanged	13,966,503	Forest to Barren	16,158
Grassland/Shrub-unchanged	1,979,306	Forest to Grassland/Shrub	526,073
Agriculture-unchanged	6,827,971	Forest to Agriculture	381,544
Wetlands-unchanged	3,628,173	Forest to Wetlands	44,527
Open Water to Urban	915	Grassland/Shrub to Open Water	338
Open Water to Barren	1,414	Grassland/Shrub to Urban	1,123
Open water to Forest	1,655	Grassland/Shrub to Barren	407
Open Water to Grassland/Shrub	3,735	Grassland/Shrub to Forest	43,754
Open Water to Agriculture	3,245	Grassland/Shrub to Agriculture	4,002
Open Water to Wetlands	2,855	Grassland/Shrub to Wetlands	13,005
Urban to Open Water	2,956	Agriculture to Open Water	13,184
Urban to Barren	158	Agriculture to Urban	32,620
Urban to Forest	2,011	Agriculture to Barren	2,655
Urban to Grassland/Shrub	1,771	Agriculture to Forest	258,407
Urban to Agriculture	4,296	Agriculture to Grassland/Shrub	30,520
Urban to Wetlands	790	Agriculture to Wetlands	57,328
Barren to Open Water	1,604	Wetlands to Open Water	5,786
Barren to Urban	118	Wetlands to Urban	4,556
Barren to Forest	241	Wetlands to Barren	6,019
Barren to Grassland/Shrub	55	Wetlands to Forest	58,038
Barren to Agriculture	1,446	Wetlands to Grassland/Shrub	32,950
Barren to Wetlands	333	Wetlands to Agriculture	60,150

2006 (Figure 4-2). In Wake County, urban areas increased 16% from 1992-2001 (Figure 4-3, Table 4-5). The impact of increased urban/developed areas on species and ecosystems is not limited to the direct effects of habitat loss associated with land use change. Increases in impervious surface (Figure 4-4), coupled with reduced habitat connectivity as a result of urban sprawl, pose additional risks to wildlife, particularly in cases in which urban growth encroaches on priority conservation areas.

Table 4-4. Land cover change in coastal regions of North Carolina covered by NOAA's Coastal Change Analysis Program (CCAP) for the period 1996-2006. Percentage of total area is indicated in parentheses.

Land Cover Class	Acres 1996		Acres 2006		Percent change
High Intensity Developed	2,774	(0.1%)	3,088	(0.2%)	11.3%
Medium Intensity Developed	6,099	(0.3%)	6,868	(0.4%)	12.6%
Low Intensity Developed	34,764	(1.9%)	36,054	(1.9%)	3.7%
Developed Open Space	23,774	(1.3%)	25,413	(1.4%)	6.9%
Cultivated	388,630	(20.8%)	392,822	(21.0%)	1.1%
Pasture/Hay	33,089	(1.8%)	33,060	(1.8%)	-0.1%
Grassland	42,344	(2.3%)	67,610	(3.6%)	59.7%
Deciduous Forest	22,978	(1.2%)	23,549	(1.3%)	2.5%
Evergreen Forest	331,183	(17.7%)	270,661	(14.5%)	-18.3%
Mixed Forest	33,671	(1.8%)	34,066	(1.8%)	1.2%
Scrub/Shrub	138,602	(7.4%)	169,345	(9.1%)	22.2%
Palustrine Forested Wetland	338,939	(18.2%)	298,950	(16.0%)	-11.8%
Palustrine Scrub/Shrub Wetland	56,070	(3.0%)	79,816	(4.3%)	42.3%
Palustrine Emergent Wetland	17,773	(1.0%)	24,955	(1.3%)	40.4%
Estuarine Forested Wetland	<1	*	16	*	
Estuarine Scrub/Shrub Wetland	1,109	(0.1%)	1,221	(0.1%)	10.1%
Estuarine Emergent Wetland	23,975	(1.3%)	24,102	(1.3%)	0.5%
Unconsolidated Shore	6,438	(0.3%)	5,995	(0.3%)	-6.9%
Bare Land	6,526	(0.3%)	9,772	(0.5%)	49.7%
Water	358,188	(19.2%)	359,561	(19.3%)	0.4%
Palustrine Aquatic Bed	10	*	12	*	

* percentages less than 0. 1% are not shown

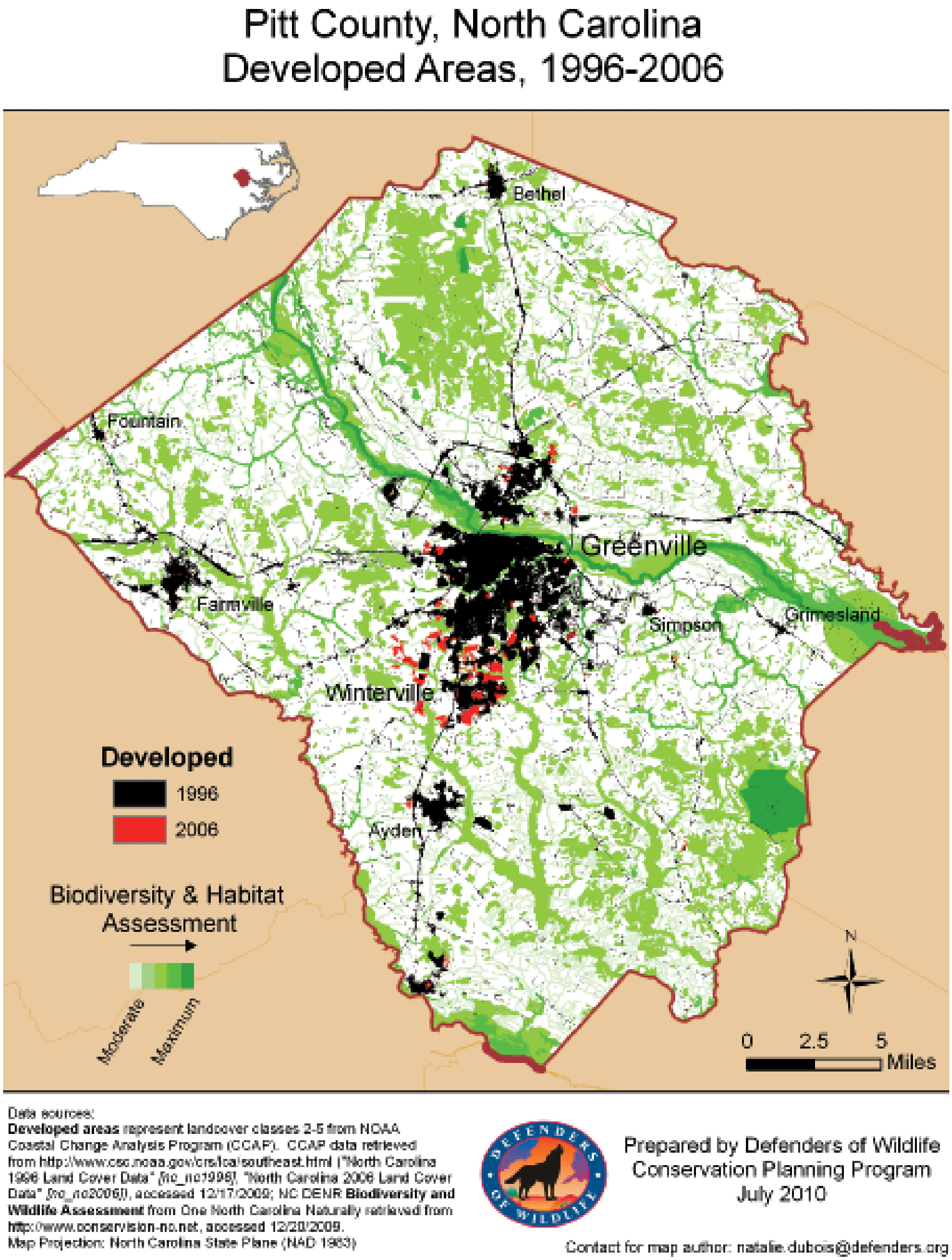

Figure 4-2. Developed areas in Pitt County, North Carolina, including open space, low intensity, medium intensity, and high intensity classifications from the NOAA Coastal Change Analysis Program land cover data sets for 1996 (black) and 2006 (red) are overlaid with the NCDENR Biodiversity and Habitat Assessment.

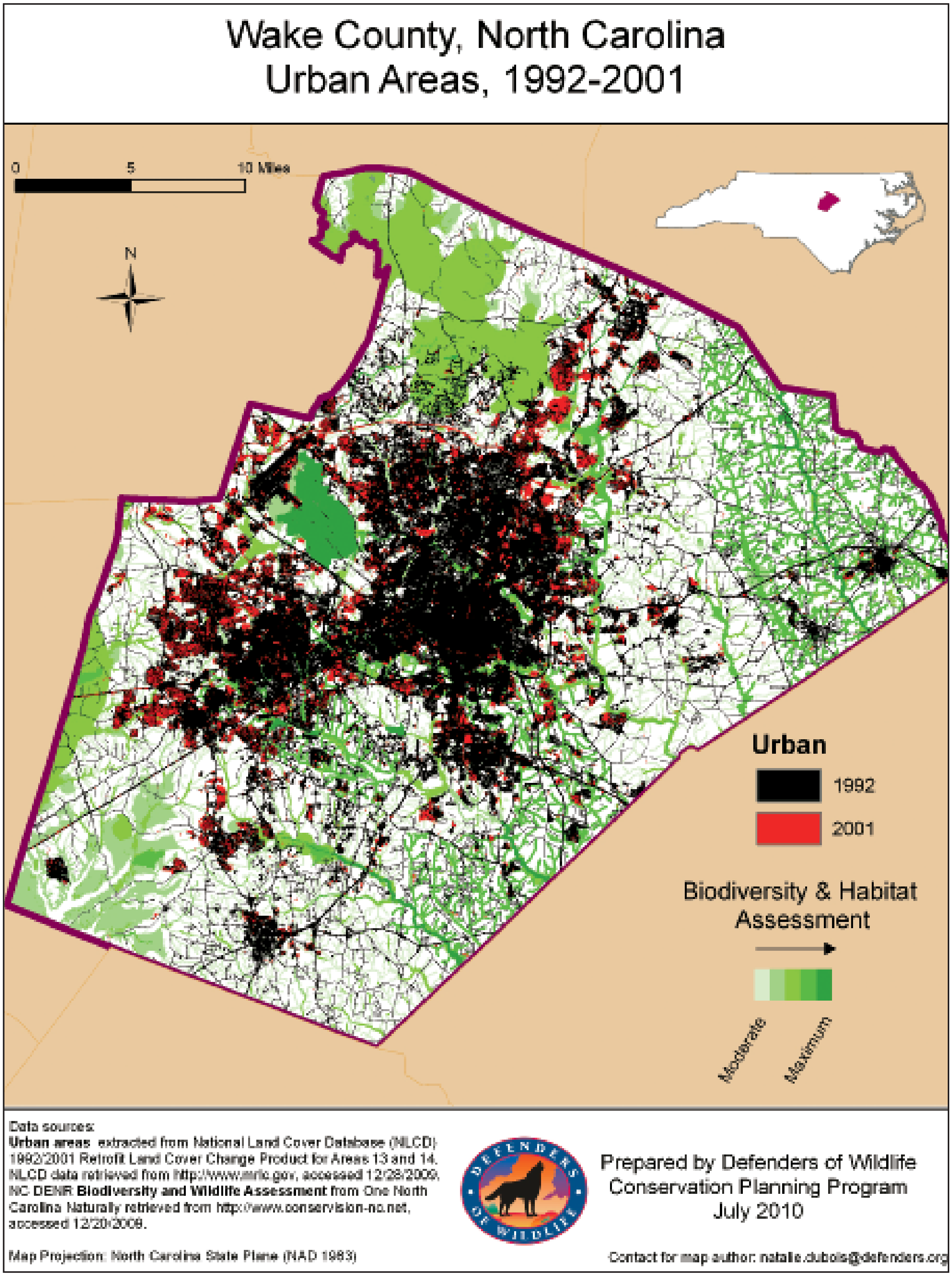

Figure 4-3. Urban areas in Wake County, North Carolina derived from the NLDC 1992/2001 Retrofit Land Cover Change Product (Fry et al. 2009) for 1992 (black) and 2001 (red) are overlaid with the NCDENR Biodiversity and Habitat Assessment.

Table 4-5. Land cover change in Wake County, North Carolina for the period 1992-2001 derived from the National Land cover Database (NLCD) 1992/2001 Retrofit Land Cover Change Product (Fry et al. 2009). Percentage of total area is indicated in parentheses.

Land Cover Class	Acres 1992		Acres 2001		Percent Change
Open Water	63,037	(2.6%)	66,503	(2.7%)	5.5%
Urban	624,842	(25.4%)	729,958	(29.6%)	16.8%
Barren	3,134	(0.1%)	3,742	(0.2%)	19.4%
Forest	1,149,219	(46.6%)	1,018,701	(41.3%)	-11.4%
Grassland/Shrub	141,386	(5.7%)	172,978	(7.0%)	22.3%
Agriculture	407,881	(16.6%)	396,278	(16.1%)	-2.8%
Wetlands	74,929	(3.0%)	76,268	(3.1%)	1.8%

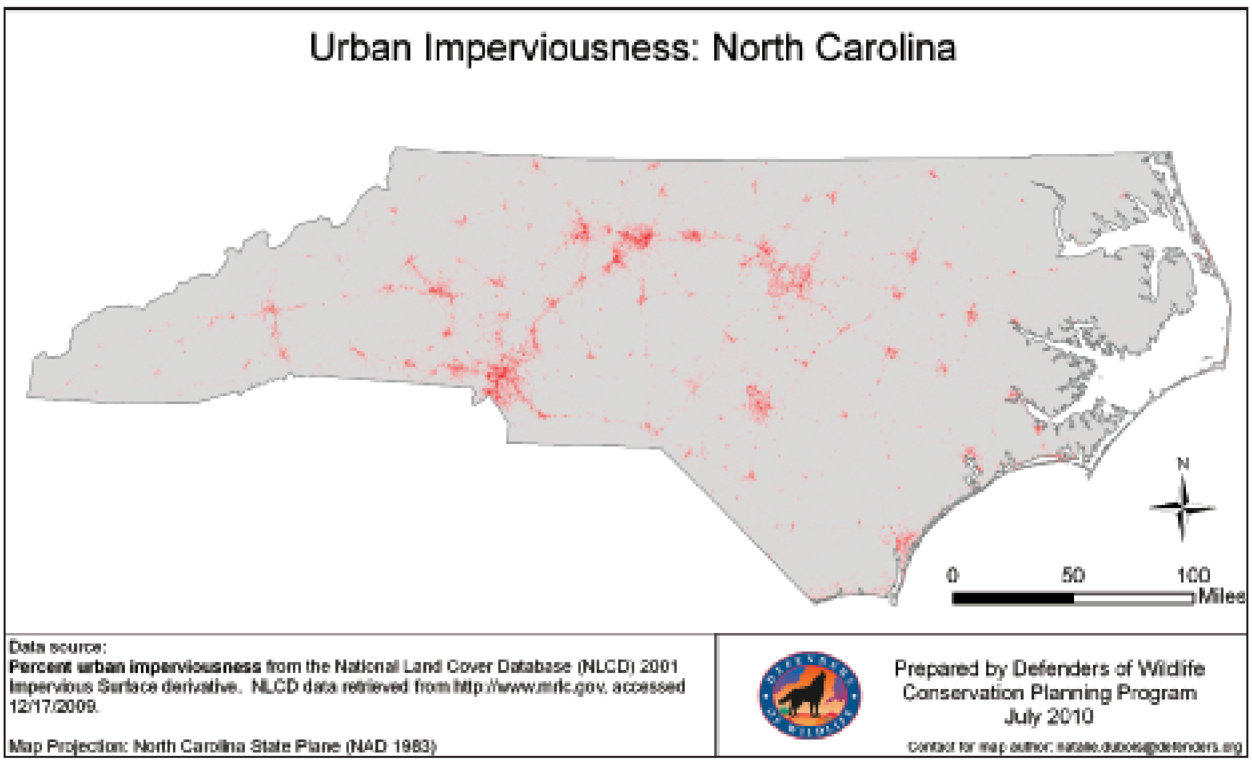

Figure 4-4. Map of urban imperviousness for North Carolina based on the National Land Cover Database (NLCD) 2001 Impervious Surface derivative (Homer et al. 2004).

Projected growth and development

Given the rapid rate of land conversion to urban and suburban development, it will be particularly valuable to understand how future patterns of urbanization may impact climate-sensitive regions. Theobald (2005) and the EPA (2009) have released a set of tools as part of the Integrated Climate and Land-Use Scenarios (ICLUS) that spatially predicts the impact of development using census data to forecast future housing density patterns. Other modeling frameworks, such as SLEUTH (developed by Keith Clarke, University of California Santa Barbara) utilize land-use change data as the basis for their models. Agarwal et al. (2002) provide a review and assessment of a number of different land use models and approaches (see Box 4-1 for examples). Projections of land use change can be important tools for understanding how patterns of urbanization affect the landscape, particularly at the interface between conservation priority and future urban development areas.

Box 4-1. Examples of tools used to model projected urban development or land use change

RENCI Urban Growth Model, UNC-Charlotte: Regional model for projected urban growth by decade through 2030 for a subset of counties in North Carolina. Additional models are in development. The urban growth model developed by RENCI at UNC Charlotte (Renaissance Computing Institute) has been used to look at potential conflicts between development and highly valued natural resources under historical growth patterns and a conservation scenario based on the Green Growth Toolbox (GGT) developed by NCWRC. http://renci.uncc.edu/whole-study

ICLUS v1.2: Projected U.S. housing density growth across the urban-rural gradient for 2010-2100 under IPCC scenarios developed by EPA. Implemented as an ArcGIS e xtension. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216195

Consortium for Atlantic Regional Assessment: Online maps showing projected change in land use as percentage of land area change of open space by county for 2000-2050. http://www.cara.psu.edu/land/landuseprojections.asp

Housing Density Maps: State maps produced by the Silvis Lab at the University of Wisconsin-Madison estimate housing density by decade between 1940-2030. Maps and data are available for download. http://silvis.forest.wisc.edu/Library/HousingData.asp

Uplan: Simple rule based urban growth model intended for regional or county level modeling. Implemented within ArcGIS. http://ice.ucdavis.edu/project/uplan

SLEUTH: Simulation model for projected land use using complex rules. Program is freely available, but requires a fair amount of programming knowledge and has extensive data requirements. http://www.ncgia.ucsb.edu/projects/gig/project_gig.htm

The Biodiversity and Spatial Information Center (BaSIC) is using a version of SLEUTH in their ***Designing Sustainable Landscapes*** project.

The Southeast Regional Assessment Project (SERAP): The first regional assessment funded by the USGS National Climate Change and Wildlife Science Center. In addition to developing landscape change datasets that can be used to project changes to the Southeast's climate and ecosystems, SERAP will integrate models of urbanization and vegetation dynamics with regional climate models to assess how landscape change could impact priority species. SERAP is an extension of BaSIC's ***Designing Sustainable Landscapes*** project. http://serap.er.usgs.gov/

Photo: U.S. Global Change Research Program, 2009

The ICLUS tools use a statistical model of urban growth that is directly integrated with ArcGIS and incorporates scenarios of housing density and derived impervious surface cover based on the IPCC social, economic, and demographic storylines (A1, A2, B1, B2). The ICLUS outputs are derived from a pair of models: a demographic model that generates population projections and a spatial allocation model (SERGoM, Theobald 2005). Each scenario is run for the conterminous United States, or for smaller regions as specified by the user, projected through 2100 by decade. Unlike some other modeling approaches, ICLUS uses projected population growth to estimate future patterns of housing density and captures a wider gradient of urban land use (e.g. urban vs. rural) than is commonly captured in the categories utilized in land cover data sets such as the NLCD. These projections are based on derived relationships from historic data. An example of the output is shown in Figure 4-5. This approach differs from that utilized by other models such as SLEUTH, which uses cellular automata to model emergent behavior from a set of initial conditions and behavioral rules. Cellular automata models are scale independent, allowing local, regional and continental scale processes to be described in a single framework. In the Southeast, the Biodiversity and Spatial Information Center (BaSIC) is currently using SLEUTH-R (Jantz et al. 2010) to model urban growth as part of the "Designing Sustainable Landscapes" project (DSL). The DSL Project uses vegetation and urban dynamics modeling to examine the potential impacts of landscape-level changes on the future capability of habitats to support wildlife populations (BaSIC, personal communication, www.basic.ncsu.edu/dsl). A third approach is being used by researchers from RENCI at UNC Charlotte (Renaissance Computing Institute, http://renci.uncc.edu/) who were initially commissioned by the Open Space Protection Collaborative to develop urban growth models for more than 20 counties in the greater Charlotte region. RENCI's model uses satellite imagery to forecast future urban growth using logistic regression models that are integrated with population-based models of urbanization pressure. This work is being expanded to include two-thirds of the state by the end of 2011.

The urban growth model developed by UNC Charlotte has been used to look at potential conflicts

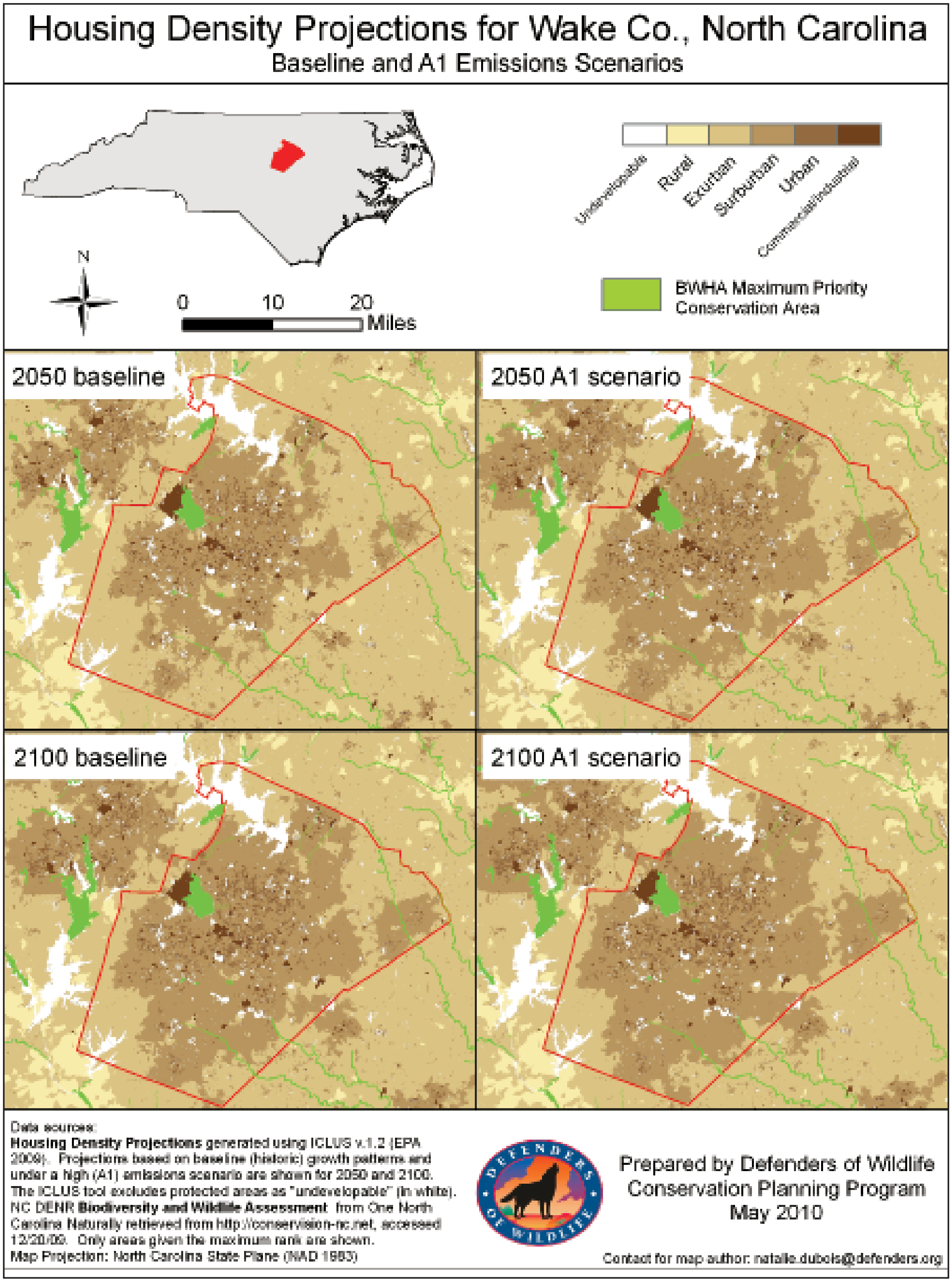

Figure 4-5. The ICLUS tool (EPA 2009b) was used to project mid and end of century housing density for Wake County, North Carolina using a baseline (historic) growth pattern and growth patterns under an A1(IPCC) emissions scenario. Areas assigned the *maximum* ranking in the NCDENR Biodiversity and Wildlife Assessment are indicated in green.

between development and highly valued natural resources under historical growth patterns and a conservation scenario based on the Green Growth Toolbox (GGT) developed by NCWRC. Maps comparing projected development patterns produced using GGT recommendations with projected development patterns projected from historical trends differed significantly over a 25-year period. Incorporating GGT recommendations into development planning for the entire state of North Carolina reduced overlap with conservation priority areas by as much as75% (RENCI at UNC Charlotte 2009). An example from Cabarrus County, in which conservation conflicts were reduced by approximately 50% under the GGT conservation planning scenario, is shown in Figure 4-6.

4.1.2 Potential Impacts of Land Use Change on Species and Habitats

Recommendations for climate change adaptation strategies frequently include expanding protected area networks and connectivity as top priorities (Heller and Zavaleta 2009, Lawler 2009, Mawdsley et al. 2009), in part to address issues related to species range shifts under climate change. As conditions change, some plant and animal populations will be unable to persist in their current locations, but they may be able to disperse into more suitable locations. However, barriers created by human development (see map of urban imperviousness, Figure 4-4) may make it difficult for many species to follow

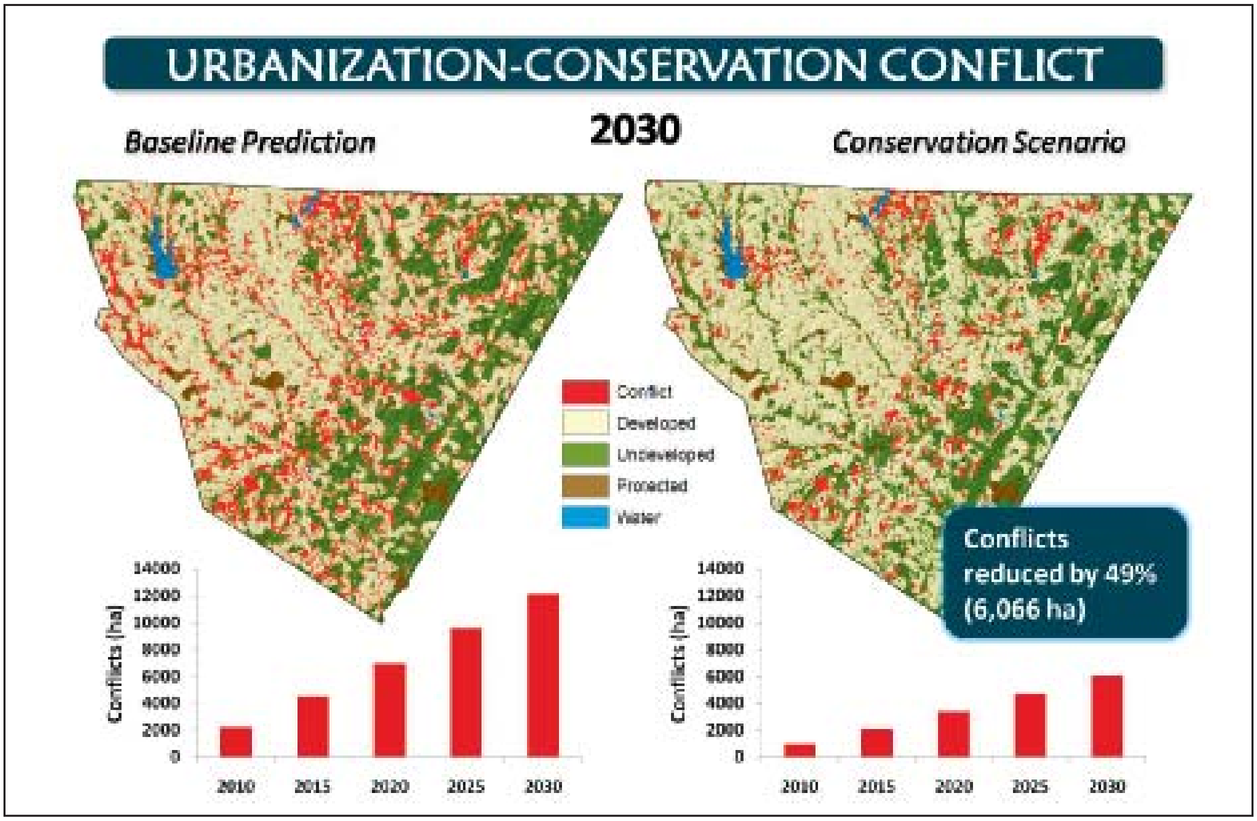

Figure 4-6. Maps of Cabarrus County showing projected growth under historical growth patterns and using a conservation scenario based on the Green Growth Toolbox framework. The same amount of development occurs under each scenario, but conflicts with priority conservation areas are reduced by 49% under the GGT (RENCI at UNC Charlotte, used with permission).

climatic gradients and move into new areas of suitable habitat. In addition, current reserve networks, many of which protect only a small, potentially biased samples of environmental conditions across the range of an individual species or habitat type, are likely to become increasingly less representative under combined impacts of climate change and habitat loss (Pyke 2004).

The negative consequences of expanding urban development on species and habitats are well established (e.g., Chace and Walsh 2006, Hansen et al. 2005, McKinney 2002). Direct habitat loss, habitat fragmentation, and isolation can pose significant threats to population viability on their own. However, interactions between climate change and other drivers, such as land use change, may have greater impacts on biodiversity than any one driver alone (Brook et al. 2008). In a survey of 248 papers from the climate change literature that addressed the conservation and management of biodiversity or ecosystems, Felton et al. (2009) found that fewer than half of the studies addressed climate change in relation to other anthropogenic threats. Recent reviews emphasize that the lack of integration of climate change impacts with other synergistic threats is likely to inadequately capture future impacts on biodiversity (Brook et al. 2008, de Chazal and Rounsevell 2009). For example, Warren et al. (2001) examined responses of 46 species of butterflies that were expected to expand their ranges as a result of climate warming over the last 30 years, and found that three-quarters had declined as a result of habitat loss, with sedentary species and habitat specialists among the most adversely affected. Jetz et al. (2007) estimated that globally 10 - 20% of land bird species would be imperiled by climate change and land conversion by 2100, but that differences in species diversity and range will affect the relative influence of these drivers. For example, they suggest that climate change will be the principal driver of range contractions at higher latitudes, while land conversion will be the principal driver of species range contractions in the tropics (Jetz et al. 2007). However, their analysis did not examine the potential for range shifts (in addition to contractions) to occur as a result of climate change.

Projections of species range shifts under climate change often assume that species distributions are limited primarily by temperature without accounting for the spatial configuration of the landscape or habitat. To address this issue, some authors have attempted to integrate a metapopulation dynamics framework with broader scale changes in species ranges. Opdam and Washer (2004) characterize range shifts as the result of extinction of (meta) populations at the warm range limit and colonization into regions that have transitioned into suitable thermal conditions at the cooler end of the range. The ability of a species to shift into more suitable areas will be a function of new climate conditions (e.g. temperature) and extreme weather conditions. However, the authors suggest that some species metapopulations will be unable to persist in areas where fragmentation has severely degraded habitat quality and patch availabilty, and will likely exhibit range contractions (Opdam and Washer 2004). Modeling work has produced similar results, indicating that extinction thresholds are lower under the combined effects of habitat fragmentation and climate change (Travis 2003). McInery et al. (2007) further demonstrated that the effect of habitat fragmentation on range shifts may be dependent on species dispersal characteristics and populations dynamics during periods of climate change. Their model suggests that range shifts are more successful in less fragmented (clumped) landscapes for species with low colonization rates. However, for species with especially strong dispersal and colonization abilities, fragmentation could have the opposite effect, facilitating range shifts so long as the availability of suitable habitat keeps pace with climatic shifts on the landscape (McInerny et al. 2007).

Potential Impacts on Species and Habitats in North Carolina

Urban development, fragmentation, and other land conversions currently threaten many terrestrial habitat types in North Carolina (NC WAP), and species already sensitive to habitat fragmentation are likely to be further impacted by climate change. Habitat conversion may create barriers to migration, and expanded reserve networks may be required as thermally suitable conditions move across the landscape. In some areas, development may have already destroyed or converted remaining natural habitat in these areas, limiting the ability of populations to shift. For example, the limited range of Mabee's salamander (*Ambystoma mabeei*) has been highly impacted by draining of wetlands and conversion of forest into cropland (Petanka 1988 in NatureServe 2009). Like other ambystomids, which require vernal ponds for breeding, specific habitat requirements and limited movement make the species particularly vulnerable to habitat loss and degradation. Five species of ambystomid are currently identified as priority species in the NC WAP. Of the 31 amphibian species prioritized for conservation in North Carolina, many, if not most, have narrow habitat requirements for at least a portion of their life cycle. Even species occurring primarily in protected areas, such as pine woods littersnake (*Rhadinaea flavilata*), black swamp snake (*Seminatrix pygaea*), and Chattahoochee slimy salamander (*Plethodon chattahoochee*, NatureServe 2009) may face increasing threats to habitat availability as habitat conditions are altered by climate change. Species with requirements for large areas of intact habitat may also be particularly vulnerable. For example, a number of forest interior dwelling species, such as black-billed cuckoo (*Coccyzus erythropthalmus*), cerulean warbler (*Dendrica cerulea*), magnolia warbler (*D. magnolia*), Swainson's warbler (*Limnothlypis swainsonii*), and wood thrush (*Hylocichla mustelina*), are identified as avian priority species in the NC WAP.

Habitat specialists … will likely be some of the greatest affected by the combined effects of habitat loss and climate change.

Habitat specialists and species with restricted ranges will likely be some of the greatest affected by the combined effects of habitat loss and climate change. Such populations are more vulnerable to extinction by rare events and susceptible to additional stressors such as climate change. For example, Carolina northern flying squirrel (*Glaucomy sabrinus coloratus*) occurs only in isolated localities in 12 or 13 counties in North Carolina, and Tellico salamander (*Olethodon aureolus*) occurs in only two counties in North Carolina located between the Little Tennessee and Hiwassee rivers (NatureServe 2009). Appalachian cottontail (*Sylvilagus obsucurus*) is another priority species with a fairly limited geographic distribution that is broken into small isolated populations throughout portions of its range. Species such as rock shrew (*Sorex dispar*), an Appalachian endemic with very specific habitat requirements (e.g. cool, damp forest with deep talus (NatureServe 2009)), may also be more at risk.

Other types of land use, for example logging, may impact priority species such as eastern spotted skunk (*Spilogale putorius*) and ambystomids such as spotted salamander (*Ambystoma maculatum*) and marbled salamander (*A. opacum*), which prefer forested areas with significant cover (NatureServe 2009). Conversion to pine plantations is a known threat to populations of mimic glass lizard (*Ophisaurus mimicus*), which has a spotty distribution throughout its range (NatureServe 2009). In addition to densely urbanized areas, roads pose additional barriers to a number of species, particularly those with limited movement, such as green salamander (*Aneides aeneus*), barking treefrog (*Hyla gratiosa*), black swamp snake (*Seminatrix pygaea*), and eastern box turtle (*Terrapene carolina*) (NatureServe 2009).

4.2 Renewable Energy Development

In the United States, more than 90% of CO_2 released comes from the combustion of fossil fuels (Lieberman et al. 2007). Concerns about global climate change and air quality are driving increased interest in alternative energy resources. Expanding development and use of renewable energy in the U.S., such as wind, solar, or biofuels, will reduce dependence on fossil fuels and decrease harmful greenhouse gas emission, reduce environmental pollution, and increase energy security. However, the sustainable development of renewable fuel alternatives will also require an understanding of how alternative energy production and associated land-use choices may affect important ecological systems (Dale et al. 2010). In the U.S., states have been creating policies aimed at reducing greenhouse gas emissions for many years, although efforts have expanded and intensified in the past several years (Rabe 2002). Given the complexity and diversity of emissions and mitigation, states have promoted a variety of legislative policies on renewable energy, air pollution control, agriculture, forestry, waste management, transportation, and energy development, among others (Rabe 2002). In almost all cases there have been multiple drivers behind, and multiple benefits from, these state policies (Rabe 2002).

In this section, we summarize a few of the relevant federal and state renewable energy incentives available in North Carolina and implications for wildlife and habitat in the state. We also review regions that have been identified as high potential for alternative energy, and evaluate available research on the impacts of biofuels and wind energy production on North Carolina's land use and biodiversity.

4.2.1 Renewable Energy Policy

The state of North Carolina has a 30 plus year history in providing tax incentives for the use and application of alternative energy technologies (NC Department of Revenue 2009). To promote and encourage the increased use of renewable energy, the 1977 session of the North Carolina General Assembly enacted legislation that provided incentives in the form of a tax credit for the construction or installation of solar energy systems to heat, cool, or provide hot water to buildings in North Carolina. Throughout the years, other tax credits encouraging investment in additional renewable resources such as hydroelectric, solar and wind energy, or methanol gas, were enacted. The 1999 session of the General Assembly unified these multiple incentives into one statute that addresses nearly all renewables (§ 105-129.15/16A). This statute provides a tax credit for personal and corporate taxpayers of 35% of the cost of renewable energy property constructed, purchased or leased by a taxpayer and placed into service in North Carolina during the taxable year (§ 105-129.15/16A). This effort has provided an important incentive for the development and use of alternative energy in North Carolina.

In 2007, the North Carolina legislature took critical steps towards requiring electric utilities to embrace energy alternatives to meet the state's power demands. When signed into law by Governor Easley, North Carolina was the first state in the Southeast to require electric utilities to tap renewable and efficiency programs to meet the state's growing energy needs (Murawski 2007). Under the law (S.L. 2007-397, Box 4-2) utility companies in the state need to meet the alternative energy criteria set in the "Renewable Energy and Energy Efficiency Portfolio Standard." By 2021, electric public utilities must meet 12.5% of retail electricity demand through renewable energy or energy efficiency measures, and electric membership corporations and municipalities that sell electric power in the state would have to meet a standard of 10% by 2018. Resources that can be used to meet the standard include solar energy, wind energy, hydropower, geothermal energy, ocean current or wave energy, biomass resources, and energy efficiency measures. The law also includes provisions to

Box 4-2. North Carolina Session Law 2007-397

SESSION LAW 2007-397

SENATE BILL 3 AN ACT TO:

1. PROMOTE THE DEVELOPMENT OF RENEWABLE ENERGY AND ENERGY EFFICIENCY IN THE STATE THROUGH IMPLEMENTATION OF A RENEWABLE ENERGY AND ENERGY EFFICIENCY PORTFOLIO STANDARD (REPS),
2. ALLOW RECOVERY OF CERTAIN NONFUEL UTILITY COSTS THROUGH THE FUEL CHARGE ADJUSTMENT PROCEDURE,
3. PROVIDE FOR ONGOING REVIEW OF CONSTRUCTION COSTS AND FOR RECOVERY OF COSTS IN RATES IN A GENERAL RATE CASE,
4. ADJUST THE PUBLIC UTILITY AND ELECTRIC MEMBERSHIP CORPORATION REGULATORY FEES,
5. PROVIDE FOR THE PHASEOUT OF THE TAX ON THE SALE OF ENERGY TO NORTH CAROLINA FARMERS AND MANUFACTURERS, AND
6. ALLOW A TAX CREDIT TO CONTRIBUTORS TO 501(C)(3) ORGANIZATIONS FOR RENEWABLE ENERGY PROPERTY.

encourage the use of solar energy, swine and poultry wastes, as well as implementation of energy efficiency programs (S.L. 2007-397).

Numerous federal programs also support the development and use of alternative energy in North Carolina. For example, the USDA "Commodity Corporations Credits for Production of Ethanol and Biodiesel" encourages bioenergy investments by providing financial support for purchasing agricultural commodities to increase ethanol and biodiesel production (Box 4-3). Production tax credits provided through the "Renewable Energy Production Incentive" for wind, solar, and other alternative energy sources offer significant incentives for public power and other tax-exempt entities to produce energy from alternative sources (Energy Policy Act 2005, Pub.L. 109-58). More recently, the American Recovery and Reinvestment Act of 2009 (*ARRA* Pub.L. 111-5) provides significant provisions that benefit renewable energy development, including a Treasury Department grant program for renewable energy developers, a long-term extension of the wind energy production tax credit, an Energy Department loan guarantee program for developers and manufacturers, an expansion of Energy Department research, development and deployment funding, and a tax credit for advanced energy manufacturers. Appropriations for energy totaled over $61 billion dollars, and included numerous provisions for increasing energy efficiency for state and local governments and improvements in renewable energy technology. These incentives, coupled with increasing public support for developing alternative energy, have provided the demand needed to intensify wind, biofuel, and solar prospects in North Carolina.

Box 4-3. Biodiesel and ethanol credits

Commodity Corporation Credits for production of ethanol and biodiesel

- The U.S. Department of Agriculture established the Commodity Credit Corporation (CCC) Bioenergy Program in Fiscal Year 2001. Under the program, the CCC makes payments to eligible bioenergy producers to encourage increased purchases of agricultural commodities for the purpose of expanding production of bioenergy (ethanol and biodiesel) and to encourage the construction of new production capacity.
- The 2002 Farm Bill continued the program through Fiscal Year 2006, providing $150 million annually. Payments are based on the increase in bioenergy production compared to the previous year's production.

NC GreenPower is a statewide green power program designed to encourage the use of renewable energy in North Carolina and meet the legislative requirements outlined in S.L. 2007-397. NC GreenPower is an independent, nonprofit organization created by state-government officials, electric utilities, nonprofit organizations, consumers, renewable-energy advocates and other stakeholders (DSIRE 2010). This program offers production payments for grid-tied electricity generated by solar, wind, small hydro (10 megawatts or less) and biomass resources (DSIRE 2010). North Carolina's three investor-owned utilities–Dominion North Carolina Power, Duke Energy, and Progress Energy–and many of the state's municipal utilities and electric cooperatives, are participating in the NC GreenPower Program (DSIRE 2010).

4.2.2 Wind Energy Development

With an average annual growth rate of more than 30% over the past half-decade, wind is the fastest growing sector of the energy industry in the United States (Pasqualetti et al. 2007, NRC 2007). Nationally, the cost of wind-generated electricity has fallen from nearly 40 cents per kilowatt hour in the early 1980s to 3-10 cents per kilowatt hour, depending on wind speed and project size. According to the National Renewable Energy Laboratory (NREL), North Carolina has outstanding potential for wind energy. Wind resources vary across the state, and patterns of wind energy development will likely follow the spatial distribution of these resources.

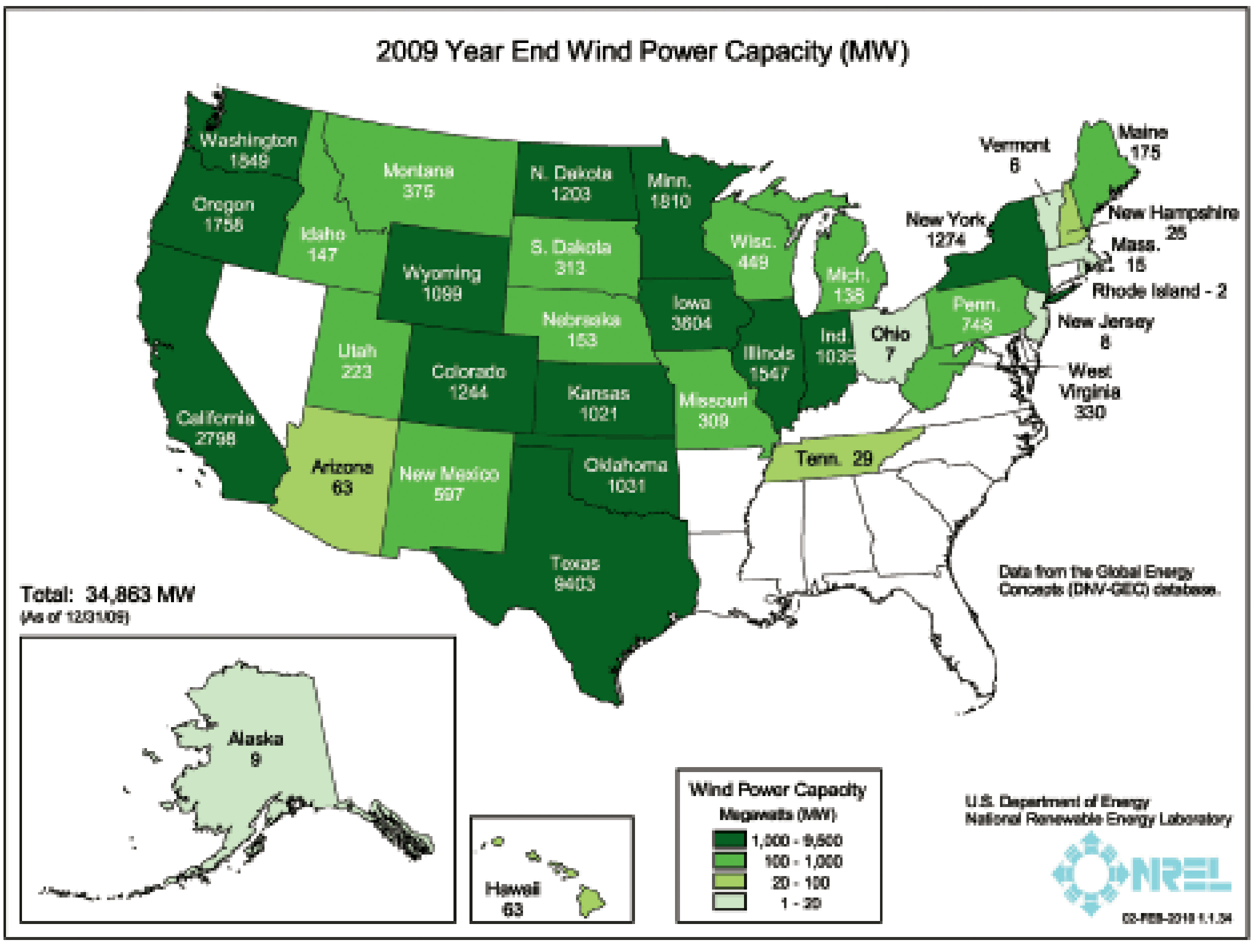

Figure 4-7. Map of installed wind capacity as of December 31, 2009. As of this date, 34,863 MW of wind power had been installed across the United States (Source DOE 2010b).

Wind energy is classified according to wind power classes, which are based on typical wind speeds. These classes range from less than 4 to greater than 10. Areas with annual average wind speeds around 6.5 m/s and greater at 80 m height are generally considered suitable for utility-scale wind development (DOE 2010a). Although there are clearly opportunities for significant wind development in North Carolina, as of June 2010 wind power installments have not been installed (Figure 4-7, DOE 2010b). However, in 2009, the University of North Carolina at Chapel Hill signed an agreement with Duke Energy to construct up to three demonstration wind turbines in Pamlico Sound (Duke Energy 2010). Under this agreement Duke Energy will supply and install the wind turbines while the University will conduct research on electricity generation from offshore wind farms in North Carolina. Installation of these turbines is expected to begin in summer 2010.

The Department of Energy's Wind Program and NREL recently completed a wind resource map for North Carolina (Figure 4-8). This new map shows wind speed estimates at 80 meters above the ground and identifies the location of resources that could be used for utility-scale wind development. Figure 4-8 clearly demonstrates that North Carolina has both offshore and ridgeline wind resources for utility-scale wind production across the state. The best area for wind energy production is along the Atlantic coast and barrier islands followed by the higher ridge crests in western North Carolina.

Potential Impacts of Wind Energy Development on Species and Habitats

Although land-based wind energy offers a promising alternative to carbon-emitting fossil fuels, wind energy facilities can negatively impact wildlife and habitat (USFWS 2003). Birds, especially raptors (Hunt 2002), and bats are particularly sensitive to mortality from the rotor blades, and wind farms may impact bird movements, breeding, and habitat use (Johnson et al. 2002, USFWS 2003). Although wind energy is not an entirely new phenomenon, research on the impacts of turbines on wildlife is relatively recent. Significant concerns about bird mortality were triggered by research from the Altamont Pass Wind Resource Area in California, where Orloff and Flannery (1992) estimated that several hundred raptors were killed each year due to turbine collisions, wire strikes, and electrocutions (USFWS 2003). More recent research has suggested that mortality estimates from this study were statistically biased (Hunt 2002), but the Altamont turbines are still estimated to kill 40-60 subadult and adult golden eagles each year, as well as several hundred red-tailed hawks and American kestrels (USFWS 2003). Erickson et al. (2001) reviewed bird collision reports from 31 studies and showed that 78% of carcasses found at utility-scale wind energy facilities outside of California were songbirds protected by the Migratory Bird Treaty Act (16 United States Code 703–712) (in Kunz et al. 2007). However, other studies have demonstrated that bird-turbine collisions are much less frequent than collisions with automobiles, buildings and windows, or communication towers (Berg 1996). Indeed, the National Audubon Society strongly supports wind power as a clean alternative energy source that reduces the threat of global warming, as long as proper siting, operation, and mitigation are employed to minimize the impact on birds and other wildlife (Audubon 2010).

Recent research on the impact of terrestrial wind energy development on bats suggests that certain species may be disproportionately susceptible to mortality from turbines. A recent review by Arnett et al. (2008) found five key patterns in bat fatalities at wind turbines in the United States: (1) Fatalities were heavily skewed toward migratory bats and were dominated by tree-roosting lasiurine species in most studies; (2) Studies consistently reported peak of turbine collision fatality in midsummer through fall; (3) Fatalities were not concentrated at individual turbines (i.e., fatalities were distributed among turbines at facilities), and current studies have not identified consistent relationships with habitat variables; (4) Red-strobe rights recommended by the Federal Aviation Administration did not influence bat fatality; and (5) bat fatalities were highest during periods of low wind speed, and they were related to weather variables associated with the passage of weather fronts. Additional studies have concluded that larger turbines may kill more bats (Cryan and Brown 2007), bat fatalities are more clustered around the base of towers than bird fatalities (Cryan and Bailey 2009), and that there is also evidence on non-collision decompression, a phenomenon in bats where drops in air pressure cause the lungs to overexpand and fill with fluid (Baerwald et al. 2008).

Large numbers of bats have been killed at wind-energy facilities constructed along forested ridge tops in the eastern United States (Arnett 2005, Johnson 2005, Fiedler et al. 2007, Kunz et al. 2007). Cryan and Brown (2007) hypothesize that the dominance of migratory tree bats killed during summer and fall at turbines and other anthropogenic structures is related to flocking and mating behaviors Wind turbines may offer the most prominent feature in a landscape where bats can meet along their migratory routes and breed (Arnett et al. 2008). There is also evidence to support the hypothesis that migratory bats congregate in the fall during migration (Arnett et al. 2008). These mating and migration behaviors may explain why bats are disproportionately affected by turbine mortality. Unlike birds, bats do not collide with other tall anthropogenic structures with the frequency and magnitude that have been observed at wind turbines (Arnett 2005, Cryan

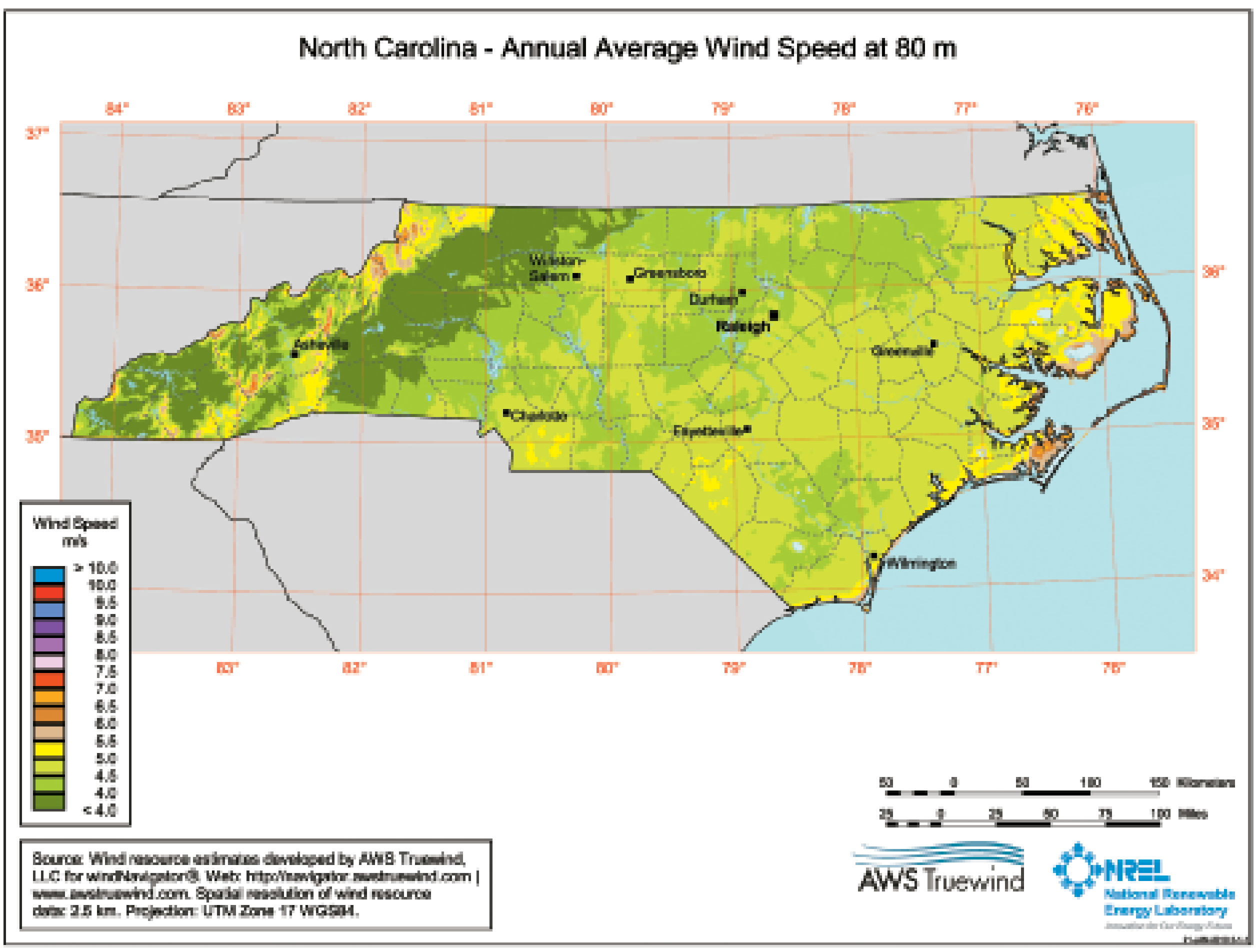

Figure 4-8. Predicted mean annual wind speeds (meters/second) at 80-m height for North Carolina (Source: DOE 2010a).

and Veilleux 2007). A number of bats species are known, or at least suspected, to be in decline across the U.S. (Racey and Entwistle 2003, Winhold and Kura 2005) at the same time that wind energy developments are increasing (Kunz et al. 2007).

Until very recently, U.S. wind turbines have mostly been land-based (USFWS 2003). The wildlife and habitat impacts from off-shore wind turbines differ from those of terrestrial turbines. There are two types of offshore wind turbines: bottom-mounted (installed on or in the seafloor) and floating (Deese and Schmitt 2010). Most existing offshore turbines are bottom-mounted in waters less than 50 feet deep, although a few have been placed in waters that are 150 feet deep. Although the specific impacts on wildlife and habitat will depend on the type and number of turbines, installation on the sea floor and increased ship traffic due to shifts in navigable waters have the potential to interfere with animal behavior, communication, physiology, and increase collision risk (Nedwell et al. 2003). However, long-term research on the impacts of offshore wind on wildlife is limited, even from European countries (Sweden, Denmark, and Norway) that have more than ten offshore wind projects in operation (USFWS 2003).

Recently published research on the impacts of offshore wind on marine habitat suggests that turbine foundations may function as artificial reefs and provide critical habitat for local fish and crabs, and it may even be possible to increase or decrease the abundance of various species by altering the structural design of the foundation (Wilhelmsson 2009). However, the inefficiency of mortality surveys for carcasses at sea or onshore can make measuring the impact of offshore wind turbines on shorebirds, seabirds, and marine mammals more challenging (USFWS 2003). Recent developments in using high definition imagery technology for carcass surveys may improve our understanding of the impacts of offshore wind energy on seabirds and marine mammals (Thaxter and Burton 2009). The potential for significant offshore turbine impacts on birds and mammals suggests that considerable research and monitoring will be needed (USFWS 2003).

Photo: Cooper's Hawk, Alex Theoharides, 2009

One of the biggest challenges in understanding the potential impact of turbines on wildlife is that the scale of wind production to date has been relatively small. As the demand for alternative energy increases, newly developed facilities with larger turbines may initiate or contribute to the decline of sensitive wildlife (USFWS 2003). However, each individual wind project poses a unique set of circumstances and should be evaluated on its own merits (Audubon 2010). Careful evaluation of proposed facilities will be essential to minimizing wildlife mortality and avoiding incompatible land uses.

Potential Impacts on Species and Habitats in North Carolina

Significant wind potential exists in some of North Carolina's most sensitive biological regions. In the Southern Blue Ridge Ecoregion, for example, some of the highest areas of wind potential in the state ("outstanding" and "superb") overlap with, or are adjacent to, high priority biodiversity areas (Figure 4-9). These areas will not only be sensitive to the construction and placement of the turbines themselves, but once built, wind turbines may also significantly affect some of the critical species in greatest conservation need (SGCN) that migrate through or breed in these areas.

Given the potential for wind energy development and high biodiversity in the Southern Blue Ridge Ecoregion, it is not surprising that a number of groups have taken an active interest in understanding the impacts of turbines in western North Carolina. Over 200 avian species breed or regularly occur as migrants or winter residents in the Southern Blue Ridge (Lee et al. 1985, Hunter et al. 1999). The NC WAP has identified 46 avian species in this region as SGCN, 16 of which have state listing status (Special Concern, Significantly Rare, Threatened, or Endangered, Table 4-6). In addition, the Southern Blue Ridge Ecoregion supports 12 endemic species, including subspecies such as Southern winter wren (*Troglodytes troglodytes pullus*) and Appalachian ruffed grouse (*Bonasa umbellus monticola*; Lee and Browning in prep. in Smalling 2003). Many of these are restricted to higher elevation areas that may be potential wind sites (Smalling 2003).

Of particular concern in this region is the large number of neotropical migrants that pass through the area on the their way to, or back from, breeding grounds. Raptors in particular are known to use the Appalachian corridor for migration (Smalling 2003) and can be disproportionately affected by wind turbines, particularly if they are sited along ridge lines. Along migration corridors, raptors will often fly directly above the ridges and tend to hug the ridges in flight as wind speed increases (Van Fleet and Small 2010). Specific raptors of concern for North Carolina in this region include Cooper's hawk (*Accipiter cooperii*), sharp-shinned hawk (*Accipiter striatus*), Northern saw-whet owl (*Aegolius acadicus*), peregrine falcon (*Falco peregrinus*), and American kestrel (*Falco sparverius*). However, raptor species

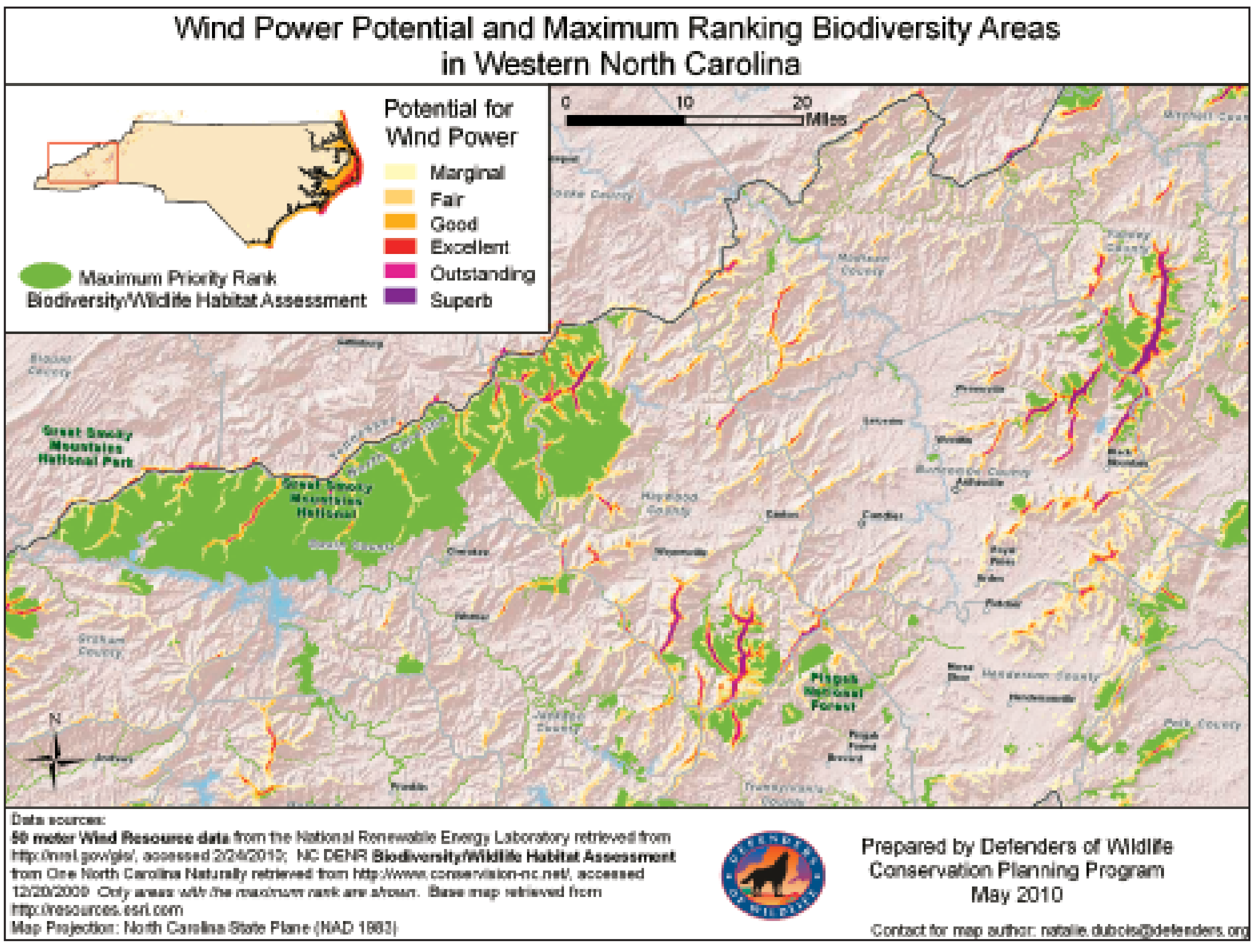

Figure 4-9. Map illustrating areas of significant wind potential and co-occurrence with areas of high biodiversity value in western North Carolina.

Table 4-6. Priority bird species identified in the NC WAP that occur in habitat types in the Southern Blue Ridge Ecoregion.

Scientific Name	Common Name	State Status (Federal Status)	Habitat type									
			Spruce-fir Forest	Northern Hardwood Forest	Cove Forest	Dry Coniferous Woodlands	Montane Oak and Mixed Hardwoods	Early Successional	High Elevation Rock Outcrops	Low Elevation Cliffs/Rock Outcrops	Montane Floodplain Forest	Bogs and Associated Wetlands
Accipiter cooperii	Cooper's Hawk	SC		X	X	X	X					
Accipiter striatus	Sharp-shinned Hawk	SR	X	X	X	X	X					
Aegolius acadicus	Northern Saw-whet Owl	T	X	X								
Ammodramus savannarum	Grasshopper Sparrow							X				
Caprimulgus vociferous	Whip-poor-will						X	X				
Carduelis pinus	Pine Siskin		X									
Certhia Americana	Brown Creeper	SC	X	X	X		X					
Chordeiles minor	Common Nighthawk							X				
Coccyzus americanus	Yellow-billed Cuckoo				X		X				X	
Coccyzus erythropthalmus	Black-billed Cuckoo	SR		X	X		X					
Colaptes auratus	Northern Flicker				X		X					
Colinus virginianus	Northern Bobwhite							X				
Contopus virens	Eastern Wood-Pewee				X		X					
Dendroica cerulean	Cerulean Warbler	SR			X		X					
Dendroica discolor	Prairie Warbler					X		X				
Dendroica magnolia	Magnolia Warbler	SR	X									
Dendroica pennsylvanica	Chestnut-sided Warbler		X	X				X				
Dolichonyx oryzivorus	Bobolink							X				
Empidonax alnorum	Alder Flycatcher	SR						X				X
Empidonax traillii	Willow Flycatcher							X				X
Eremophila alpestris	Horned Lark							X				
Falco peregrinus	Peregrine Falcon	E							X	X		
Falco sparverius	American Kestrel							X				
Helmitheros vermivorous	Worm-eating Warbler				X	X	X					
Hylocichal mustelina	Wood Thrush				X		X					
Icterus spurious	Orchard Oriole							X				
Limnothlypis swainsonii	Swainson's Warbler				X						X	
Loxia curvirostra	Red Crossbill	SC	X			X						
Melanerpes erythrocephalus	Red-headed Woodpecker					X	X					
Oporornis formosus	Kentucky Warbler						X				X	
Passerculus sandwichensis	Savannah Sparrow	SR						X				
Pheucticus ludovicianus	Rose-breasted Grosbeak			X			X					
Picoides villosus	Hairy Woodpecker		X	X	X		X					
Poecile atricapilla	Black-capped Chickadee	SC	X	X			X					
Pooecetes gramineus	Vesper Sparrow	SR						X				
Scolopax minor	American Woodcock							X				
Sitta pusilla	Brown-headed Nuthatch					X						
Sphyrapicus varius	Yellow-bellied Sapsucker	SC		X	X		X					
Spizella pusilla	Field Sparrow							X				
Sturnella magna	Eastern Meadowlark							X				
Tyrannus tyrannus	Eastern Kingbird							X				
Tyto alba	Barn Owl							X				
Vermivora chyrsoptera	Golden-winged warbler	SR		X			X	X				X
Vermivora pinus	Blue-winged warbler	SR						X				
Wilsonia canadensis	Canada Warbler		X	X			X					
Wilsonia citrine	Hooded Warbler				X		X				X	

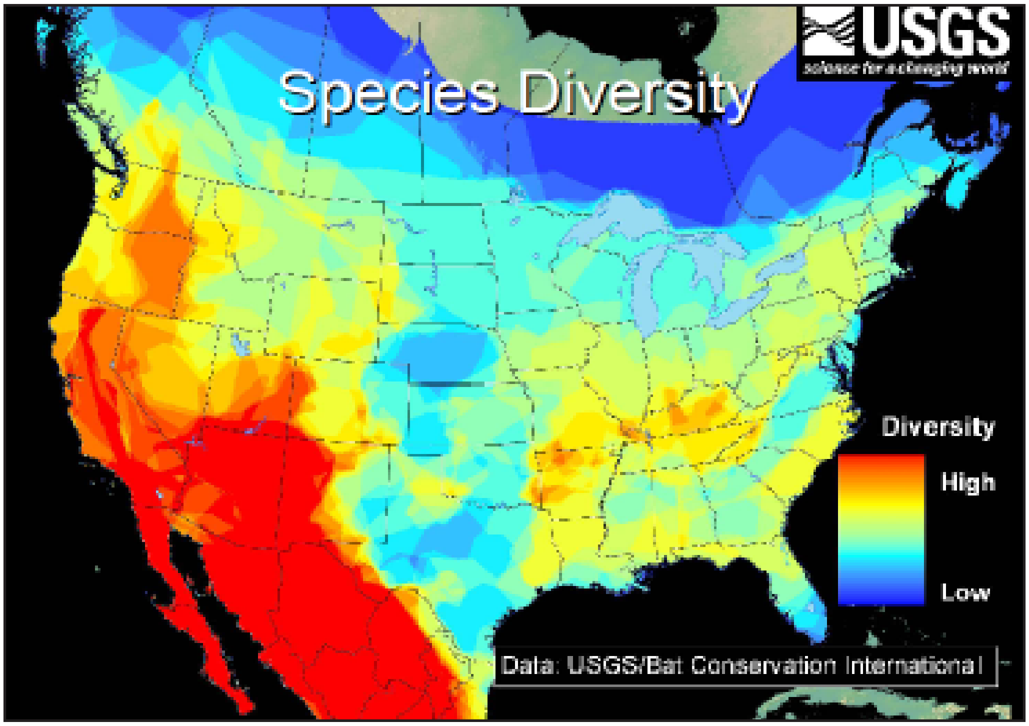

Figure 4-10. Bat diversity across the United States (Source: Cryan 2008, used with permission).

that may be impacted by ridgeline wind turbines are not limited to those species that breed in North Carolina. The Southern Blue Ridge Ecoregion follows the Appalachian migration corridor, which supports significant aggregations of raptors during migration. Over 20 species of raptors, from golden eagles (*Aquila chrysaetos*) and Northern harriers (*Circus cyaneus*) to red-tailed hawks (*Buteo jamaicensis*) and Northern goshawk (*Accipiter gentilis*), use this corridor during the spring and fall. During a fall 2009 hawk count at the Ashland Nature Center, 18 species and over 13,000 individual raptors were counted (HMANA 2010). Specific considerations for the impacts of ridge wind turbines on raptors will be critical to siting and impact assessments in this region.

The negative impact of wind development on bats in the Southern Blue Ridge Ecoregion is also of concern. The western portion of the state has localized regions of fairly high diversity compared to other states in the southeast (Figure 4-10). The NCWRC has identified seven bat species of greatest conservation need that regularly use this region for breeding, migration, or hibernation (Table 4-7). All seven species have state listing status and one (Indiana bat) is listed as federally endangered (range map: Figure 4-11). The Southern Blue Ridge Ecoregion may also be an important migratory corridor for a number of other bat species of regional significance. For example, turbine-sensitive tree bats such as silver-haired (*Lasionycteris noctivagans*), hoary (*Lasiurus cinereus*,) and Eastern/Western red (*Lasiurus borealis and Lasiurus blossevillii*) bats have distributions that range across North Carolina and may use the Appalachian corridor as a migratory route (Figure 4-12). In addition, the federally endangered gray bat (*Myotis grisescens*), and the Ozark and Virginia big-eared bats (*Corynorhinus townsendii ingens* and *C. townsendii virginianus*) have distributions that cross the Southern Blue Ridge Ecoregion (Figures 4-13 and 4-14), and North Carolina may play an important regional role in their conservation.

Table 4-7. Priority bat species identified in the NC WAP that occur in habitat types in the Southern Blue Ridge Ecoregion.

Scientific Name	Common Name	State Status (Federal Status)	Habitat type			
			Northern Hardwood Forest	Low Elevation Cliffs/Rock Outcrops	Caves and Mines	Montane Floodplain Forest
Corynorhinus rafinesquii	Rafinesque's Big-eared Bat	T			X	
Corynorhinus townsendii virginianus	Virginia Big-eared Bat	E (E)			X	
Lasionycteris noctivagans	Silver-haired Bat	SR	X			
Myotis grisescens	Gray Bat	E (E)			X	
Myotis leibii	Small-footed Bat	SC		X	X	
Myotis septentrionalis	Northern Long-eared Bat	SC		X	X	
Myotis sodalis	Indiana Bat	E (E)			X	X

Photo: Gray bat (Myotis grisescens), *Adam Mann, Environmental Solutions and Innovations*
www.fws.gov/midwest/endangered/mammals/grbat_fc.html

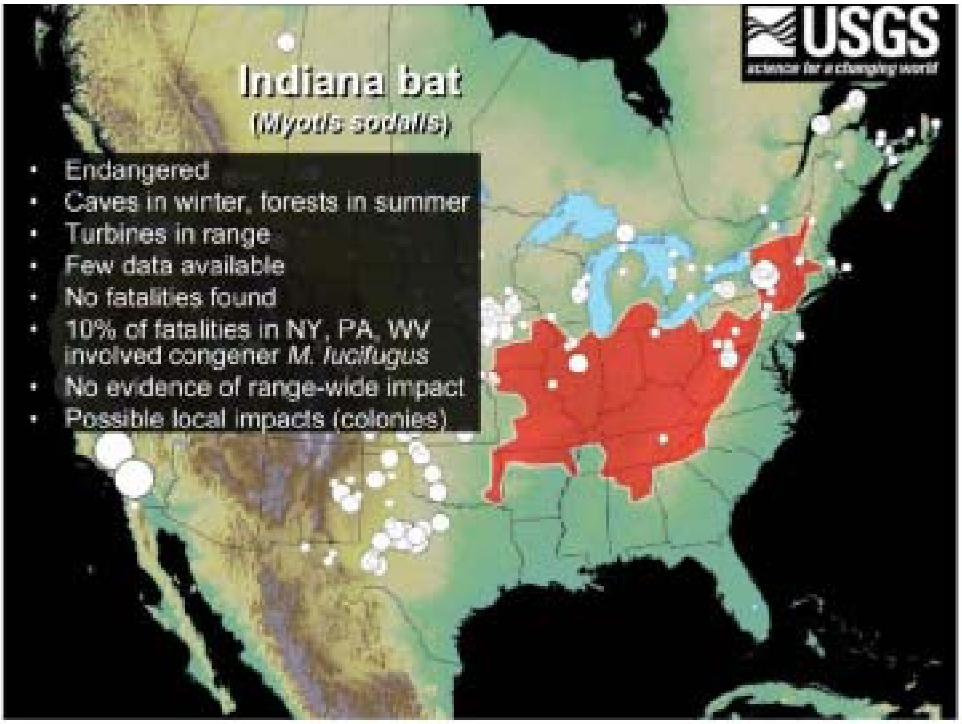

Figure 4-11. Range of the Indiana bat (*Myotis sodalis*). White circles indicate the location of wind energy sites as of 2007, with circle size representing production: 1-100 megawatts (smallest), 100-300 Mw, 300-500 Mw, and (largest) 500-700 Mw. Since this map was produced, a carcass of this species was found beneath a wind turbine in Indiana in early 2010 (P. Cryan, personal communication; Source: Cryan 2008, used with permission).

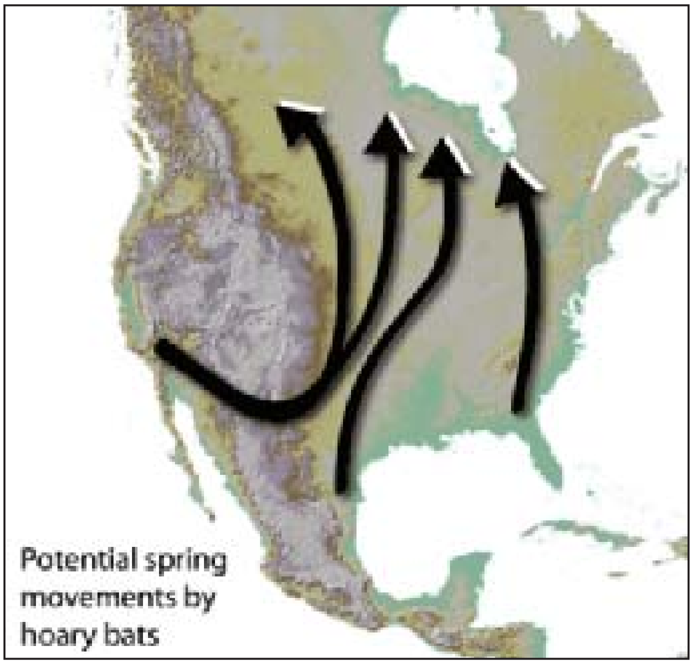

Figure 4-12. Path of potential spring migration for hoary bats in North America (Source: Cryan 2010, used with permission).

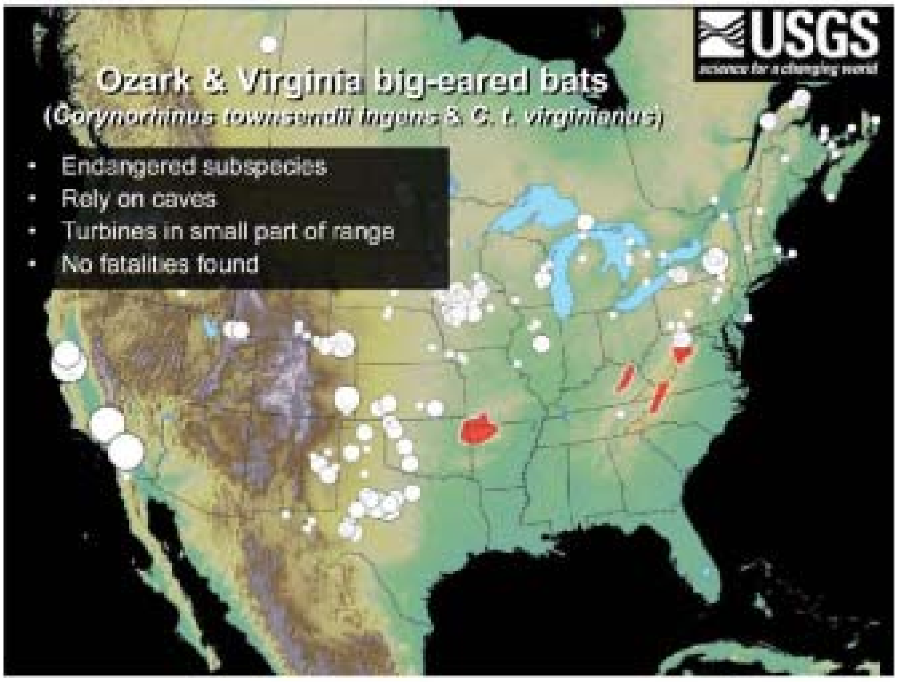

Figure 4-13. Range of Ozark and Virginia big-eared bats (*Corynorhinus townsendii ingens* and *C.t. virginianus*). White circles indicate the location of wind energy sites as of 2007, with circle size representing production: (smallest) 1-100 megawatts, 100-300 Mw, 300-500 Mw, and (largest) 500-700 Mw. (Source: Cryan 2008, used with permission).

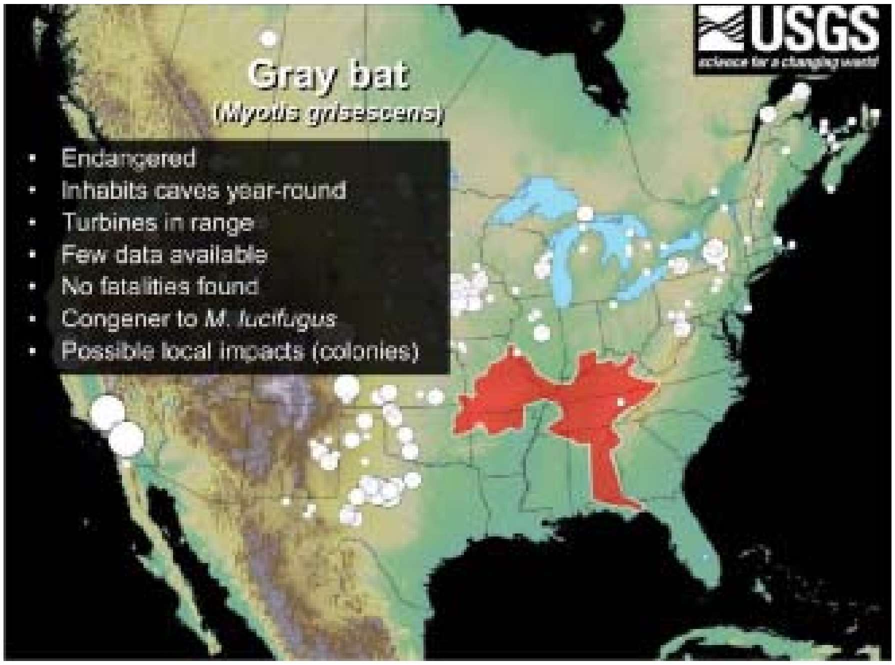

Figure 4-14. Range of Gray bat (*Myotis grisenscens*). White circles indicate the location of wind energy sites as of 2007, with circle size representing production: (smallest) 1-100 megawatts, 100-300 Mw, 300-500 Mw, and (largest) 500-700 Mw. (Source: Cryan 2008, used with permission).

Significant wind potential also exists off of the coast of North Carolina, however research on the impacts of off-shore and near-shore wind energy development on pelagic and migrating birds, marine mammals, and reptiles is quite limited. Offshore waters off the North Carolina coast provide one of the richest and most important areas for pelagic birds in the western Atlantic, while inshore waters provide important foraging areas for a variety of birds all months of the year (Manning 2004). Although the management of pelagic bird falls under a variety of jurisdictions in North Carolina, the NC WAP identified 23 priority species for the southeastern U.S. including black-capped petrel *(Pterodroma hasitata)*, Manx shearwater *(Puffinus puffinus)*, and the federally endangered Bermuda petrel *(Pterodroma cahow)*. Although the USFWS has management jurisdiction over pelagic birds, cold inshore waters are a critical zone during winter for gannets, loons, and alcids. Placement of wind turbines in both off-shore and near-shore areas may have a significant impact on these species at that time. Many species associated with beach and dune habitats will utilize both open waters and in-shore areas for foraging and may also be impacted by wind turbine development. The NC WAP identifies 13 priority avian species that rely on beach and dune habitats, including sanderling *(Calidris alba)*, red knot *(Calidris canutus)*, and American oystercatcher *(Haematopus palliatus)*. Five sea turtles are also associated with this region, including loggerhead *(Caretta caretta)*, leatherback *(Dermachelys coriacea)*, and green *(Chelonia mydas)* turtles. Finally, North Carolina's barrier islands offer an important stopover for thousands of shorebirds during their long migrations to rest, forage, or spend the winter (Dinsmore et al. 1998).

Promoting and developing alternative energy is an important part of any state's climate change adaptation portfolio. While it is readily apparent that wind energy can and does have impacts on the avian and natural communities, those impacts may be mitigated or avoided with careful and thorough research of potential sites, and by learning from the experiences of other wind development efforts across the country. State agency staff may become involved in reviewing potential impacts of wind on public or private lands through the National Environmental Policy Act or North Carolina's Environmental Policy Act or because of specific expertise (for a review of regulatory context for wind development in NC see Appendix C). Recent recommendations from the USFWS Wind Turbines Guidelines Advisory Committee (WTGAC) provide a framework for developing effective measures to avoid or minimize impacts to wildlife and their habitats related to land-based wind energy facilities Although the draft guidelines are currently in review, they are expected to achieve the following (WTGAC 2009):

Photo: Red Knot, www.thinkstock.com

1. Provide a consistent methodology for conducting pre-construction risk assessments and post-construction impact assessments to guide siting decisions by developers and agencies.

2. Encourage communication and coordination between the developer and relevant state and federal agencies during all phases of wind energy project development.

3. Provide mechanisms to encourage the adoption and use of the guidelines by all federal agencies, as well as the wind energy industry, while recognizing the primary role of the lead agency in coordinating specific project assessments.

4. Complement state and tribal efforts to address wind/wildlife interactions and provide a voluntary means for these entities to coordinate and standardize review of wind projects with the USFWS.

5. Provide a clear and consistent approach that increases predictability and reduces the risk of liability exposure under federal wildlife laws.

6. Provide sufficient flexibility to accommodate the diverse geographic and habitat features of different wind development sites.

7. Present mechanisms for determining compensatory mitigation, when appropriate, in the event of unforeseen impacts to wildlife during construction or operation of a wind energy project.

8. Define scientifically rigorous and cost-effective study designs that improve the ability to predict direct and indirect wildlife impacts locally and regionally.

9. Include a formal mechanism for revision in order to incorporate experience, technological improvements, and scientific advances that reduce uncertainty in the interactions between wind energy and wildlife.

These voluntary guidelines for land-based turbines, coupled with the recent recommendations for monitoring the impacts of marine mammals and seabirds (Thaxter and Burton 2009), offer a comprehensive approach to appropriate siting for wind energy development.

4.2.3 Biofuel Development

Biofuels are combustible materials that are derived from biomass (e.g. plants, micro-organisms, or organic waste) and potentially offer an alternative energy source that is economically efficient, socially equitable, and environmentally sound (Bringezu et al. 2009). There are a number of different types of biofuels that are often categorized into 'generations' based on the number of steps it takes to generate usable fuel from the source (Bringezu et al. 2009, Table 4-8). Each of these types of biofuels is created from different feedstocks, ranging from sunflower and sugarcane to wood and algae, and thus requires different processing techniques and technology. The potential impact of biofuel production on biodiversity conservation will depend on the source of feedstock and the technology required for processing, as well as indirect changes in land use that result from use of the feedstock for fuel.

Ethanol, the most common first generation biofuel, is widely used as a gasoline additive in the United States and is growing in demand as renewable fuel standards have increased (RFA 2010). In 2006, the U.S. became the leading fuel ethanol producer (Bringezu et al. 2009) and since that time the number of biorefineries has tripled (RFA 2010). Most of the ethanol produced in the U.S. is produced from corn (RFA 2010), although interest in alternative sources such as switchgrass and other woody biomass is increasing (Bringezu et al. 2009). Because growing corn requires large amounts of fertilizers, pesticides, and fossil fuel inputs for distillation, the environmental benefits of corn ethanol may not outweigh the costs.

North Carolina's long growing season is conducive the production of a wide range of biomass resources for alternative energy production, an initiative which the agricultural leadership generally supports (BCNC 2010). The North Carolina Grows Biofuels project is a statewide effort to determine the extent and potential of biomass for biofuels production in the state (BCNC 2010). Energy crops and fast-growing

Table 4-8. Types of biofuels (Source: Bringezu et al. 2009, © United Nations Environment Programme)

Table 2.1: **Types of biofuels – overview with basic technologies, important feedstocks and examples of co-products**

Biofuel	Basic technology	Feedstocks	Co-products
Solid biofuels *	Traditional use of dried biomass for energy	Fuel wood, dried manure	
First generation biofuels			
Plant oils **	1) As transport fuel: Either adaptation of motors to the use of plant oils; or modification of plant oils to be used in conventional motors 2) For generation of electricity and heat in decentralised power resp. CHP stations	1) Rapeseed oil, sunflower, and other oil plants, waste vegetable oil 2) Rapeseed oil, palm oil, jatropha, and other oil plants	Oilcake as animal feed
Biodiesel	Transesterification of oil and fats to provide fatty acid methyl ester (FAME) and use as transport fuel	- Europe: Rapeseed, sunflower, soya - USA: Soya, sunflower; - Canada: Soya, rapeseed (Canola) - South- and Central-America: Soya, palm, jatropha, castor - Africa: Palm, soya, sunflower, jatropha - Asia: Palm, soya, rapeseed, sunflower, jatropha	- Oilcake as animal feed; - Glycerine; - Oilcake in some palm oil mills used for energy recovery
Bioethanol	Fermentation (sugar); hydrolysis and fermentation (starch); use as transport fuel	- USA: Corn - Brazil: Sugar cane - Other South- and Central-America: Sugar cane, cassava - Europe: Cereals, sugar beets - Canada: Maize, cereals; - Asia: Sugar cane, cassava; - Africa: Sugar cane, maize	- Maize and cereals yield animal feed DDGS (Dried Distillers Grains with Solubles). - Sugar cane bagasse is used for energy recovery
Biogas (CH_4, CO_2, H_2)	Fermentation of biomassused either in decentralised systems or via supply into the gas pipeline system (as purified biomethane); 1) For generation of electricity and heat in power resp. CHP stations 2) As transport fuel: either 100% biogas fuel or blending with natural gas used as fuel	Energy crops (e.g. maize, miscanthus, short rotation wood, multiple cropping systems); biodegrable waste materials, including from animal sewage	Residues used as fertiliser (nutrient recycling)
Solid biofuels	1) Densification of biomass by torrefaction or carbonisation (charcoal); 2) Residuals and waste for generation of electricity and heat (e.g. industrial wastes in CHP)	Wood, grass cuttings, switchgrass; grains; charcoal, domestic refuse, and dried manure	

Table 4-8. Types of biofuels (Source: Bringezu et al. 2009, © United Nations Environment Programme)

Second generation biofuels			
Bioethanol	Breakdown of cellulosic biomass in several steps incl. hydrolysis and finally fermentation to bioethanol	Ligno-cellulosic biomass like stalks of wheat, corn stover and wood; special-energy-or-biomass crops (e.g. Miscanthus); sugar cane bagasse	
Biodiesel and range of "designer"-biofuels such as biohydrogen, biomethanol, DMF***, Bio-DME****, mixed alcohols	Gasification of low-moisture biomass (<20% water content) provides "syngas" (with CO, H_2, CH_4, hydrocarbons) from which liquid fuels and base chemicals are derived	Ligno-cellulosic biomass like wood, straw, and secondary raw materials like waste plastics	Fischer-Tropsch synthesis can be used to produce various feedstocks for chemical industry (not only for fuel but also e.g. plastics)
Third generation biofuels			
Biodiesel, aviation fuels, bioethanol, biobutanol	Bioreactors for ethanol (production can be linked to sequestering carbon dioxide from power plants); Transesterification and pyrolysis for biodiesel; other technologies under development	Marine macro-algae micro-algae in ponds or bioreactors	High-protein animal feed,biopolymers, agricultural fertilisers

*Traditional use of biomass included for complete overview

**Also known as straight vegetable oil. Plant oil used as direct fuel in transport is common in German agriculture with about 838,000 tonnes mostly rapeseed oil in 2007, representing 1.4% of total fuel consumption in transport.

***2,5-Dimethylfuran.

****Dimethyl ether

Source: own compilation after different sources trees, and the technologies needed to convert them, are currently being field tested at the BCNC Biofuels Campus and at 20 research stations across North Carolina in partnership with the North Carolina Department of Agriculture and NC State University (Figure 4-15, BCNC 2010). North Carolina already meets 4% of its energy needs using biomass, ranking eighth nationwide in biomass utilization (Rich 2007). The majority of this biomass energy comes from wood-fired boilers and landfill gas-to-energy projects, but a small and increasing amount is derived from biofuel production.

In an effort to ensure ecologically responsible development of biofuels, the Biofuels Center of North Carolina (BCNC) has partnered with the North Carolina Department of Environment and Natural Resources to determine the environmental impact biofuels technology and their suitability for long-term development in the state (BCNC 2010). In addition, the BCNC is partnering with the Environmental Defense Fund (EDF) to develop a responsible economic framework for developing biomass resources in North Carolina. As a critical first step, EDF and BCNC created "*Envisioning North Carolina's Biomass Future - A framework for thought and action"* (EDF/BCNC 2009), which outlines the vision, core principles, policy considerations, and recommendations to achieve a sustainable biomass industry in North Carolina.

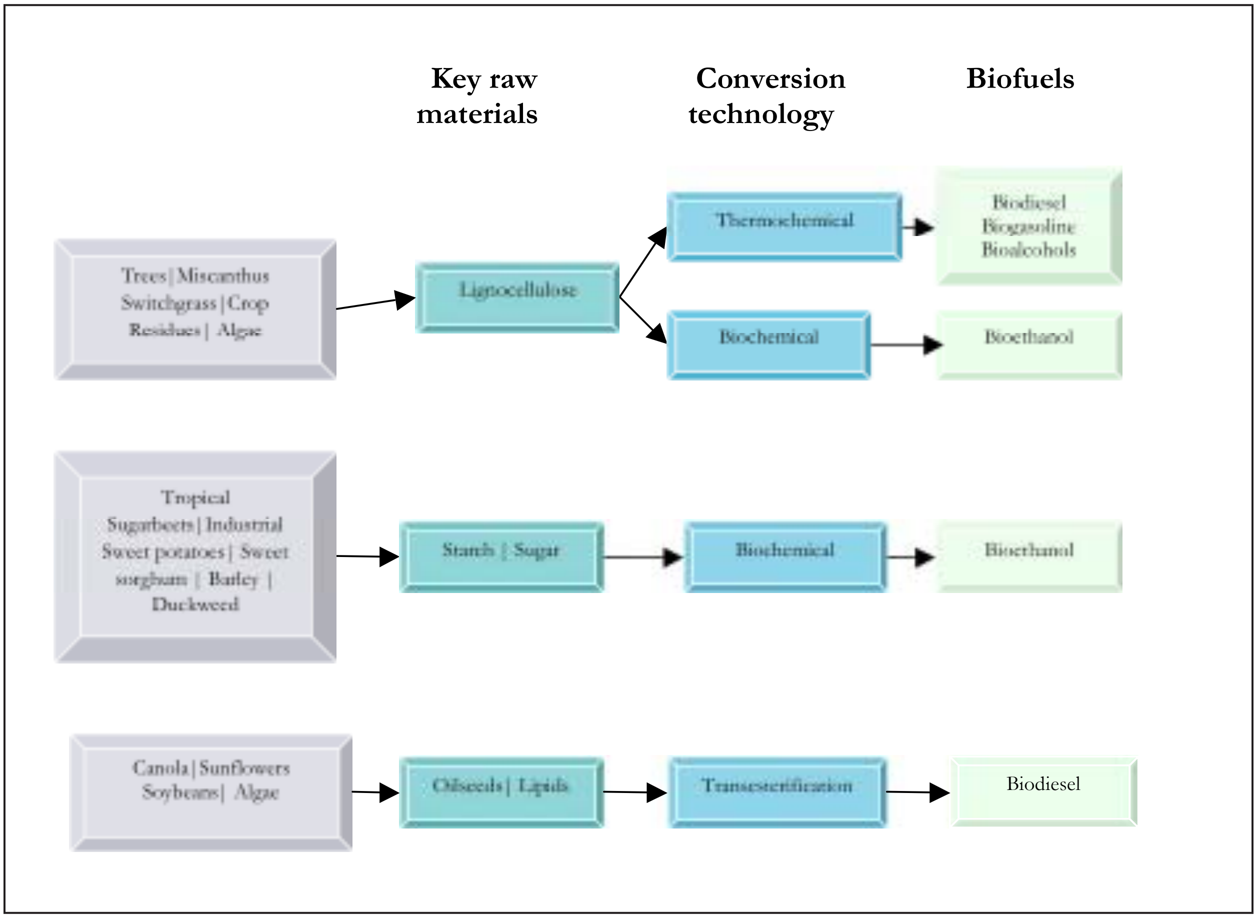

Figure 4-15. Energy crops currently being field-tested in North Carolina for economic viability, and the possible technologies that could lead to biofuels production in this state (Based on "Biomass to Biofuels" (BCNC 2010).

Potential Impacts of Biofuel Development on Species and Habitats

The development of a biofuels economy can have an impact on species and habitats at multiple stages of production, from land conversion for biofuel feedstocks and the logistics of harvest, to treatment and transportation from field to refinery (Dale et al. 2010). Increased biofuel is associated with clearing native habitat, displacing agricultural activities into new areas, and an increasing likelihood of alien species introductions. As demand for ethanol increases and corn prices rise, expanding corn acreage could decrease area available for wildlife. Additionally, the building of refineries and their associated infrastructure can change the economic dynamics of rural areas, and thus influence changes in land-use that may impact wildlife and habitat.

Although corn is the dominant feedstock currently used in the U.S. for biofuel, current research suggests that there are important environmental drawbacks. For example, Pimental and Pitzek (2005) found that the energy outputs from ethanol produced using corn, switchgrass, and wood biomass were each less than their respective fossil energy inputs. For wildlife, corn monocultures offer few habitat benefits and may exacerbate the impact of fertilizers and pesticides on aquatic systems. Thomas et al. (2009) modeled the water quality impacts of shifting from a corn-soybean rotation to more corn-intensive rotations to simulate increasing demand for biofuels in Indiana. They found that, when managing for continuous corn production, mean annual erosion was significantly greater than in corn-soybean rotation systems. In conventional agriculture with high levels of chemical inputs, erosion leads to water quality degradation as a result of agrochemicals attaching to soil particles and washing into local waterways (Thomas et al. 2009). These agrochemicals may persist in soil sediments or biomagnify and accumulate as toxins in the food chain.

Some researchers have suggested that the push to develop and grow biofuel feedstocks may change the way land is used in the U.S., while other studies have demonstrated that biofuel targets can be met with relatively minor adjustments (Dale et al. 2010). Of particular concern is the conversion of currently protected land to monoculture biofuel production. Fargione et al. (2008) have argued that the conversion of rainforests, peatlands, savannas, or grasslands would result in 17 to 420 times more carbon dioxide being released than the annual greenhouse gas reductions that these fuels would provide from displacing fossil fuels. A recent paper by Eggers et al. (2009) found that increasing European Union biofuel production targets may have, on balance, a negative impact on biodiversity. They suggested that more of the 313 wildlife species they analyzed would suffer from habitat losses, though the magnitude of impacts varied spatially and with the feedstock type (Eggers et al. 2009). In this same study, woody crops (lignocellulosic) were found to be less detrimental to wildlife than arable crops. Although cellulosic ethanol is not currently cost-competitive, the Department of Energy (DOE) is investing in biorefineries that will produce more than 130 million gallons of cellulosic ethanol per year and projects that cellulosic ethanol will be cost-competitive with gasoline by 2012 (DOE 2007).

These impacts may differ in the United States. Kline and Dale (2008) argue that enough land is available for biofuel production in the U.S., and that strategically using previously cleared or other marginal lands would actually enhance environmental and economic sustainability. However, some conservationists are concerned about the potential conversion of privately-owned land that is currently enrolled in federal habitat conservation programs to switchgrass or other monocultures for biofuel production (Kline and Dale 2008). As the financial benefits of biofuel production increase, the incentives to keep privately-owned land in federal conservation programs may diminish. Over 300 million acres (25 million of which are dominated by grasses) are currently enrolled in

Photo: www.nj.nrcs.gov

the USDA Conservation Reserve Program (CRP) which pays farmers an annual rental rate for retiring land from crop production and planting it for wildlife cover (USDA 2010). According to the Conservation Effects Assessment Project (CEAP), CRP land is vital part of grassland bird conservation, and also provides important wildlife benefits for reptiles, amphibians, and pollinators (USDA 2010). Unfortunately, almost 60% of the current active acreage in CRP will see contracts expire by the end of 2013 (USDA 2010). If rental rates are far lower than the potential profit from growing biofuels, landowners may abandon their enrollment in CRP at the end of their contract. A loss of land that is federally contracted to prohibit disturbance during the breeding season and encourage other wildlife uses could significantly impact the conservation of grassland species.

If land that is currently being used to grow corn were instead used to produce other types of biomass for fuel, there may be a net environmental benefit, as fewer agrochemical inputs and less water may be needed. For example, switchgrass requires less nitrogen and phosphorous input than corn (Pimentel and Patzek 2005, Schmer et al. 2008). A reduction in these inputs could reduce aquatic blooms and downstream hypoxia that negatively impacts fish and their associated habitats. In addition, growing bioenergy crops where irrigation is not required could result in a net environmental benefit, particularly for water quality (Kline and Dale 2008). However, the likelihood of landowners converting corn acreage to other fuel crops given the high prices and demand for corn ethanol is still an open question.

Although the threat of habitat loss due to agricultural conversion and loss of CRP lands is widely acknowledged as an impact from biofuel expansion, the potential of increased risk to native habitats by introduced species has received less attention (IUCN 2009). Many of the plant species that are currently being considered for biofuels, such as ligno-ceullulosic feedstocks and inedible plant oils, are potentially invasive and may impact native habitats (IUCN 2009). Although these risks are most pronounced in areas where other impacts, such as drought or fragmentation, are already apparent (e.g. east and southern Africa, IUCN 2009) it will be important for natural resource agencies to consider the invasive properties of plants that are candidates for biofuel production. The IUCN (2009) provides specific guidelines on how to assess invasive potential, including five key recommendations for reducing the risks of biological invasions as a result of biofuel production (Box 4-4).

A sustainable and economically responsible biofuel industry will require forethought and careful planning to balance diverse demands for land (Kline and Dale 2008). The Council on Sustainable Biomass Production (CSBP) has developed comprehensive voluntary standards for the production of biomass and its conversion to bioenergy (CSBP 2010). These standards provide criteria for biological diversity, soil, water, and business practices, in an effort to create a third-party certification program. Growers participating in the effort are required to adhere to production and management guidelines that contribute to the conservation or enhancement of biological diversity, in particular native plants and wildlife (CSBP 2010). These efforts provide a valuable template for evaluating the various tradeoffs and benefits for biofuel production that could be used at the state level.

Potential Impacts on Species and Habitats in North Carolina

Rich (2007) suggest that North Carolina could meet at least an additional 10% of its energy consumption needs by including forest (6 %), agricultural (1%), and waste (3 %) biomass resources in the state's energy portfolio. The production potential for these resources is distributed throughout the state and could include lands that are currently being used for timber production and agriculture, or lands in the CRP. In fact, Rich (2007) included the conversion of 104,000 acres of conservation land to switchgrass and hybrid poplar in their analysis of potential energy production for the state. The unsustainable use of forestlands or the conversion of CRP lands to use for biofuel production has the potential to negatively affect wildlife and habitat in North Carolina. Figure 4-16 shows that a number of counties in North Carolina with high potential for biomass production also have large amounts of acreage in CRP contracts.

Working forests provide a number of ecosystem services including energy production, recreation, wildlife habitat, and carbon sequestration. Hardwoods cover a significant portion of the state of North Carolina (Figure 4-17), and according to Rich

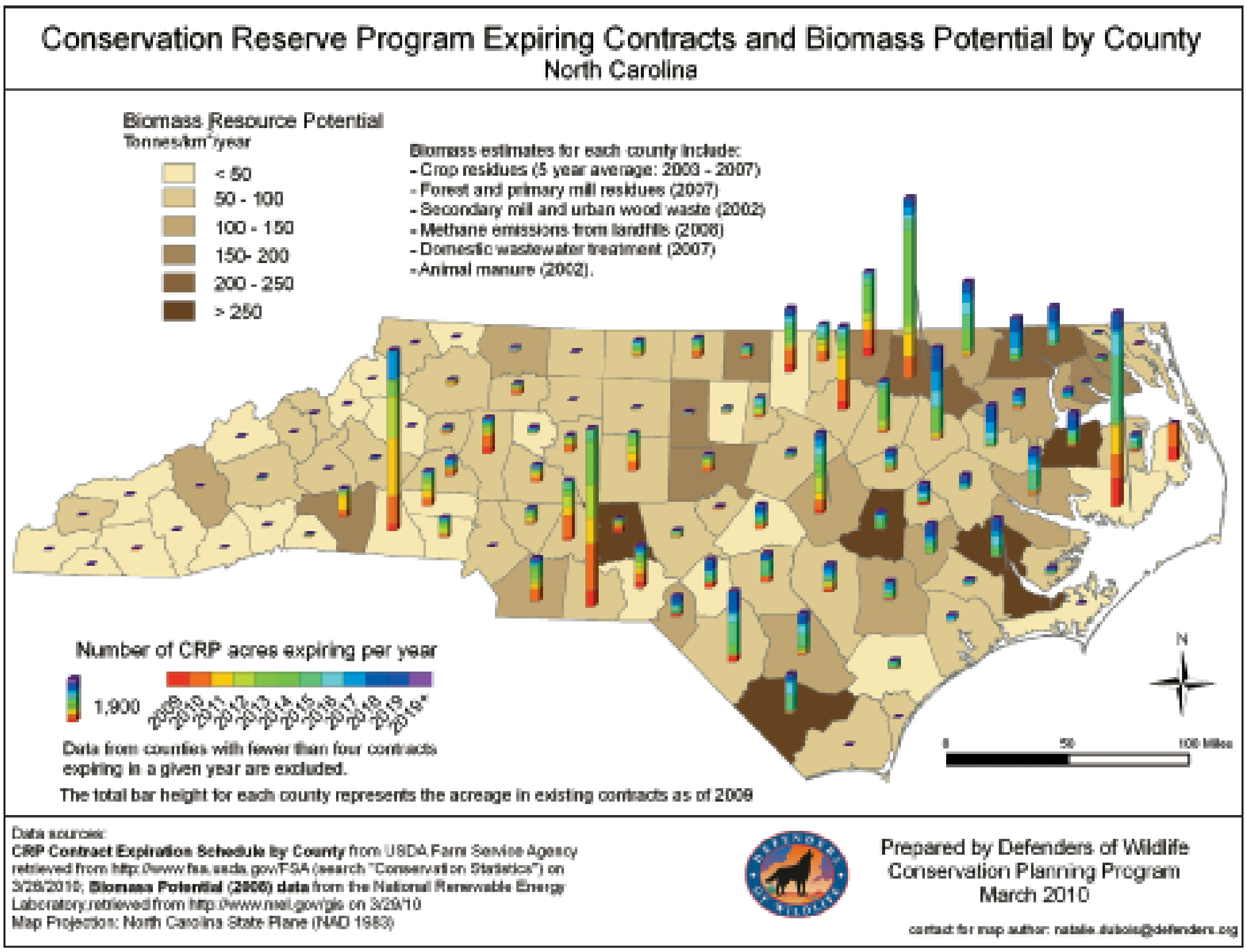

Figure 4-16. Conservation Reserve Program expiring contracts and biomass potential by county in North Carolina. Dark shaded counties have higher biomass resource potential. The height of the bar in each county indicates the acreage in existing contracts as of 2009 (expiration dates are color coded within the bar).

et al. (2007), have the potential to make up 24% of the state's biomass resources. The NC WAP identifies Northern hardwoods, and associated birch/beech/maple communities, as an important habitat type for numerous wildlife species. Over 30 bird, mammal, and amphibian priority species are associated with northern hardwoods, including the threatened Northern saw-whet owl (*Aegolius acadicus*), the endangered Northern flying squirrel (*Glaucomys sabrinus*), and Weller's salamander (*Plethodon welleri*), a species of special concern. In addition, Appalachian cove hardwood forests, and associated subtypes, represent some of the most diverse ecosystems in the world (Hunter et al. 1999). As identified in the NC WAP, this habitat type supports 33 SGCN including the brown creeper (*Certhis Americana*) (special concern), the endangered green salamander (*Aneides aeneus*), the Eastern hog-nosed snake (*Heterodon platirhinos*), and the long-tailed weasel (*Mustela frenata*). In the southern Blue Ridge and Piedmont ecoregions, oak and oak-pine forest dominate (NC WAP) and support a wide variety of important SGCN including golden-winged warblers (*Vermivora chrysoptera*), Eastern fox squirrel (*Sciurus niger*), four-toed salamander (*Hemidactylium scutatum*), and Northern pinesnake (*Pituophis melanoleucus*). Hardwood habitats are also severely threatened by development and non-native pathogens such as the woolly adelgic, gypsy moth, and beech scale. Careful planning and management in hardwood forests will need to evaluate potential impacts on SGCN to ensure biofuel production does not exacerbate these threats.

Softwoods have the potential to make up 21% of North Carolina's biomass resources (Rich et al. 2007). There are over 1 million acres of industrial timber pine plantations in the Coast Plain (NC WAP). Harvest strategies have generally provided high quality habitat for a number of SGCN species, including worm-eating warbler (*Helmitheros vermivorous*) and Eastern wood-peewee (*Contopus vierns*), but do not usually support high quality longleaf pine because of fire suppression. Endangered red-cockaded woodpecker (*Picoides borealis*), timber rattlesnake (*Crotalus horridus*) (Special Concern) and Seminole bat (*Lasiurus seminolus*), have all been identified as priority species that may be associated with

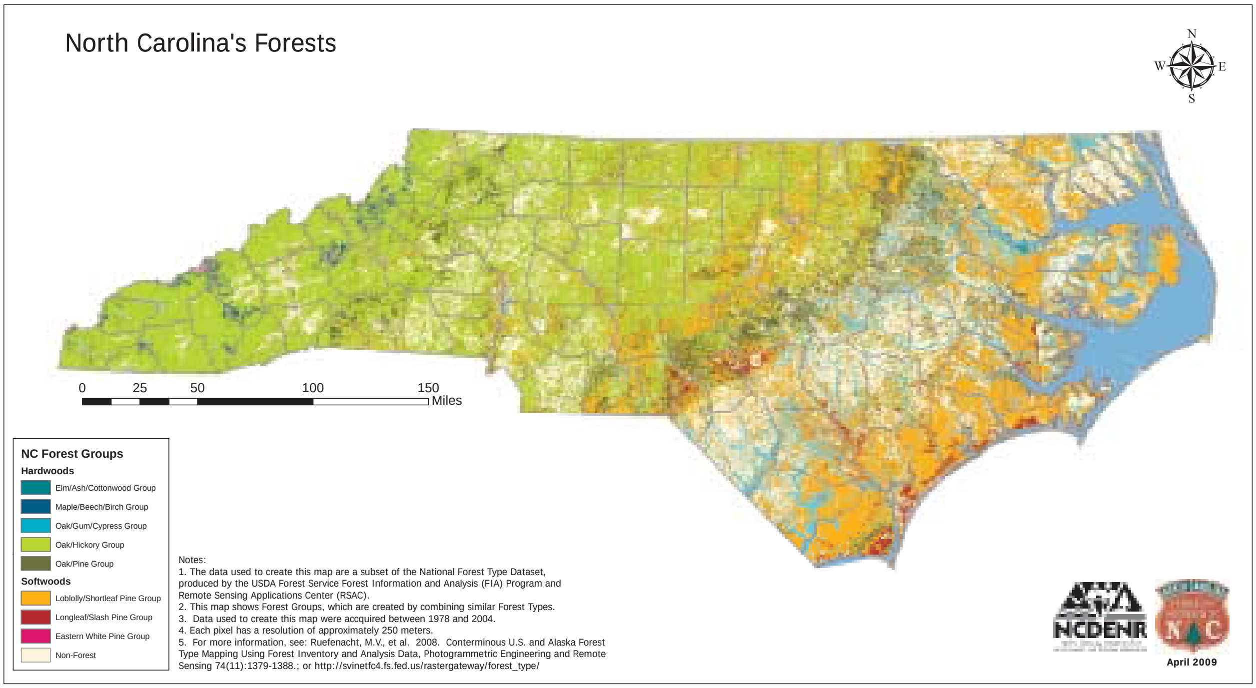

Figure 4-17. Map of forest resources for North Carolina (Source: North Carolina Di vision of Forest Resources 2009).

this habitat. However, loblolly/slash pine forest in North Carolina is mostly made up of planted, rather than natural, pine stands (NC WAP). Conservation actions identified in the NC WAP include management and protection of non-longleaf pine woodlands with easements, acquisitions, and the re-introduction of fire. However, areas where industrial timber harvesting is already occurring will be likely candidates for biomass production. Evaluating the relative importance of competing resource needs will be a critical factor in planning North Carolina's biofuel production future.

While biomass production can have impacts on important wildlife habitats, those impacts may be mitigated or avoided with sustainable natural resources planning. Although the U.S. has only recently begun to consider woody biomass as a source of fuel, European countries such as Denmark, Norway, and Sweden have been using this source of fuel for more than 30 years (Buford and Neary 2010). Criteria for sustainability that have been developed by some of these countries can be used as preliminary guidelines for woody biomass in the United States. For example, Sweden's Forestry Stewardship Council (SFSC) promotes environmentally sound, socially beneficial, and economically sustainable forest management (Buford and Neary 2010). Over one third of the country's forests have been certified under the SFSC criteria, which includes specific measurable targets including biodiversity, soil/water balance, and regeneration (Box 4-4). The potential for multi-sector state agency involvement in developing and implementing certification criteria can provide opportunities to develop a sustainable biomass economy that minimizes negative impacts to wildlife and habitat.

Box 4-4. SFSC sustainable forestry criteria examples

- **Follow a precautionary approach when choosing feedstocks:** Species should be chosen that minimize the risks to ecosystems and livelihoods from invasion, either by the feedstock species, or associated pests and diseases. Developers should also account for the possible costs of an invasion when choosing species.
- **Work with stakeholders to build capacity:** Existing regulations are often robust enough in theory to reduce and contain risks of invasions. The main barrier to their effective enforcement and success comes from a lack of capacity and understanding for the need to follow best practices.
- **Comply with local, national and regional regulations:** Regulations add an administrative and financial burden to developers, but they exist to safeguard the environment, the livelihoods of local communities, and the long-term financial sustainability of projects.
- **Develop and follow EMPs:** Develop appropriate Environmental Management Plans (EMPs) that account for the full range of risks and specify actions to manage the site of production in such a way as to minimize the risk of escape and invasion of surrounding areas, and deal effectively with any potential or actual resulting invasion.
- **Extend planning, monitoring and assessments beyond the field:** Consider developments within the wider context of the landscapes and ecosystems in which they are situated. Risks may extend beyond the site of production especially where adjacent areas may be more susceptible to invasion and the dispersal mechanism enables species to spread beyond the immediate site of a project. Thus, adopting an ecosystem approach when planning developments is preferable to only considering the risks posed by individual species.

4.3 Invasive Species

The impacts of invasive species on native plants, animals, and ecosystems are well documented (e.g., Mack et al. 2000, Mooney and Cleland 2001, Strauss et al. 2006). Invasive species compete with native species for resources, decrease forage quality, alter community structure and ecosystem processes such as nutrient cycling and fire regimes, cause genetic hybridization, increase predation, cause mortality through disease and pest outbreaks, foul and clog waterways, and impact human health as well as economic well being. These threats are recognized in the NC WAP, which states that, "Non-native and invasive species introductions (both plant and animal) continue to pose a threat to native wildlife in North Carolina." In the future, the threat from invasive plants and animals may increase. Climate change and changes in atmospheric CO_2 have been found to benefit some invasive species, potentially leading to further increases the number and types of invasive species present in different ecosystems (Dukes and Mooney 1999).

Climate changes can benefit invasive species if those changes facilitate increased success at any stage of their life cycle. To become successfully invasive in a new region and spread across the landscape, non-native species must pass through a variety of environmental filters at different temporal and spatial scales (Theoharides and Dukes 2007). Success at each of these stages depends on a distinct set of mechanisms, some of which are likely to be affected by climate change (Rahel and Olden 2008). The stages of invasion include species transport, colonization, establishment, and landscape spread (Figure 4-18). To enter a new region, an invasive species must first be transported over long distances and natural barriers, usually as a result of anthropogenic activities. Upon arrival to a new location, local environmental conditions, resource availability, biotic interactions and demographic processes control whether a species colonizes and establishes in the new community. Invasive species that are more successful in establishing and becoming abundant in a community will likely have the largest ecological impact on that community. Landscape spread occurs as invasive species establish in new locations.

Hellman et al. (2008) outline five potential consequences of climate change for invasive species. These include (1) changes to mechanisms of transport and introduction, (2) altered climatic constraints on invasive species, (3) shifts in distribution of existing invasive species, (4) changes in the impact of existing invasive species on the system, and (5) altered effectiveness of management strategies for controlling invasive species. Changes affecting transport and introduction will pose direct consequence to the first stage in the invasion pathway, whereas changes to climatic constraints can directly impact processes regulating colonization, establishment, and/or spread. Effects on distribution, impact, and management strategies may then emerge from climate-induced changes to establishment and/or spread.

Human-aided movement of plants and animals, both accidental and deliberate, has increased dramatically in the last 500 years, and especially the last two centuries, with increasing human transport and commerce (Mack et al. 2000). Climate change could increase opportunities for invasions of non-native species across the globe by opening up new travel routes and destinations. For example, thinning of the Arctic sea ice could lead to open summer waterways and a longer shipping season by the year 2040, potentially leading to an increase in introductions of non-native species (Pyke et al. 2008). Tourism and commerce may also shift as patterns for recreation and regional use become altered by climate change. Increases in the frequency of extreme weather conditions such as hurricanes or changes in weather patterns could facilitate the dispersal and introduction of invasive species to areas that were previously less exposed to introduction events (Hellmann et al. 2008).

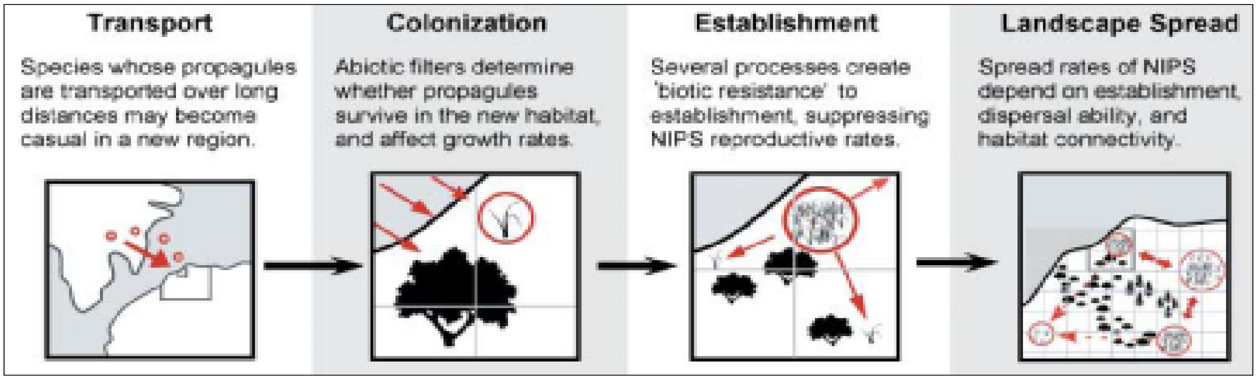

Figure 4-18. The four stages of invasion and the factors affecting non-native (nonindigenous) plant species (NIPS) success at each stage. The same processes control invasive animal and disease introductions, and could apply to native species that become invasive as a result of range expansion under climate change (Source: Theoharides and Dukes 2007, © Wiley InterScience, used with permission).

Under climate change, current climatic constraints that limit some species' ability to spread will be reduced such that previously benign non-native or current invasive species may pose new or altered threats (Hellmann et al. 2008). Such constraints include factors limiting the length of the growing season, temperature requirements for periods of dormancy, or moisture tolerances. Warmer temperatures or changes in precipitation may alter these constraints, thereby changing the competitive interactions between native and non-native species. Those species tolerant of high temperatures, drought conditions, or more frequent disturbances may do particularly well under climate change. For example, in the Great Lakes region, populations of the common reed *(Phragmites australis*), which is listed as a severe threat in North Carolina, expanded with higher than average temperatures and declines in water levels (Wilcox et al. 2003). Further warming and/or increased drought may give this species an advantage over native marsh species, especially in disturbed environments.

Climate change may affect the population densities of some invasive species, thereby altering their impact on native species within their current range (Hellman et al. 2008). For example, colder winter temperatures are associated with lower reproductive activity and lower overwinter survival in nutria (Willner et al. 1979). Already, nutria have significant impacts on wetland vegetation (Fuller et al. 1984, Taylor and Grace 1995, Evers et al. 1998), and projected increases in winter temperatures could favor overwinter survival and increased reproductive rates, resulting in additional herbivory pressure on marsh communities. Many of the traits that allow rapid colonization and establishment in invasive species are the same traits that make a species least at risk to climate change (see Table 1-2). Native species may have the potential to become invasive when they spread into new locations as a result climate change (Mueller and Hellmann 2008). One example is the mountain pine beetle (*Dendroctonus ponderosae*). Historically, the range of the mountain pine beetle has been limited by cold temperatures at higher altitudes and latitudes that prevent the beetle from completing its life cycle in a single season. However, warmer temperatures in recent years have allowed the beetle to complete its life cycle in a single season. The resulting expansion in the beetle's range has exposed new species of trees to pine beetle infestation and produced epidemic breakouts in existing and new environments (Carroll et al. 2003, Logan and Powell 2001).

Managers often employ a combination of mechanical, chemical, and biological tools to combat invasive species. Some studies predict that invasive species may increase their tolerance of chemical tools such as herbicides and insecticides due to higher carbon dioxide levels in the atmosphere, while mechanical methods such as hand-pulling of weeds may become less effective under warmer conditions that no longer limit overwinter survival (Hellmann et al. 2008). Additionally, altered interspecific interactions may change the effectiveness of some biological controls (Rahel and Olden 2008). Some current controls may produce unintended consequences for other organisms. For example, pressure to increase use of herbicides may amplify the negative effects on non-target organisms, such as amphibians or aquatic species (Hellmann et al. 2008).

Additional resources related to invasive species, including a list of species occurring in North Carolina are included in Appendix D.

Photo: Invasive kudzu, www.sarracenia.com

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Conservation Planning and Adaptation Strategies for Wildlife under Climate Change

Given the complexity of climate change and associated threats to biodiversity, strategic conservation planning that incorporates adaptive management will be critical for maintaining important wildlife populations and habitats. Strategic conservation planning offers a framework for agencies to organize available data, prioritize species and habitats based on their vulnerability or other values, and identify appropriate management or conservation strategies. If implemented correctly, adaptive management will provide an opportunity for 'learning by doing' and updating conservation strategies, which will be key to managing in the face of uncertainty. Understanding not only the biological, but also the political and human dimensions of conservation are critical for devising a coordinated plan and implementing sound conservation actions under climate change. The State Wildlife Action Plans (SWAPs) offer a unique opportunity for agencies to integrate these dimensions into developing adaptation strategies and actions for wildlife and habitat. The SWAPs also provide a template for state agencies to engage and coordinate climate change activities both within and between states.

In this chapter, we describe the conservation planning process, as well as important considerations for implementation, with specific reference to adaptive management. We also identify climate change adaptation strategies, actions for wildlife and habitat, and discuss the importance of social and institutional adaptive capacity for developing and implementing actions. Finally, we provide information on what other states are currently doing and identify emerging federal programs and partnerships, which may be critical for regionally coordinated climate change adaptation.

Understanding, not only the biological, but also the political and human dimensions of conservation are critical for devising a coordinated plan and implementing sound conservation actions under climate change.

5.1 The Conservation Planning Process

Conservation planning is a stepwise and iterative process. A number of organizations have developed conservation planning frameworks that outline the process in preparing for, drafting, and implementing a plan. For example, the Nature Conservancy (TNC) has developed the Conservation Action Planning (CAP) methodology as one of three key analytical methods that support the application of TNC's strategic framework for success (TNC 2007). In addition, the Conservation Measures Partnership (CMP) developed a set of conservation planning and adaptive management standards that can be used as guidance for identifying and prioritizing conservation actions (CMP 2007). The CMP is a consortium of conservation organizations including World Wildlife Fund, RARE, National Fish and Wildlife Foundation, and others whose mission it is to improve the practice of biodiversity conservation by developing and promoting common standards for conservation planning and monitoring effectiveness (CMP 2007). These frameworks, among others, provide templates for the process and outcomes of a conservation planning effort. Although each framework may describe the process in a different way, the conservation planning process generally involves the following key steps:

Identifying and involving key stakeholders

The first step in a conservation planning process is to identify and involve key stakeholders. Internal stakeholders will include the group of individuals who comprise your project team and those responsible for identifying the scope, vision, and conservation targets. Team members will generally include the managing organization's staff experts as well as other key internal and external partners (CMP 2007). It is especially important to involve all those people who will be responsible for implementing and monitoring the plan. These internal stakeholders will also be responsible for agreeing on the framework for the planning process as well as identifying additional stakeholders.

Additional stakeholders will be a valuable part of assessing the resource problem, developing objectives, identifying management actions, and promoting long-term program support. Stakeholders should include individuals with a breadth of experience and technical expertise who can identify key areas of uncertainty or factors in the decision-making process. Active adaptive management will require a commitment of time resources and regular engagement of stakeholders.

Photo: ci.chapel-hill.nc.us

Identifying conservation targets

Once the project team has been identified, the next step will be to identify conservation targets, where targets are the elements of biodiversity that stakeholders seek to conserve. Conservation planning has traditionally focused on individual species - most often endangered or game species. Over the last decade, government agencies and private organizations have started shifting to conservation planning that is beneficial for the diversity of species and their habitats. This approach attempts to protect whole ecosystems rather than individual pieces of the system in isolation. While there are some species that need special attention, an ecosystem approach provides a more comprehensive look at conservation needs. Thus, in order to ensure the conservation of biodiversity at multiple spatial scales, planners should consider both a course and a fine filter approach.

Collecting information and identifying data gaps

The next or concurrent step is to identify existing and available data, including GIS data, as well as data gaps and key uncertainties. The data available for this process will be a key component of science-based conservation planning, will ensure the stakeholders make full use of all relevant information when making their decisions, and will provide the context for understanding threats, potential actions, and identifying ecologically significant areas. This step will also allow the project team to articulate whether additional data may need to be collected, or target future research efforts.

Evaluating current threats and the viability of conservation targets

Models can be developed to characterize different ideas about how the system works. In the adaptive management and planning process, a model is used as a representation of system behaviors and responses, and can be as informal as a verbal description or as formal as a detailed mathematical expression of change. At this stage, models should incorporate different hypotheses about how a system works but also key uncertainties about process and management effects. In a facilitated stakeholder workshop, participants identify the various factors that are thought to influence the conservation of the target species or habitat, including the observed and predicted climate change impacts on their targets (Table 5-1). For example, Figure 5-1 represents how a group of stakeholders may map out the climate change and other direct and indirect threats that impact the status of coldwater habitat and fishes using the software tool Miradi (CMP 2010).

Photo: www.thinkstockphotos.com

Table 5-1. In a stakeholder workshop, brainstorming all of the factors that are thought to influence the conservation of target species or habitats can be a useful way to evaluate current threats.

Direct threats	Indirect threats	Sociological factors	Policy factors
Increasing temperature	CO_2 increases in the atmosphere	Poverty in rural communities	Lax local zoning
Loss of riparian area	Lack of support for climate change legislation	Lack of support for climate change legislation	Unregulated harvest
Overfishing			

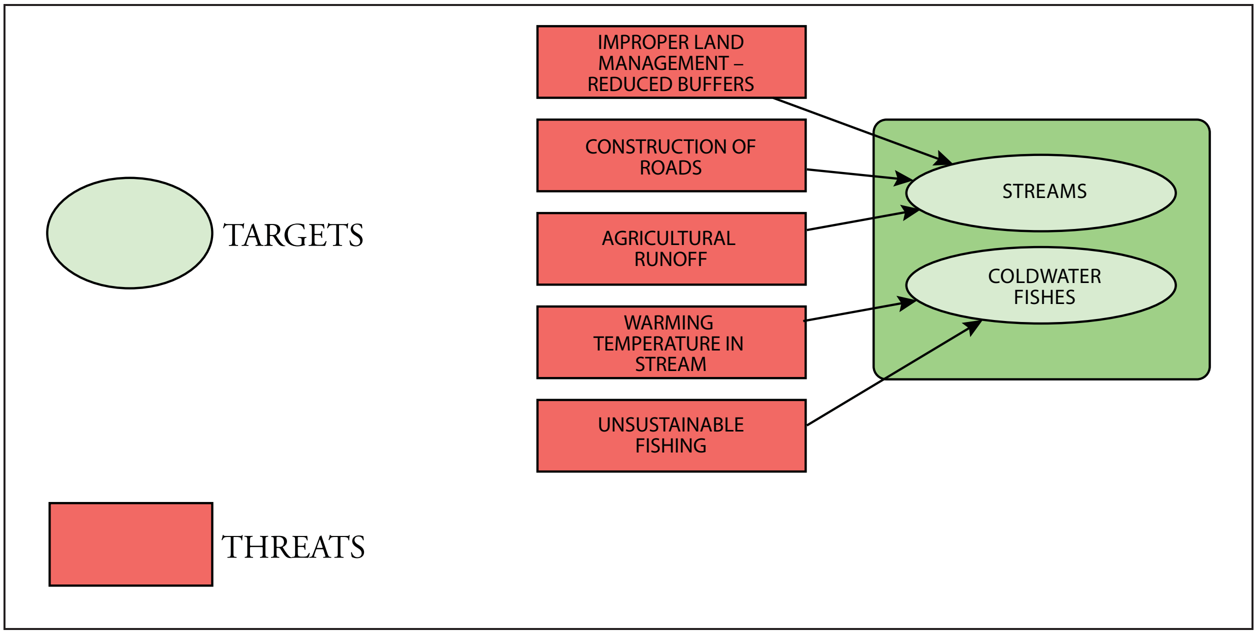

Figure 5-1. Developing a concept map or model helps to identify climate change and other direct and indirect threats to coldwater habitats and fish. Targets are represented by green circles, threats are identified by red boxes.

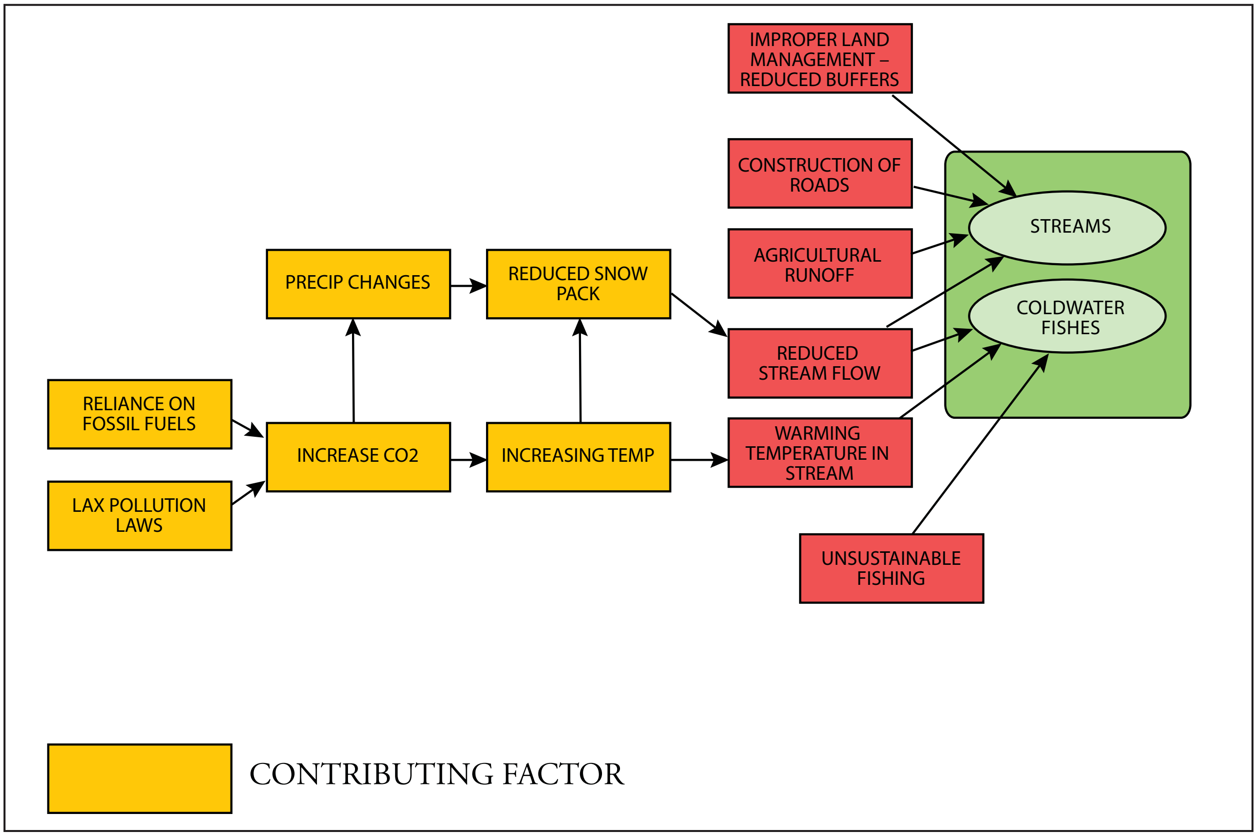

Figure 5-2. Identifying the underlying causes or drivers of certain threats can help frame the problem more clearly. Underlying causes or drivers of threats are identified by orange boxes.

Once threats have been identified, stakeholders can work together to identify what the drivers of those threats may be. For a simplistic climate change example, we know that increasing stream temperatures are a result of increased atmospheric carbon dioxide and what the underlying causal mechanisms may be (Figure 5-2). This approach is valuable for other threats, such as land use change (Figure 5-3). These steps will help stakeholders frame the problem more clearly and set the stage for identifying appropriate conservation actions.

Identifying and prioritizing actions for reducing threats and increasing viability of conservation targets

Once the threats to conservation targets have been established, a set of actions that improve the status of or reduce the threat to your conservation target should be identified and prioritized. Stakeholders should work together to identify potential management actions and identify alternative scenarios for decision-making. These actions should be explicit and well-documented and reflect the activities that are under the agencies control. Building on the previous example, conservation actions can be identified by looking at the conceptual model and identifying 'management intervention points' where the agency or stakeholders can provide the most appropriate input (Figure 5-4). In this example, snow fences can be described as a "resistance" adaptation strategy. These types of strategies may help to buy-time for a system in the short term until other adaptation strategies are developed but are unlikely to be viable over longer time periods due to the magnitude and pace of climate change (Mawdsley et al. 2009).

Conservation or management actions will generally include a diversity of strategies, such as land acquisition, conservation easements, outreach, habitat restoration, hunting regulations, or new legislative policies. The type and priority of the action will be dependent on the management agency involved, the expertise available, the public/economic context, or the potential impact on the conservation targets.

Based on the threats identified, management actions should be selected from a set of possible alternatives. Alternative actions will be evaluated based on many factors, such as resource status, the current level of understanding about the resource, socio-economic feasibility of implementation, and cost/benefit. Structured decision making provides many tools and methods for facilitating stakeholders in evaluating alternative actions and prioritizing among them (see Runge et al. 2010). Part of prioritizing the actions is also identifying a process for operationalizing or implementing the plan, for example, identifying

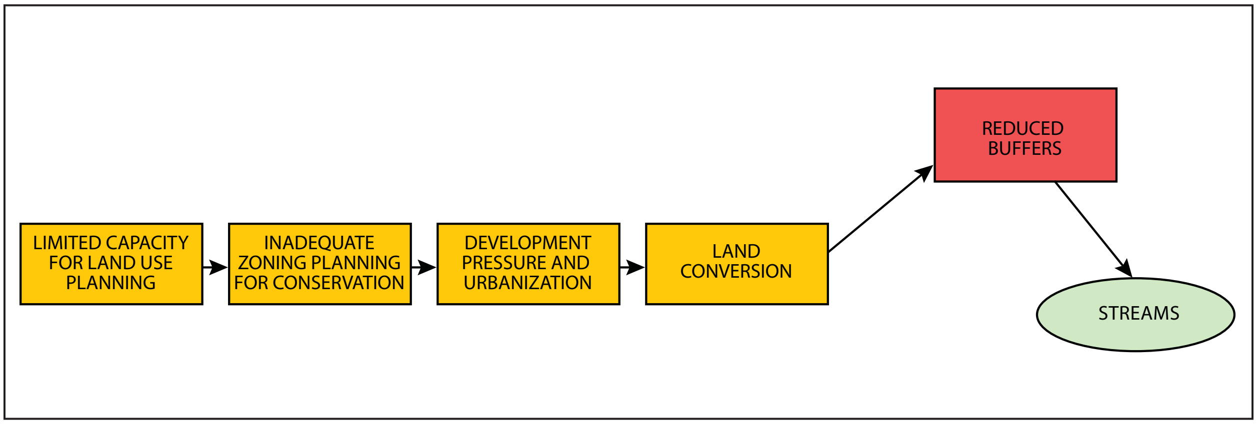

Figure 5-3. The concept diagram is a valuable tool for climate change and other stressors.

available funds, staff leads, schedules for implementation, monitoring, and re-evaluation of the actions.

Understanding the human dimensions of wildlife management will also be key to evaluating and prioritizing alternative actions. The study of human dimensions of wildlife management is described as "how and why humans value natural resources, how humans want resources managed, and how humans affect or are affected by natural resources management decisions" (Decker et al. 2001). Human dimensions research focuses on a number of integrated social and wildlife issues such as: cultural and social values, human behavior, risk perception, legal and institutional frameworks of management, communication and education, and decision-making processes of management (Decker et al. 2001). By working closely with natural resource managers, human dimensions experts strive to incorporate new understanding into management planning and action. Social science methods and tools used to evaluate the human dimensions of wildlife and case studies on how human dimensions assessments have been used to develop natural management actions can be found at: http://www.hd.gov/HDdotGov/.

Identify specific, measurable goals and objectives

One of the most critical steps in any planning effort is the creation of specific, measurable goals and objectives that are associated with your expected impact on the conservation targets given your management actions. Goals generally represent your desired future condition, or at least the maintenance of the current condition, of your targets and should reflect the values of the stakeholders, including social, economic or other factors. Although the terms are often used interchangeably, objectives can be distinguished from goals if they specify desired changes in the short and medium-term that may ultimately support the

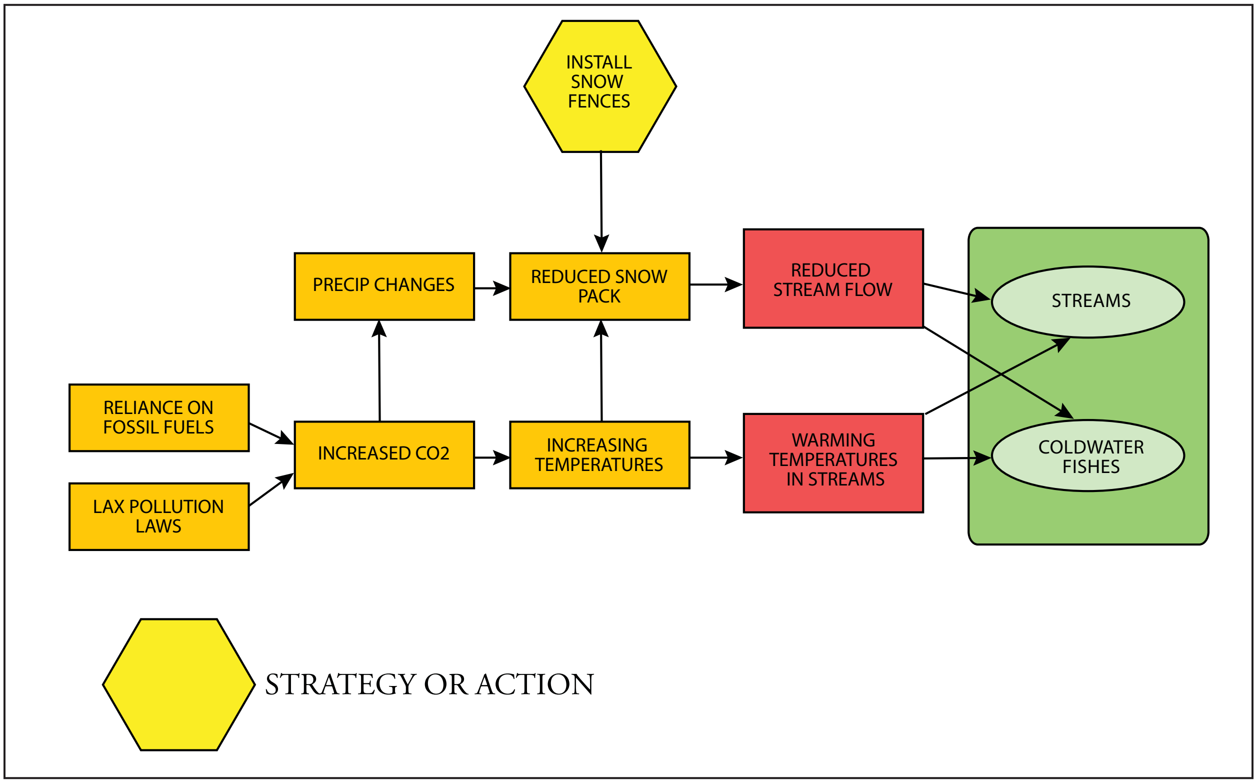

Figure 5-4. Appropriate management actions can be identified using a conceptual model. Management intervention points or conservation actions are identified by yellow hexagons.

achievement of target goals (CMP 2007). Because our knowledge of the life history requirements of species and how ecosystems function is too incomplete to provide definitive answers, goals and objectives can provide guidelines for how to make critical decisions in the face of uncertainty (Groves 2003).

Identifying clear and measurable objectives will guide decision-making and will be used to evaluate management effectiveness over time. Following the S.M.A.R.T. principles can provide a practical framework for setting short and long-term goals. The acronym has a number of slightly different meanings, which can provide a more comprehensive approach to setting goals:

S – specific, significant, stretching

M – measurable, meaningful, motivational

A – agreed upon, attainable, achievable, acceptable, action-oriented

R – realistic, relevant, reasonable, rewarding, results-oriented

T – time-based, timely, tangible, trackable

One important consideration, particularly as it relates to climate change, is to identify both short and long-term goals and objectives. A useful tool as part of this process can be to develop a "results chain" for each action (CMP 2007). Results chains explore the assumptions surrounding suggested management actions, and help in developing goals, objectives, and measurable indicators that can be formally monitored. From our example, the assumption may be that by installing snow fences (action), we can increase the height and size of snow pack in key areas (result), which will ultimately restore or maintain natural stream flows as winters get warmer (secondary result), ultimately resulting in providing cold-water fish habitat. Figure 5-5 demonstrates what that might look like in a results chain format. The process of developing goals and objectives might result in the stakeholders revaluating their priorities based on the uncertainties or feasibility of monitoring outcomes or of meeting measurable objectives.

Results chains allow stakeholders and agency managers to ask critical questions about their assumptions, and promote dialogue on how management strategies may reduce threats and improve the status of target species and habitats. The results chain can also provide a template for developing management goals, objectives, and indicators for each intermediate result in the chain as well as testing the underlying assumptions. In addition, it allows for visual reflection on the key factors and attributes (indicators) that may need to be monitored over time. In the example, an assumption was that snow fences will increase snow pack in key areas that will in turn provide and increase source for water in target streams. To test this assumption, an experimental design could evaluate both snow pack and stream flow indicators before and after installation. More specifically, we can ask "how much additional snow pack do we want and during what time frame?" These kinds of questions can promote thoughtful consideration of the goals, objectives, and indicators, and provide a transparent and repeatable framework for conservation planning.

Implementing, monitoring and adaptive management

Adaptive management is widely promoted as the systematic approach for improving resource management under high levels of uncertainty by learning from management outcomes (Sexton et al. 1999, Gregory et al. 2008, Williams et al. 2009). Given the urgent need for tools to help environmental management professionals make decisions under uncertainty (Gregory et al. 2006), true adaptive management offers a conceptual framework and guidelines for improving the effective management of natural resource systems in a climate changed world (Williams et al. 2009).

Resource managers are often faced with making decisions about dynamic ecological systems with significant uncertainty about what the outcome will be of implementing management actions. Management decisions often include multiple or competing objectives, predictions of system response, risk analysis, identification of alternative actions, and uncertainty. Adaptive management offers a structured and disciplined approach to these complex wildlife management decisions. This approach to managing natural resources can be traced back to the work of Holling (1978) and Walters (1986), but is rarely implemented under the operational definition provided by the DOI technical guide:

Adaptive management [is a decision process that] promotes flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.

(Williams et al. 2009)

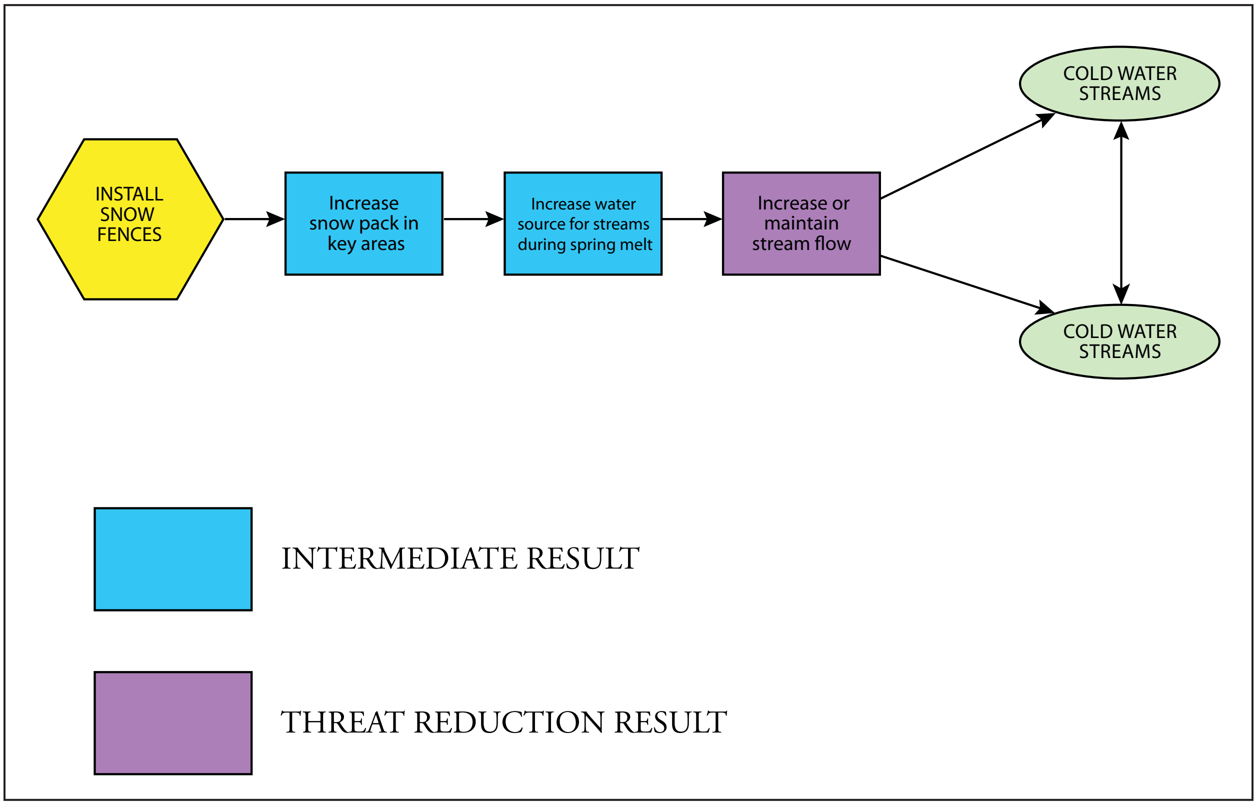

Figure 5-5. Example of a results chain based on installing snow fences to restore stream flows. Results chains allow you to more easily develop both short and mid-term objectives and may help stakeholders verify assumptions about the potential impacts of management actions.

The iterative steps of AM closely parallel those of the conservation planning process and include: problem assessment, designing the management action, implementation, monitoring, evaluation, and adjustment (Figure 5-6). Thus, adaptive management offers a structured yet flexible framework to deal with the new challenges of climate change.

Implementing, monitoring, and evaluating actions are among the most critical, and often overlooked, steps in the conservation planning process. The AM process allows managers to learn about complex systems by designing management actions around clearly stated objectives, monitoring the results of implementing the strategies, and adjusting management actions and priorities based on those results. Monitoring key indicators that are tied explicitly to stated goals and objectives will also allow agencies to assess whether conservation actions are effective or are having had the desired impact. Results from monitoring in an adaptive management framework are used to test multiple competing hypotheses or measure progress towards stated goals and objectives. Learning is promoted by comparisons of model estimates against predictions. These steps are then repeated in an iterative process to improve overall management of the system. Wildlife managers committed to the principles of AM will be able to better anticipate the effects of climate change, refine management actions based on research and monitoring, and be flexible in responding to new threats.

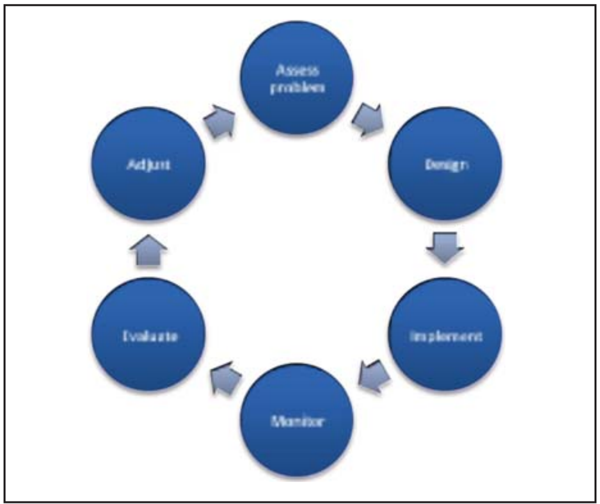

Figure 5-6. The adaptive management process (Adapted from: Williams et al. 2009)

5.2 Important Considerations in Conservation Planning for Climate Change Adaptation

In the context of climate change, the term adaptation is currently used to describe adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects. These adjustments moderate harm or exploit beneficial opportunities in response to climate change. However, the term adaptation continues to cause confusion and debate, both over the precise use and definition and over what defines an "adaptation project." Some of the confusion stems from the widely used scientific definition, which states that adaptation is the process of genetic change within a population due to natural selection in which the average state of a character within a species population becomes better suited to some feature of the environment through evolution. This type of adaptation, also referred to as autonomous adaptation (IPCC 2007), is a biological response to climate conditions and does not involve human intervention or management. In this report, climate change adaptation refers to strategies taken by wildlife managers to anticipate, prepare for, and respond to the expected impacts of climate change that will allow target species, habitats, and ecosystems to respond to change.

Throughout a conservation planning process to develop adaptation strategies, there are a number of over-arching considerations: engaging partners, coordinating across boundaries, recognizing appropriate spatial and temporal scales, addressing uncertainty, incorporating vulnerability assessments, and implementing an adaptive management framework. These considerations are especially important within the context of climate change adaptation.

5.2.1 Engaging Diverse Partners and Coordinating Across Boundaries

The broad spatial and temporal scales associated with climate change will require collaboration beyond traditional boundaries and the development of non-traditional partnerships in order to accomplish ecologically meaningful conservation goals. Likewise, the scale of the resources and data needs for the planning process will require conservationists to work collaboratively in order to leverage resources and build on existing tools and approaches. In the face of a changing climate, the development and implementation of complementary federal, state, local, and tribal government as well as private sector, climate adaptation strategies will be necessary to ensure that target species, habitats, and ecosystems are resilient and can adapt to climate change. For example, not every federal or state agency may need to develop a separate approach to assessing species or habitat vulnerability – instead agencies could work in partnership to develop and disseminate a suite of planning tools that can be used by all partners. The Association of Fish and Wildlife Agencies (AFWA) is currently running regional workshops across all of the partner states to identify opportunities for collaborating and sharing information on climate change.

Partnership development and coordination should begin in the early stages of the planning process. Stakeholders and partners that could be brought into the planning process to facilitate coordination include state and federal agencies (including partners from other sectors of government such as state transportation, land use, economic development, disaster planning, and water agencies that will also be developing plans for climate change adaptation for human systems), the interested public, local experts, natural resource-based industries, and the academic community, and conservation non-profit organizations.

5.2.2 Recognition of Appropriate Spatial and Temporal Scales

The scale of climate change is global, but management decisions are typically made and implemented locally. The maintenance of biological diversity and a fully connected network of habitats across the landscape require conservation planning at multiple spatial scales (Angelstam et al. 2003). In the future, management decisions will need to be coordinated at a species' range-wide scale with a broader ecological, social, and economic landscape context in mind. The temporal scale of planning also needs to be considered. Planning horizons are generally short (5-10 years), but planning for climate change adaptation will require both short and long-term considerations. Although climate changes are projected to accelerate through at least the end of this century, predicting the specific impacts of climate change becomes more uncertain over periods greater than 50 years. Planning time scales will ultimately be project specific but will need to explicitly address uncertainties associated with the time period chosen.

5.2.3 Incorporating Vulnerability Assessments

Evaluating current conservation approaches and priorities will be a key component of planning and implementing wildlife adaptation strategies under climate change. The pace and scale of climate change, coupled with declining budgets for wildlife management and continuing degradation of habitats, requires conservation practitioners to set clear priorities and practice strategic conservation. To do this, wildlife managers may need to address fundamental questions, such as the following list adapted from The Nature Conservancy's guidance on incorporating climate change adaptation into regional conservation assessments (TNC 2009): 1) How do management strategies need to be modified to address current and future impacts of climate change 2) Do existing conservation targets need to be adjusted? 3) Do boundaries or project scope need to be adjusted? 4) Should conservation targets be addressed elsewhere? 5) Do new conservation targets need to be identified and addressed? 6) Does a conservation target need to be removed because we cannot envision a feasible strategy to maintain target viability or because it will increase due to climate change? (Game et al. 2010). Working through questions like these will allow managers to assess and revise current conservation approaches and design new strategies.

Adaptation to climate change is fundamentally linked to the concept of vulnerability. Vulnerability assessments can play an important role in identifying which species or habitats to target or prioritize, which management actions may be most effective given projected impacts, and what areas on the landscape might be suitable for facilitating wildlife adaptation. To design effective adaptation strategies and prioritize limited conservation resources, practitioners need to determine which species, habitats, and ecosystems will be most vulnerable, and what aspects of their ecological and evolutionary biology determine their vulnerability. In 2009, AFWA produced a useful guide for incorporating climate change into State Wildlife Action Plans or other management plans (AFWA 2009). This guide serves as a valuable reference for evaluating current conservation activities and identifying where vulnerability assessments may fit in the planning process.

5.2.4 Addressing Uncertainty

The greatest challenge to wildlife managers in planning for climate change adaptation may lie in dealing with the uncertainty inherent in future climate change projections. Although reducing uncertainty is routinely identified as an important reason for implementing adaptive management, the AM process will not be particularly valuable if not used to improve management actions over time. Thus, AM should be used to target key uncertainties that will improve an agency's ability to achieve management objectives. Identifying these uncertainties will be an important part of the planning process, and can be explicitly incorporated into formal decision analysis tools, such as those in structured decision-making (Runge et al. 2009).

To date, managers have relied on trends in historical data or sustainability paradigms to identify management goals and objectives (Lackey 1995, Landres et al. 1999 in Millar et al. 2007). However, rapid shifts in climate may make management actions based on past conditions obsolete, or even create new problems where wildlife or habitat are more susceptible to the impacts of climate change (Millar et al. 2007). As suggested in Millar et al. (2007), "Accepting that the future will be different from both the past and the present forces us to manage [forests] in new ways".

Some conservation actions are likely to be beneficial under a range of future climate conditions. For example, enhancing habitat connectivity is regularly identified to reduce the impact of fragmentation on wildlife. Not surprisingly, habitat connectivity has also been suggested to facilitate range shifts in response to new climate patterns, as species will need well-connected natural landscapes to be able to adapt (Mawdsley et al. 2009). In addition to connectivity, actions such as restoring natural processes, protecting large and representative natural areas, or restoring stream buffers, are all considered 'no regrets' actions, in that they are generally beneficial for conservation with or without the threat of climate change (Mawdsley et al. 2009).

The effectiveness of other climate change adaptation actions may be more sensitive to the uncertainties associated with climate projections. For example, translocation or managed relocation has been identified as a potential intervention for facilitating species adaptation (e.g. Mawdsley et al. 2009). However, the relative risks associated with moving species outside of their natural range coupled with the uncertainty in projected future habitat distributions may make translocation of species controversial. Lawler et al. (2010) provide a graphical representation of certain types of management actions that are dependent on the direction or magnitude of climate changes, highlighting those actions that are more and less robust to uncertainties associated with impact projections. (Figure 5.7) To be successful all actions must be coupled with careful and rigorous monitoring, analysis, and re-evaluation as further information becomes available.

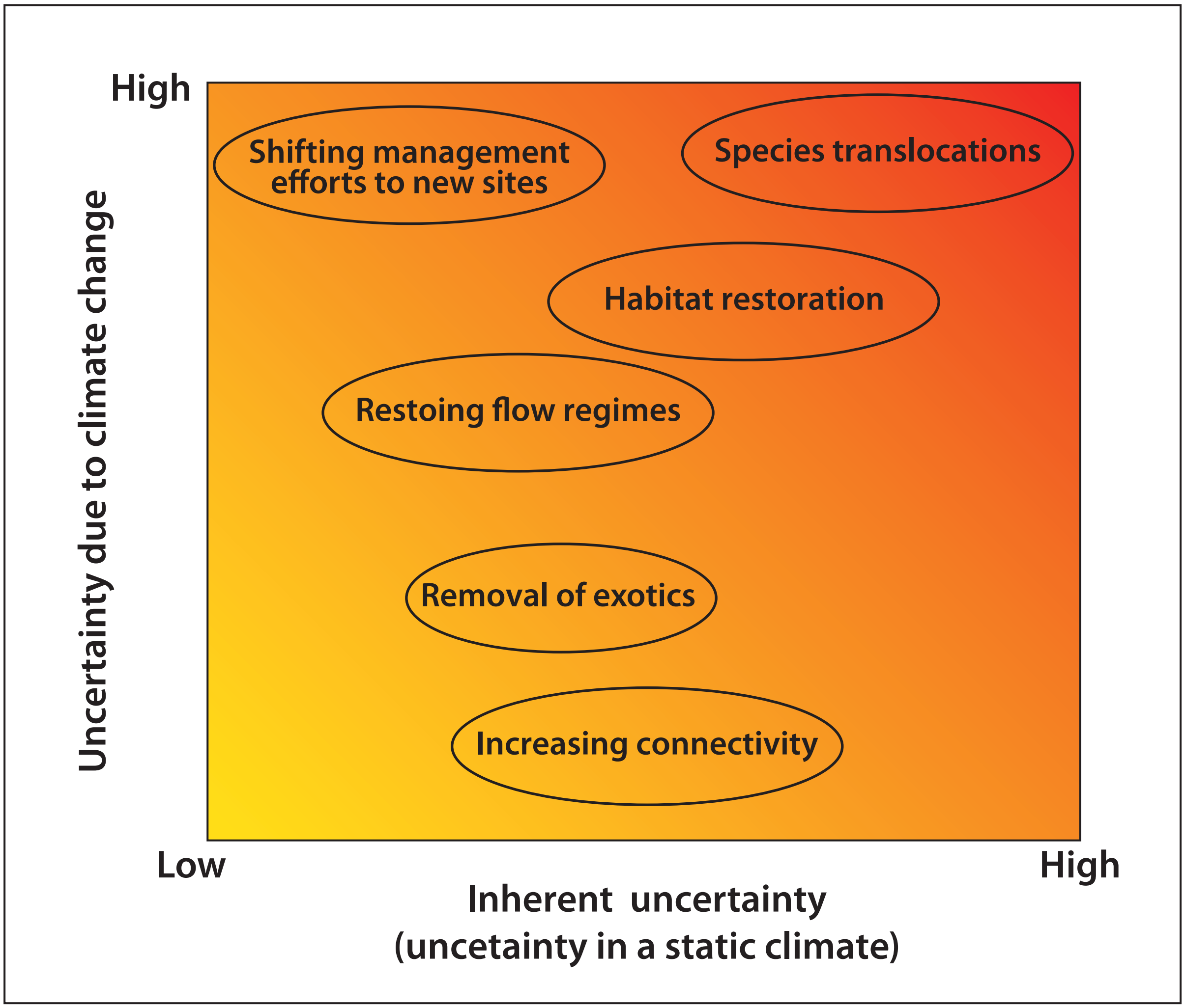

Figure 5-7. Management actions for addressing climate change, plotted with respect to the relative degree of uncertainty associated with their outcomes. Inherent uncertainty (x axis) is the uncertainty associated with a management action, irrespective of climate change. The uncertainty due to climate change (y axis) is a measure of how dependant the outcome of a management action is on a particular direction or magnitude of climatic change. Actions at the bottom and top of the plot are, respectively, more and less robust to uncertainties in climate-change impact projections. The plot is necessarily a generalization – specific management actions of one type or another may be associated with relatively more or less uncertainty than the levels depicted here (Source: Lawler et al. 2010, © The Ecological Society of America, used with permission).

5.3 Adaptation Strategies

Conservation actions may be classified into three broad types of climate change adaptation strategies – resistance, resilience, and facilitation – aimed to help species, habitats, and ecosystems maintain or change towards a functional future state in response to climate changes.

Resistance strategies

Resistance strategies include those management actions designed to keep an ecosystem or species from changing in response to climate change by limiting exposure to the impacts of climate changes. These types of actions may help to "buy time" for a system in the short-term until other adaptation strategies are developed or help to maintain conditions in sensitive or high value ecosystems (Millar et al. 2007) but are unlikely to be viable over longer time periods due to the pace of climate change. The use of dredge material on coastal shorelines or offshore islands to prevent inundation caused by sea level rise and maintain an intact coastal ecosystem is an example of a resistance strategy.

Resilience strategies

Resilience strategies include management actions aimed at supporting an ecosystem or species by increasing the amount of change that a system can absorb without undergoing a fundamental shift to a different set of processes and structures. Removing invasive species to increase an ecosystem's ability to recover from other disturbances or preserving ecological heterogeneity in a landscape are resilience-building strategies that enable an ecosystem to maintain ecological functions and biodiversity. These types of strategies are often emphasized as early response options to climate change because they may be more robust to a range of future climate scenarios (Lawler et al. 2010) and because there is less uncertainty in how species and ecosystems will respond to these interventions; these types of strategies may be considered the backbone of a strong climate change adaptation response.

Facilitation strategies

Facilitation strategies include management actions that are direct interventions to facilitate a change in state of the ecosystem or species population towards a desirable future state with native species, intact ecological functions and continued provisioning of essential ecological services. While management actions that resist change and build resilience may be preferable alternatives for early implementation (Lawler et al. 2010), more targeted actions to manage and direct ecosystem and species-level responses to climate change may be necessary to avoid unsustainable land management expectations and biodiversity loss (Galatowitsch et al. 2009). Facilitation actions "mimic, assist, or enable ongoing natural adaptive processes such as species dispersal and migration, population mortality and colonization, changes in species dominances and community composition, and changing of disturbance regimes (Millar et al. 2007)," and may be more appropriate for dealing with large degrees of climate change projected in the future depending on the management objective. Actions to facilitate change may include increasing landscape connectivity and permeability to allow species and ecological communities to shift in response to climate change, trans-locating sensitive species that are unable to keep pace with climate change, changing the plant species used in restoration projects, and creating man-made disturbances such as fire treatments.

5.4 Management actions for climate change adaptation

Translating the resistance, resilience, and facilitation strategies into management actions for on-the-ground implementation is a significant challenge. Designing actions is context specific and depends on the conservation targets and goals, the projected climate change impacts, the location of the project, the socio-economic environment and many other local factors. There have been numerous attempts to list and categorize general categories of adaptation actions derived from the principles of resistance, resilience and facilitation strategies (Mawdsley et al. 2009). Rather than discussing all of these attempts here, below is a listing of some of the more prominent distinctions adapted from several sources (Heller and Zavaleta 2009, Hodgson et al. 2009, Mawdsley et al. 2009, Theoharides et al. 2009).

Prevent undesired effects of climate change

One strategy for managing target species, habitats and ecosystems under climate change is to implement actions so that these targets are better able to resist the impacts of climate change (Millar et al. 2007). To prevent change, managers must build up species' and ecosystem defenses against the direct and indirect effects of rapid climate changes. For example, in forest systems, resistance strategies might involve actions such as preventing extreme forest fires by creating fuel breaks around high value resources or intensive removal of invasive species and intervention to block future invasions. These types of actions are likely to "require intensive intervention, accelerating efforts and investments over time, and a recognition that eventually these efforts may fail as conditions change cumulatively (Millar et al. 2007)." These types of actions may best be applied in the short-term and to resources of high value; systems with low sensitivity to climate change may respond best to resistance treatments (Millar et al. 2007).

Protect adequate and appropriate natural areas

Maintaining resilient ecological communities and allowing species to move in response to climate change will require the strategic expansion of a connected network of conservation areas and management of these lands for climate change (Hannah et al. 2007). Large conservation areas tend to contain more species and tend to encompass greater levels of environmental heterogeneity (diversity of landscape features, habitats and resources) than small areas. Heterogeneity generally promotes higher levels of species richness and endemism, and provides opportunities for populations to survive different extremes by shifting among different habitat types, soils, aspects, or elevations within the larger landscape (Hodgson et al. 2009). While simply expanding the conservation footprint to create large conservation areas is essential, strategically protecting lands that add to the representation and redundancy of conservation targets will also be important. Conservation areas should represent the biological features or targets of interest and the range of environmental conditions under which they occur, and should provide redundancy so that targets are represented multiple times and are therefore less prone to extinction caused by extreme events. Protecting land along ecological gradients (altitudinal, latitudinal, etc) will also be an important strategy to help species shift their ranges and move in response to climate change and adding protected areas on the edges of species current distributions may held species move and peripheral populations become increasingly important with climate change (Hannah et al. 2007).

As the climate changes, strategic decisions about where to spend limited conservation dollars to protect habitat will be of critical importance. One action may be to identify and protect conservation areas that include climate refugia, or areas that may be less affected by climate change than other areas (e.g. due to local currents, topography, or geographic location) (Mawdsley et al. 2009). For example, mountainous regions may provide refugia because they are highly heterogeneous and contain a wide range of micro-climates within the sites. Potential refugia can be located using the paleological records to identify sites where refugial populations persisted during historic periods of rapid climate change (Mawdsley et al. 2009). These locations may serve as sites for long-term retention of species, or for introduction of sensitive species from other locations.

Photo: U.S. Global Change Research Program, 2009

Promote landscape connectivity to facilitate species movements and gene flow

To facilitate species movement and exchange of genetic material to maintain resilient species populations, conservationists and managers will need to identify and protect areas critical for climate-induced wildlife movement such as corridors for terrestrial species and stepping-stone habitats for species that need stopover locations between protected areas. Actions that facilitate species movements also include increasing stream and river connectivity through such approaches as dam removals and stream and floodplain restoration projects. A key component of maintaining and restoring ecological connectivity will be to increase the permeability of the human landscape, or the lands and waters outside of protected areas to wildlife movement. Actions to increase permeability include wildlife friendly farming, installation of fish ladders in dammed rivers, and use of predator-friendly enclosures for domestic pets or livestock to prevent human-wildlife conflicts. Finally, increasing ecological connectivity will require coordination among different land management agencies and private landowners at local, state, and federal levels. Rather than preserving areas in isolation, agencies, organizations, and individuals should work together to develop a connected network of conservation lands and waters.

Reduce non-climate threats

In general, systems and species that are already stressed will be less resilient to climate change and reducing non-climate threats will give wildlife species maximum flexibility to respond to climate change (Mawdsley et al. 2009). Many ecological threats may interact synergistically with climate change, including invasive species (Hellmann et al. 2008), wildfire (Marlon et al. 2009), and fragmentation (Jackson and Sax 2010) resulting in an increased impact on native species. Managers may need to redefine acceptable or manageable levels of these ongoing threats based on the idea that the impact of these stresses will likely be greater than anticipated when the effects of climate change are added. Minimizing ongoing threats to species or ecosystems is a robust adaptation action for helping species and ecosystems deal with climate change. Actions that build resilience are less dependent on specific future climate conditions and therefore have less uncertainty associated with their outcomes (Lawler et al. 2010). Actions may include invasive species removal or restoring altered hydrology in coastal marsh ecosystems.

Maintain healthy ecosystems

Maintaining ecological function and promoting biodiversity is tied to increased ecosystem resilience and the provision of ecosystem services that humans depend on. Actions that build resilience focus on maintaining critical ecosystem functions such as water purification and carbon cycling and high levels of overall biodiversity, rather than focusing on maintaining specific historical compositional components of an ecosystem. To implement actions that build resilience, managers would need to define key indicators of ecosystem function, and then design management actions to keep those functions operational (Mawdsley et al. 2009). Studies have concluded that various levels of diversity appear to be critical for resilience and for the provision of ecosystem services (Hooper et al. 2005) and therefore protection of different levels of biodiversity (genetic, species, functional, landscape, etc) may be a key component of these actions.

Implement "proactive" management and restoration actions

Actions in this category include all interventions in habitats, ecosystems and species populations to enhance the ability of these targets to accommodate anticipated future climate change impacts. Examples include translocation of species to new locations, barrier island expansion, facilitating marsh migration, and planting species that are thought to be more resilient to anticipated climate changes in a particular location. Implementation of proactive actions may carry a higher degree of uncertainty in terms of meeting the objectives because they may be designed to address a specific climatic change (Lawler et al. 2010). Therefore, proactive actions may best be implemented cautiously and refined continuously.

While many of these actions are not novel, the way in which they are planned and implemented is novel and reflects the explicit incorporation of information on climate change impacts to species and ecosystems. A conservation project that is not explicitly planned and implemented through a climate change lens, using a process similar to the planning process described above, cannot be considered a climate change adaptation action. Traditional static views of biodiversity will need to be revised to incorporate our understanding of the dynamic and changing landscapes and climates and the process of setting management goals and objectives can no longer be based on meeting historical target conditions. Setting strategic priorities for implementation of adaptation actions will be necessary to deal with the pace and magnitude of climate change as well as limited conservation funding and agency natural resource management budgets.

Photo: U.S. Global Change Research Program, 2009

5.5 Building Institutional Adaptive Capacity

Traditionally, management of wildlife and habitat has relied on the principle of stationarity – the idea that the future is statistically indistinguishable from the past. Given the magnitude and associated uncertainty of impacts under climate change, stationarity may not be a viable assumption. Although natural resources professionals have always managed dynamic and complex ecological systems, the uncertainty associated with the extent and potential impacts of climate change offer new management challenges. Thus, management of natural resources under climate change will require even greater flexibility, creativity, and adaptive learning.

Climate change adaptation is a new field. There is uncertainty in the magnitude of climate change and its impacts, and in the ecological responses to those impacts. To prepare for applied, on-the-ground responses, our conservation institutions must themselves adapt and become adaptive to constant change at large scales. Based on a survey of federal and state agency representatives, conservation practitioners, and natural resource scientists, we observed federal and state agencies, as well as nongovernmental organizations involved in the following types of actions aimed at improving institutional adaptive capacity (Theoharides et al. 2009):

Programmatic Changes:
Addressing adaptation to climate change involves making climate change a part of program priorities, securing increased funding to reflect that new focus, modifying management plans to address projected climate change impacts, forming internal and external working groups, and increasing internal capacity to address adaptation.

Planning:
A significant amount of planning, revision of existing plans, reprioritization of conservation actions, identification of new management goals, and development of monitoring protocols will precede implementation of adaptation projects. The goal of planning should be to ensure that management actions are not maladaptive and to ensure that conservation investments consider future changes and are re-prioritized as needed.

Collaboration:
Climate change requires conservation partners to work together at landscape- scales, across jurisdictional boundaries to adequately understand and respond to the impacts of climate change. Forming working groups, partnerships and collaborative structures and processes will be important to effectively work at this scale. The Department of the Interior Landscape Conservation Cooperatives are an example of this type of collaborative institution forming. Climate change adaptation will also involve collaboration across sectors, for example with land use, economic development, water, and disaster planning agencies to help assure that plans and actions are compatible and an efficient use of limited resources.

Increasing science and technical capacity:
Developing tools, predictive science, models, guidance documents, and planning information are all key components of adaptation to climate change. Developing and implementing active adaptive management programs within wildlife management agencies is also a key part of climate change adaptation as many adaptation strategies will be implemented under changing and uncertain conditions with incomplete information. Improving the institutional capacity of wildlife agencies to understand the human dimensions of climate change adaptation by incorporating methods and tools from the social sciences will become more important to assure that wildlife management actions will be effective as human systems also seek to adapt to climate change.

Increasing flexibility:
Because of the uncertainty, changing information, and potential for unexpected climatic shifts, climate change adaptation calls for increased flexibility and nimbleness from federal and state wildlife management agencies. Agencies will be forced to adjust timeframes, plan for alternative future scenarios, and revise plans, actions, and objectives more actively than in the past.

5.6 Current Federal and State Adaptation Efforts

A number of state and federal agencies are taking critical first steps towards developing climate change adaptation plans, coordinating regional stakeholders, and developing regional-scale data. Here, we highlight a few of state and federal efforts that may be of interest for the North Carolina Wildlife Resources Commission (NCWRC) and identify potential opportunities and resources that may support North Carolina State Wildlife Action Plan climate change revisions.

Because of the uncertainty, changing information, and potential for unexpected climatic shifts, climate change adaptation calls for increased flexibility and nimbleness from federal and state wildlife management agencies.

5.6.1 Federal Climate Change Efforts

USGS National Climate Change and Wildlife Science Center

The National USGS Climate Change and Wildlife Science Center (NCCWSC) was established by Congress to "provide the science and technical support needed to help fish and wildlife resource managers anticipate climate change impacts and evaluate options that will facilitate adaptation to changing landscapes" (USGS 2010). According to the 5-year strategic plan, the NCCSWC intends to pursue three goals: (1) work in close partnership with the natural resource management communities to understand high priority science needs and what is needed to fill those knowledge gaps; (2) work with the scientific community to develop science information and tools that can inform management strategies for responding to climate change; (3) deliver these relevant tools and information in a timely way directly to resource managers. Center activities will focus on providing habitat and population modeling and forecasting information and tools, integrating physical climate models with ecological models, assessing vulnerabilities and forecasting changes, and developing standardized approaches (USGS 2010).

In 2009, the NCCWSC funded 17 proposals that will advance our understanding of how climate change may affect wildlife, fish, and terrestrial and aquatic habitats. Of these, 2 projects will be particularly beneficial for NCWRC (Box 5-1). Additional projects will provide important insights on species vulnerability, genetic adaptations, forecasting climate impacts, and multi-scale responses to climate change. The NCCWSC also funded the launch of an integrated Southeast Assessment pilot that will provide a suite of regional analyses and an interdisciplinary framework for adaptive management and strategic conservation (USGS 2010).

Box 5-1. North Carolina specific projects funded by the National USGS Climate Change and Wildlife Science Center (NCCWSC) in 2009.

Development and Dissemination of High-Resolution National Climate Change Dataset. Principal Investigator: Jaime Collazo, NC State University. Source: http://nccw.usgs.gov/documents/Summary_for_NCCWSC-Collazo.pdf

Modeling the response of imperiled freshwater mussels to anthropogenically induced changes in water temperature, habitat, and flow in streams of the southeastern and central United States. Principal Investigator: Thomas Kwak, North Carolina Cooperative Research Unit. Source: http://nccw.usgs.gov/documents/Summary_for_NCCWSC-Kwak.pdf

FWS Landscape Conservation Cooperatives

Landscape Conservation Cooperatives (LCCs) are science partnerships between the Fish and Wildlife Service (USFWS), the United States Geological Survey (USGS), states, federal resource management agencies, tribes, NGOs, universities, and other stakeholders within a given geographic area. The goal of the LCCs is to carry out the elements of the FWS's Strategic Landscape Conservation (biological planning, conservation design, conservation delivery, monitoring, and research) by providing scientific and technical support for landscape conservation carried out in an adaptive management framework to address climate change and other landscape scale stressors. The LCCs will prioritize strategic habitat conservation, conservation planning, research, and development of inventory and monitoring programs and assist scientists and resource managers as they deal with uncertainty. They will also facilitate identification of shared needs and priorities among partners in the region, and focus science support and conservation around these needs at the landscape scale. The LCCs will comprise a national network of interdependent units that provide a link between science and conservation delivery.

With an initial federal investment of $25 million in FY2010, the Service and USGS will begin standing-up eight of these cooperatives across the country in the following geographic areas: Pacific Islands, Great Plains, Plains and Prairie Potholes, South Atlantic, North Atlantic, Great Northern, Arctic, and California (Figure 5-8). As a stakeholder in the LCC process, the NCWRC may play a key role in developing conservation priorities, research needs, partnerships, and regional plans that both compliment the SWAP and meet the needs of the South Atlantic (Figure 5-9) and Appalachian LCC.

Photo: www.thinkstockphotos.com

South Atlantic Landscape Conservation Cooperative

The South Atlantic Landscape Conservation Cooperative (SALCC) (Figure 5-9), slated to be formed in 2010, covers most of North Carolina, except for the Westernmost portion of the state which is part of the Appalachian LCC. In addition to North Carolina, the SALCC covers the Southeastern portion of Virginia, most of South Carolina and Georgia, and the Northernmost portion of Florida. The stated purpose of the SALCC is to facilitate conservation planning and design across state boundaries to supplement the State Wildlife Action Plans and provide better coverage for wide ranging species. It will also provide a broader geographic scale to address the impacts from climate change, competition for water, wildlife disease, invasive species and other critical challenges.

The SALCC will work in close partnership with the USGS proposed Southern Region Climate Change Response Center to assess the impacts of regional climate change. Efforts will include acquiring expertise to develop, test, implement and monitor conservation strategies. As of this fall, more than $3 million has been committed by partners – includ-

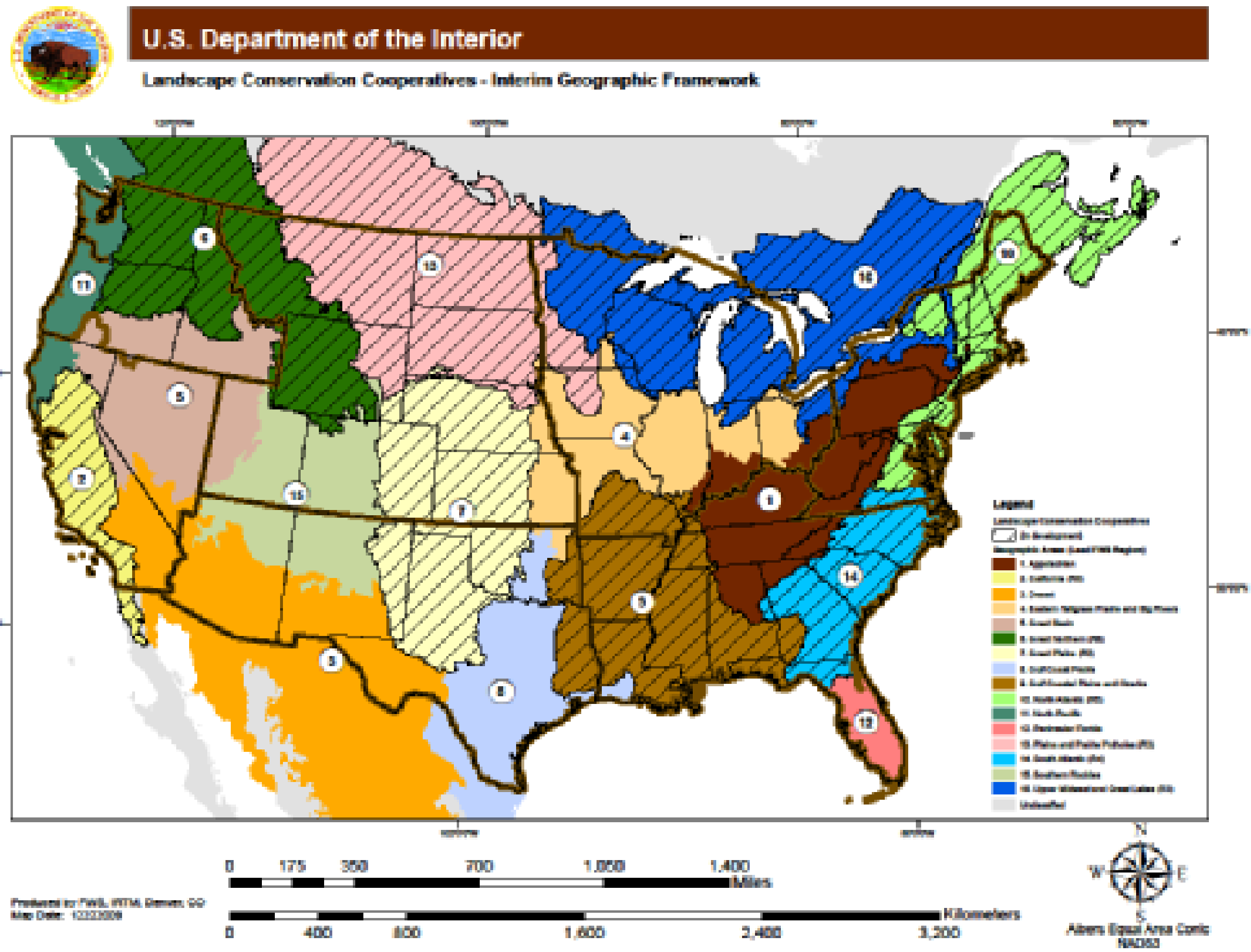

Figure 5-8. Proposed LCCs FY2010 Conterminous United States (Source: USFWS 2010a).

ing TNC, Duke Power, and Duke University – for projects focused on designing sustainable landscapes, species modeling, and adapting to impacts of accelerating climate change and sea level rise in the South Atlantic Region (USFWS 2010a). In 2010 there will be the a stakeholder-driven workshop about conservation strategies to cope with climate change that builds on the Atlantic Coast Joint Venture's Designing Sustainable Landscapes project (USFWS 2010a). It also will assist with the organization and implementation of a wildlife adaptation workshop focusing on coastal issues (USFWS 2010a).

Figure 5-9. Proposed boundary of the South Atlantic Landscape Conservation Cooperative (SALCC) (Source: USFWS 2009).

Appalachian Landscape Conservation Cooperative

The Appalachian Landscape Conservation Cooperative (ALCC) was initiated in 2010, and covers a number of states (including New York, Pennsylvania, West Virginia, Virginia, Ohio, Kentucky, Tennessee, Indiana, Illinois, Georgia, and Alabama) along with the westernmost part of the state (Figure 5-10). This cooperative intends to facilitate regional conservation planning and design to support existing conservation partnerships and promote innovative conservation approaches, with specific attention to priority species such as freshwater mussels, endemic fish, salamanders, migratory birds, bats and rare plants (USFWS 2010b). In fiscal year 2010, the ALCC will conduct multi-stakeholder scoping meetings to identify administration, structure, staffing and conservation priorities.

5.6.2 State Agency Updates to the State Wildlife Action Plans

Many states are in the process of integrating climate change into their State Wildlife Action Plans. Several states hosted workshops a couple years ago to initiate the process of updating their action plans, while other states are now beginning to think about the how to revise their plans. States also are conducting vulnerability assessments of species and habitats in their plans to help them develop appropriate conservation strategies. A few states have even developed amendments and/ or addendums to their plans to address climate change. The National Wildlife Federation (NWF), and Defenders of Wildlife have worked with many states on these efforts. Currently, NWF is collecting data and summarizing information on what all states are doing to integrate climate change in their State Wildlife Action Plans. At the time of publication, data collection is not complete. In the interest of being comprehensive and not including only a selection of states, NWF will be providing this information once complete through the website for this report via NWF's website: www.nwf.org/global-warming/statebystate.

States also are conducting vulnerability assessments of species and habitats in their plans to help them develop appropriate conservation strategies.

In addition, the Association of Fish and Wildlife Agencies' Climate Change Committee is hosting regional workshops on climate change. As a part of this effort, AFWA staff are conducting an extensive survey on what states are doing to address climate change (not only in regards to State Wildlife Action Plans). AFWA is compiling this information and putting it on its website. Not all workshops have been held; thus, data for all states through the AFWA survey is not available, but it will be in the coming months. Please see http://www.fishwildlife.org/agency_science.html for more information.

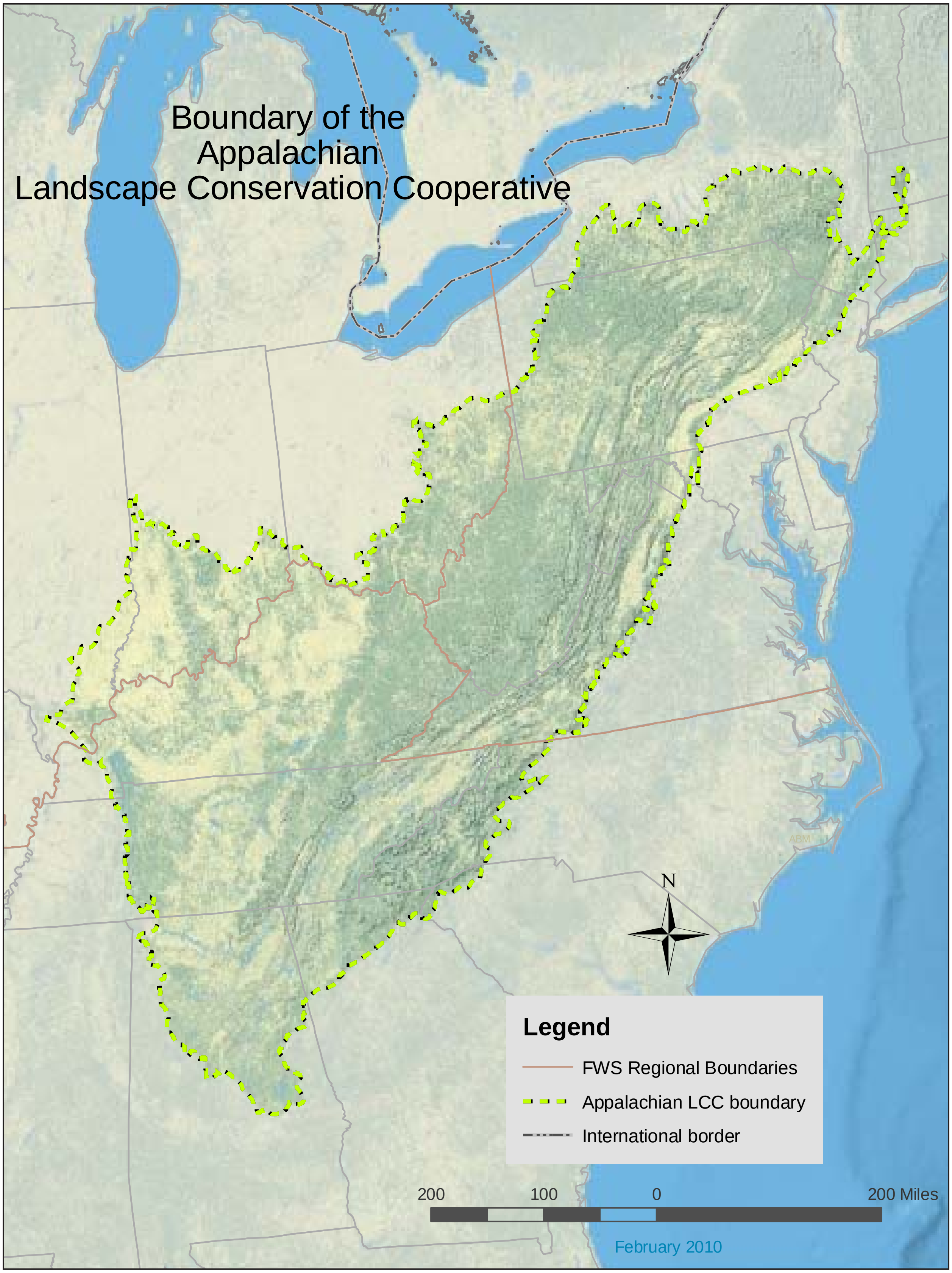

Figure 5-10. Proposed boundary for the Appalachian Landscape Conservation Cooperative (Source: USFWS 2010b)

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Annotated Bibliography

The below list of resources provide fundamental background information on climate change, adaptation, planning, vulnerability assessments, and adaptive management. This list is not exhaustive, but represents a sample of important and relevant background material that can be used as a reference for understanding basic climate change science and impacts as well as important frameworks for incorporating climate change adaptation into conservation planning. Full references along with associated download information is provided.

AFWA. 2009. Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans. *Excerpt from the Executive Summary:* The Climate Change Wildlife Action Plan Guidance Document provides voluntary guidance for state fish and wildlife agencies wanting to better incorporate the impacts of climate change on wildlife and their habitats into Wildlife Action Plans. The approaches and techniques described in this document will also be useful in modifying other wildlife plans (e.g. big game/upland game/migratory bird plans, joint venture implementation plans, national fish habitat action plan, etc.) to address climate change. The document provides an overview of the information currently available on climate change, tools that can be used to plan for and implement climate change adaptation, voluntary guidance and case studies. http://www.fishwildlife.org/pdfs/ClimateChangeGuidance%20Document_Final_reduced%20size.pdf

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Excerpt from the Executive Summary: Our goal in developing the Open Standards for the Practice of Conservation is to bring together common concepts, approaches, and terminology in conservation project design, management, and monitoring in order to help practitioners improve the practice of conservation. In particular, these standards are meant to provide the steps and general guidance necessary for the successful implementation of conservation projects. The members of CMP hope that, by developing these open standards, our colleagues in our respective organizations – and across the conservation landscape – will have a clear roadmap that will assist them to maximize the effectiveness and efficiency of their projects for maximum conservation gain. http://www.oneworldtrust.org/csoproject/images/documents/INTL41.pdf

Hannah, L. 2010. A global conservation system for climate-change adaptation. Conservation Biology 24:70–77. *Abstract:* Climate change has created the need for a new strategic framework for conservation. This framework needs to include new protected areas that account for species range shifts and management that addresses large-scale change across international borders. Actions within the framework must be effective in international waters and across political frontiers and have the ability to accommodate large income and ability-to-pay discrepancies between countries. A global protected-area system responds to these needs. A fully implemented global system of protected areas will help in the transition to a new conservation paradigm robust to climate change and will ensure the integrity of the climate services provided by carbon sequestration from the world's natural habitats. The internationally coordinated response to climate change afforded by such a system could have significant cost savings relative to a system of climate adaptation that unfolds solely at a country level. Implementation of a global system is needed very soon because the effects of climate change on species and ecosystems are already well underway.

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. (M. Parry, O. Canziani, J. Palutikof, P. van der Linden, and C. Hanson, Eds.). Cambridge University Press, Cambridge, UK. *Excerpt from Cambridge University Press website:* Climate Change 2007 – Impacts, Adaptation and Vulnerability provides the most comprehensive and up-to-date scientific assessment of the impacts of climate change, the vulnerability of natural and human environments, and the potential for response through adaptation. The report: evaluates evidence that recent observed changes in climate have already affected a variety of physical and biological systems and concludes that these effects can be attributed to global warming; makes a detailed assessment of the impacts of future climate change and sea-level rise on ecosystems, water resources, agriculture and food security, human health, coastal and low-lying regions and industry and settlements; provides a complete new assessment of the impacts of climate change on major regions of the world (Africa, Asia, Australia/New Zealand, Europe, Latin America, North America, polar regions and small islands); considers responses through adaptation; explores the synergies and trade-offs between adaptation and mitigation; evaluates the key vulnerabilities to climate change, and assesses aggregate damage levels and the role of multiple stresses. http://www.ipcc.ch/ipccreports/ar4-wg2.htm

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. *Excerpt from Cambridge University Press website:* Climate Change 2007 – Synthesis Report is based on the assessment carried out by the three Working Groups of the IPCC. It provides an integrated view of climate change and addresses the following topics: observed changes in climate and their effects; causes of change; climate change and its impacts in the near and long term under different scenarios; adaptation and mitigation options and responses, and the interrelationship with sustainable development, at global and regional levels; the long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development; and robust findings and key uncertainties. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

Karl, T. R., J. M. Melillo, and T.C. Peterson (Eds.). 2009. Global Climate Change Impacts in the United States. Cambridge University Press. *Excerpt from Cambridge University Press website:* This book is the most comprehensive report to date on the wide range of impacts of climate change in the United States. It is written in plain language to better inform members of the public and policymakers. The report finds that global warming is unequivocal, primarily human-induced, and its impacts are already apparent in transportation, agriculture, health, and water and energy supplies. These impacts are expected to grow with continued climate change – the higher the levels of greenhouse gas emissions, the greater the impacts. The report illustrates how these impacts can be kept to a minimum if greenhouse gas emissions are reduced. The choices we make now will determine the severity of climate change impacts in the future. This book will help citizens, business leaders, and policymakers at all levels to make informed decisions about responding to climate change and its impacts. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

The Nature Conservancy (TNC). 2007. Conservation Action Planning. *Excerpt from the web page:* These practices are meant to help conservation projects develop strategies, take action, and measure their success and then to adapt and learn over time. The CAP process covers the components of the Conservancy's Conservation Approach after global and ecoregional priorities have been set. It is the most recent incarnation and synthesis of what is a long legacy of project-level planning practices in the Conservancy, including Site Conservation Planning, Conservation Area Planning, and the 5-S Framework. The Conservation Action Planning methodology builds upon these previous practices using basic planning and adaptive management principles. http://conserveonline.org/workspaces/cbdgateway/cap/resources/index_html

The Nature Conservancy (TNC). 2009. Conservation Action Planning Guidelines for Developing Strategies in the Face of Climate Change. *Excerpt from the web page*: The guidance is intended to help conservation practitioners more systematically and explicitly take into consideration the potential impacts of climate change on their conservation strategies and actions. The methods were originally written for and tested by projects that already had a basic Conservation Action Plan but that did not adequately consider the potential impacts of climate change in their original plan. Thus, the guidance is best applied to existing projects that have some understanding of the conservation challenges and opportunities they face but that have not yet systematically considered climate change – these guidelines will help practitioners consider the potential effects of climate change and adjust their strategies and actions accordingly.

http://conserveonline.org/workspaces/climateadaptation/documents/climate-clinic/documents/climate-change-project-level-guidance

Theoharides, K.A., G. Barnhart, and P. Glick. 2009. Climate change adaptation across the landscape: a survey of federal and state agencies, conservation organization and academic institutions in the United States. Survey Synthesis, The Association of Fish and Wildlife Agencies, Defenders of Wildlife, The Nature Conservancy, and The National Wildlife Federation. *Excerpt from the Executive Summary:* To develop a clear definition and statement of need for adaptation we conducted 68 interviews of federal and state agency staff, non-governmental organization conservationists, and academic scientists who are thinking about or working on climate change adaptation. We asked these experts to define climate change adaptation, to discuss ongoing adaptation planning efforts, to provide us with examples of adaptation techniques and practices, and to list costs associated with these techniques. We also asked participants to discuss the challenges to planning for and implementing adaptation, the metrics associated with adaptation project monitoring, partnership opportunities, and communication strategies. http://www.defendersofwildlife.org/resources/publications/programs_and_policy/gw/climate_change_adaptation_across_the_landscape.pdf

Wildlife Management Institute and the Theodore Roosevelt Conservation Partnership. 2009. Beyond Seasons' End: *A Path Forward for Fish and Wildlife in the Era of Climate Change.* **Bipartisan Policy Center, Washington, D.C.** *Beyond Seasons' End* presents ideas of fish and wildlife professionals about actions that the human community can take to assist the wild community adapting to climate change. Impacts, recommendations and case studies are provided for coldwater fish, warmwater fish, big game, upland birds, and saltwater.

http://www.seasonsend.org/pdfs/Beyond_Seasons_End.pdf

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C.

The Department of the Interior (DOI) Adaptive Management Working Group (AMWG) sponsored the development of this technical guide to clearly and consistently define adaptive management and describe conditions for its implementation. AMWG membership includes representatives from across DOI's bureaus and offices. A writing team of resource managers, technical experts, and other specialists worked with AMWG to address four basic questions concerning adaptive management: (1) What is adaptive management? (2) When should it be used? (3) How should it be implemented? (4) How can its success be recognized and measured? These questions were used to organize both the writing effort and the structure of the guide itself, with individual chapters addressing each of the questions. The authors sought to describe adaptive management at an appropriate level of technical detail, while remaining focused on its definition, operational components, and conditions in which it applies.

http://www.doi.gov/initiatives/AdaptiveManagement/TechGuide.pdf

Appendix A

Data, Tools, and Online Resources

The availability of spatial data and other tools related to planning and climate changes is increasing at a rapid rate, so much so, that it can be hard to keep up with the rapid advances in the tools, data sets, and information that are available. Here we provide a sampling of the varied resources that are available online, drawing on information available on the web. The use of any of these resources is predicated upon evaluating the assumptions and limitations associated with the data set, as well as its appropriateness to any particular application.

Climate Change Policy and Adaptation Resources

The **NOAA Coastal Climate Change Adaptation** clearinghouse provides resources by category or state including adaptation and action plans, case studies and strategies, climate change communication, climate change science and impacts, policies and legislation, risk and vulnerability assessments, and stakeholder engagement. http://collaborate.csc.noaa.gov/climateadaptation/

The **USDA Forest Service Climate Change Resource Center** provides information and tools related to climate change for land managers, including a short course on adapting to climate change. http://www.fs.fed.us/ccrc/

The **Climate Decisions Website** is a resource to help guide decision-making about climate change adaptation, with a focus on natural resource contexts. The goal of the website is to provide information and examples to show how structured decision making can help guide the thinking and actions of decision makers who deal with climate change adaptation decisions. http://climate-decisions.org

The **Climate Decision Making Center** at Carnegie Mellon University focuses on research addressing the limits in our understanding of climate change, its impacts, and the strategies that might be perused to mitigate and adapt to change. http://cdmc.epp.cmu.edu/

The **Climate Action Network** is a worldwide network of more than 400 non-governmental organizations from 85 countries working to promote government, private sector and individual action to limit human-induced climate change to ecologically sustainable levels. www.climatenetwork.org/

In the U.S., the **U.S. Climate Action Network** is the largest network of organizations focused on climate change plays a critical role as the only network connecting organizations working on climate advocacy and policy development at all three levels of the debate: state/regional, federal, and international, all of which are becoming increasingly interdependent. http://www.usclimatenetwork.org/

The **Beyond Seasons' End** website provides a place for fish and wildlife professionals to share information and discuss ideas about confronting the threat of global climate change. The site is sponsored by the Bipartisan Policy Center, a non-profit organization dedicated to developing pragmatic and politically viable solutions to tough policy challenges. http://beyondseasonsend.org/

The **Climate Change Exchange Network** (CAKE) is a joint project of Island Press and EcoAdapt intended to help build an innovative community of practice around climate change adaptation issues for natural systems. http://www.cakex.org/

Climate Data

NOAA's **National Climatic Data Center** (NCDC) provides access to its geospatial data. The monitoring section includes U.S. and global reports, research, maps, datasets, and indices related to climate monitoring. http://www.ncdc.noaa.gov/oa/ncdc.html

The **GeoData Portal** includes a range of climatic datasets and provides an entry point to the NCDC Data Discovery Map, which allows users to search regions, states, cities, places, and zip codes for climatological data, surface data, radar imagery, and other data products. http://gis.ncdc.noaa.gov/geoportal/

Headquartered at the World Meteorological Organization in Geneva, Switzerland, the **Global Climate Observing System (GCOS)** provides data, reports, and event listings related to monitoring the climate system; detecting and attributing climate change; assessing impacts of, and supporting adaptation to climate variability and change; application to national economic development; and research to support modeling and prediction of the climate system. http://www.wmo.int/pages/prog/gcos/index.php?name=networks

The **Global Climate Observing System** (GCOS) is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) that provides information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties, and atmospheric, oceanic, hydrological, cryospheric and terrestrial processes. http://www.wmo.int/pages/prog/gcos/

The **Global Observing Systems Information Center** (GOSIC) provides access to data, metadata and information from GCOS and partner observing systems. An overview of all GCOS-relevant network components and systems can be found at http://gosic.org

Downscaled and Regional Climate Change Models

The USGS **Southeast Regional Assessment Product** (SERAP) is developing regionally downscaled climate projections and landscape change datasets that can be used to project the likely changes to the Southeast's climate and ecosystems. These regional models can be used to identify the driving factors of local climate changes and the potential impact on southeastern natural resources. In addition, the USGS will integrate urbanization and vegetation models with these regional climate models to assess how changes will impact priority species. A web-based data platform for sharing and disseminating data and results from SERAP is currently being created. http://serap.er.usgs.gov/

The North American Regional Climate Change Assessment Program (NARCCAP) is an international program serving the high resolution climate scenario needs of the United States, Canada, and northern Mexico, using regional climate models, coupled global climate models, and time-slice experiments. NARCCAP modelers are running a set of regional climate models (RCMs) driven by a set of atmosphere-ocean general circulation models (AOGCMs) over a domain covering the conterminous United States and most of Canada for the current period 1971 and for the future period 2041-2070 (50 km spatial resolution). The AOGCMs have been forced with the SRES A2 emissions scenario for the 21st century.

http://www.narccap.ucar.edu/

Data are restricted to approved users and served from the Earth System Grid. http://www.earthsystemgrid.org/

Statistically Downscaled **WCRP CMIP3 Climate Projections** are maintained in an archive by Santa Clara University/Reclamation/Lawrence Livermore Laboratory. This archive contains fine-spatial resolution translations of 112 contemporary climate projections through 2099 over the contiguous United States. The original projections are from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the IPCC 4th Assessment Report. Downscaled variables include monthly Tmin, Tmax, and precipitation (12 km spatial resolution). Data requests can be submitted through the website. http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/

Climate Wizard is a user-friendly tool developed through collaboration between The Nature Conservancy, University of Washington, and University of Southern Mississippi that allows users to access past changes in climate, as well as project future changes in rainfall and precipitation in a given area based on available climate models statistically downscaled to a 12 km^2 resolution by Maurer et al. (2007). Downscaled variables include temperature (as projected average or temperature departure) and precipitation (as projected average or predicted percent change) by month, season, or yearly averages projected for mid and end of century. http://www.climatewizard.org/

Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy. 2007. Fine-resolution climate projections enhance regional climate change impact studies. Eos Trans. AGU 88: 504.

Downscaled CCSM Projections for the U.S. are available from the NCAR's GIS Initiative Climate Change Scenarios GIS data portal. These climate change projections were generated by the NCAR Community Climate System Model (CCSM) for the 4th Assessment Report of the Intergovernmental Panel on Climate Change. Projections were produced using a statistical downscaling method and include monthly mean temperature and total precipitation (4.5 km resolution). Registration is required to download data. http://www.gisclimatechange.org/

The **USGS CASCaDE Project** provides access to U.S. downscaled climate data. The data are derived from gridded observed fields from the University of Washington Land Surface Hydrology Research Group and from Global Circulation Model (GCM) simulations of historical climate conditions (scenario 20c3m in IPCC4 studies), A2 future greenhouse-gas-and-sulfate-aerosols emissions scenarios, and B1 future emissions scenarios. The GCMs represented here, so far, are the National Center for Atmospheric Research's Parallel Climate Model 1 (PCM) and from the NOAA Geophysical Fluid Dynamics Lab's GFDL CM2.1 model. Downcaled variables include (12 km resolution). Data are available for download. http://cascade.wr.usgs.gov/data/Task1-climate/

Natural Resources Canada Climate Change Scenario website provides models for the CGCM2, Hadley-CM3 and CSIRO-Mk2, A2 and B2 scenarios for the following 30-year average periods: 2011-2040, 2041-2070 and 2071-2100. Models for individual years (2011-2100) are available by request. Downscaled variables include average monthly minimum and maximum temperature and total precipitation, and derived bioclimatic variables (10 km resolution). The models can be viewed or downloaded. http://cfs.nrcan.gc.ca/subsite/glfc-climate/climatechange

Sea Level Rise and Topographic/Elevation Data

The NOAA Coastal Services Center has developed the **Coastal Inundation Toolkit** to help communities understand and address coastal inundation issues. The toolkit can help identify exposure and examine potential impacts, map inundation, assess vulnerability, and learn how other communities are addressing sea level rise. The toolkit includes links to many relevant data sources, a number of which are included elsewhere in this list. http://www.csc.noaa.gov/digitalcoast/inundation/index.html/

The NOAA Coastal Services Center maintains the **Topographic and Bathymetric Data Inventory** which an index of the best-available elevation data sets by region. The southeast regional inventory was completed in May 2009. Users can zoom in to an area on the map and click on the data set to access up to 20 data attributes, including vertical accuracy, datums, and point spacing. http://www.csc.noaa.gov/topobathy/index.html/

NOAA's **National Ocean Service (NOS) Data Explorer** is a GIS mapping portal that offers access to many products, including bathymetry, coastal maps, environmental sensitivity index maps, aerial photographs, and more. http://oceanservice.noaa.gov/dataexplorer/

NOAA's **National Geophysical Data Center** (NGDC) provides a variety of data products, including coastal relief digital elevation models, bathymetric maps, and satellite-derived data. http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html

The USGS **Center for LIDAR Information Coordination and Knowledge** (CLICK) is a resource center for LIDAR information, discussion, and data. Its primary mission is to support scientific research on lidar point data. Voluntarily contributed LIDAR point clouds are available for download as tiles. http://lidar.cr.usgs.gov/

The **National Elevation Dataset** (NED) is a data set that contains bare-earth raster surfaces, maintained at three resolutions: 1 arc-second (~30m), 1/3 arc-second (~10m), and 1/9 arc-second (~3m). The 1/9 layer coverage is produced from LIDAR data and is available only for selected areas, including North Carolina. NED data can be downloaded from the National Map Seamless Server. http://seamless.usgs.gov/

EPA's Sea Level Rise Publications discuss nationwide impacts of SLR, including beach erosion, floods, estimates of future sea level rise, and threats to coastal wetlands. http://www.epa.gov/climatechange/effects/coastal/slrreports.html

EPA's Climate Change Program has made available maps all the data underlying the article on **Maps Vulnerable to Sea Level Rise** by Titus and Richman (2001). http://epa.gov/climatechange/effects/coastal/slrmaps_GIS.html

These data, as well the EPA coastal data used to create the elevation maps published in a February 2008 draft report on sea level rise, are also available at http://maps.risingsea.net/data.html.

Titus, J. G. and C. Richman. 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf coasts. Climate Research 18:205-228.

Jim Titus has also produced **Sea Level Rise Planning Maps** showing which lands *would* be protected from sea level rise given existing policies. The draft EPA report is summarized in the Titus et al. 2009. North Carolina specific information, including a report by Clark et al. (2010) can be found at http://plan.risingsea.net/North_Carolina.html

The data set used to create these maps in this report is available from: http://risingsea.net/ERL/data.html

Clark, W., J Kassakian, and J.G.Titus. 2010. North Carolina. In: The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 1: Mid-Atlantic (J.G. Titus and D. Hudgens eds). Report to the U.S. Environmental Protection Agency.Washington, D.C.

Titus, J. G., D. E. Hudgens, D. L. Trescott, M. Craghan, W. H. Nuckols, C. H. Hershner, J. M. Kassakian, C. J. Linn, P. G. Merritt, T. M. McCue, J. F. O'Connell, J. Tanski, and J. Wang. 2009. State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast. Environmental Research Letters 4:044008.

Woods Hole Science Center completed a **National Assessment of Coastal Vulnerability to Sea-Level Rise** in 2000. This project, within the USGS Coastal and Marine Geology Program's National Assessment, used a coastal vulnerability index (CVI) to determine the relative risks due to future sea-level rise for the U.S. Atlantic, Pacific, and Gulf of Mexico coasts. The CVI quantifies the relative risk that physical changes will occur as sea level rises based on the following criteria: tidal range, wave height, coastal slope, shoreline change, geomorphology, and historical rate or relative sea level rise. Reports and data are available at the following site http://woodshole.er.usgs.gov/project-pages/cvi/

The **Sea Level Rise Affecting Marshes Model** (SLAMM) simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. http://www.fws.gov/slamm/ or http://warrenpinnacle.com/prof/SLAMM/index.html

Land Use and Land Cover Data

The USGS **Gap Analysis Program** (GAP) recently released a national land cover map (based on 2001 satellite data) and online map viewer. These maps utilize the NatureServe Ecological Systems Classification, which provides a consistent, detailed classification of vegetative types across the U.S. The National GAP land cover map contains 551 cover classes (82 of which are occur in North Carolina). http://www.gap.uidaho.edu/landcover.html

Regional and state subsets of the national data are available thro e goal of monitoring these habitats by updating the land cover maps every five years. Data are available for 2006, 2001, and 1996. http://www.csc.noaa.gov/crs/lca/locateftp.html

The **National Land Cover Database** (NLCD) 2001 is based on satellite imagery compiled across all 50 states and Puerto Rico as a cooperative mapping effort of the MRLC Consortium. This land cover database contains standardized land cover components classified using the Anderson scale. A 1992 data set is also available, although somewhat different methodology was used to classify the earlier data set. Data are available by zone or using the seamless map server. The NLCD 1992/2001 Retrofit Land Cover Change Product provides land cover *change* information at the Anderson Level I classification scale across the two time periods. In addition, two derived data sets are available, NLCD 2001 Urban Imperviousness, and NLCD 2001 Percent Canopy. http://www.mrlc.gov/

The SILVIS Lab at the University of Wisconsin-Madison produces maps showing the **Wildland-Urban Interface**. National and state maps and data are available for download. Housing Density models are also available by decade from 1940 – 2030. http://silvis.forest.wisc.edu/maps.asp

The **Biodiversity and Spatial Information Center** (BaSIC) is currently using SLEUTH-R (Jantz et al. 2010) to model urban growth as part of the "Designing Sustainable Landscapes" project. The DSL Project uses vegetation (VDDT/TELSA) and the urban dynamics modeling to examine the potential impacts of landscape-level changes on the future capability of habitats to support wildlife populations (Adam Terand, personal communication, www.basic.ncsu.edu/dsl). These modeling approaches are currently being applied throughout the Southeastern U.S. as a part of the USGS's Southeastern Regional Assessment Project (http://serap.er.usgs.gov/).

Jantz, C. A., S. J. Goetz, D. Donato, and P. Claggett. 2010. Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model. Computers, Environment and Urban Systems 34: 1–16.

For a list of some other **Urban Growth Models** assessing projected development see Box 4-1.

Natural Resources and Biodiversity

The following natural resources and biodiversity tools can be found at:
http://www.conservision-nc.net/

- **One North Carolina Naturally Conservation Planning Tool** is composed of multiple assessment layers published by NCDENR in support of land use planning efforts in North Carolina.

- The **North Carolina Biodiversity/Wildlife Habitat Assessment** prioritizes aquatic and terrestrial habitat, landscape function and connectivity. The majority of the state's Wildlife Action Plan priority species and their associated habitats as identified by the N.C. Wildlife Resources Commission are included.

- The **North Carolina Open Space and Conservation Lands** layer is intended to inform the user about the location of existing conservation lands that are in "permanent conservation" and are actively managed by a public entity.

- The **North Carolina Water Services Assessment** prioritizes lands that are most critical to protect water resources for North Carolina's residents.

- The **North Carolina Farmland Assessment**, developed by the state Department of Agriculture and Consumer Services, prioritizes viable and threatened agriculture lands.

- The **North Carolina Forestry Lands Assessment** prioritizes forestry lands that are important for sustaining the forest products sector of economy and providing ecosystem services. These layers are available for download or through a web based map viewer.

Southeast GAP (SEGAP) Vertebrate Distribution Models are currently in review from SEGAP and available by request (draft maps are currently available as images). http://www.basic.ncsu.edu/segap/

North Carolina models based on first generation GAP data are available at http://www.basic.ncsu.edu/ncgap/

The USDA Forest Service Northern Research Station has produced **Atlases of Tree and Bird Species Habitats for Current and Future Climates**. http://www.nrs.fs.fed.us/atlas/

The USFWS **Critical Habitat** portal is an online service for information regarding threatened and endangered species final Critical Habitat designation across the U.S. http://criticalhabitat.fws.gov/

NCDENR Division of Coastal Management maintains the following data sets distributed by county: an inventory and classification of **Wetland Types** for North Carolina coastal area, an inventory of **Potential Wetland Restoration and Enhancement** sites in coastal North Carolina, and the **North Carolina Coastal Region Evaluation of Wetland Significance** (NC-CREWS) layer, a watershed based GIS wetland functional assessment model.
http://dcm2.enr.state.nc.us/Wetlands/download.htm

The USFWS **National Wetlands Inventory** provides a series of topical maps to show wetlands and deepwater habitats. http://www.fws.gov/wetlands/Data/DataDownload.html

Stewardship and Land Conservation

The **North Carolina GAP Stewardship** layer assigns a status rating to lands in North Carolina deemed to offer permanent protection to biodiversity. These status levels are based on the degree to which biodiversity is protected on the sites. Additionally, the protected areas are further identified by ownership and stewardship entities for each site. The time period for this data layer is 1994-1998. Data are available for download at http://www.basic.ncsu.edu/ncgap/

There are two national inventories of protected areas:

The **Protected Areas Database of the United States** (PAD-US) is a GIS database hosted by the USGS Gap Analysis Program that illustrates and describes public land ownership, management and conservation lands nationally, including voluntarily provided privately protected areas. Version 1.1 of this data set was released by GAP in May 2010 and can be downloaded from the USGS PAD-US web site. http://gapanalysis.nbii.gov/PADUS

PAD-US (CBI Edition) was published in May 2010, by the Conservation Biology Institute. PAD-US 1.1 (CBI Edition) is freely available for download from the Data Basin Protected Areas Center in multiple formats. The Data Basin Protected Areas Center supports multiple functions, including the ability for users to visualize and download individual state protected area datasets, and to combine them with other available conservation-related data. http://www.databasin.org/protected-center/features/PAD-US-CBI

Other Data Clearinghouses

NC OneMap is a state clearinghouse for data from a variety of state, county, and federal partners maintained by the North Carolina Center for Geographic Information & Analysis. http://www.nconemap.com/

Data clearinghouses for other federal agencies and programs:

USDA Natural Resources Conservation Service http://datagateway.nrcs.usda.gov/

USDA Forest Service http://fsgeodata.fs.fed.us/index.html

USGS Eastern Geographic Science Center http://egsc.usgs.gov/science.html

U.S. Fish and Wildlife Services http://www.fws.gov/GIS/data/national/

USFWS Southeast Region http://www.fws.gov/southeast/gis/

National Park Service http://www.nps.gov/gis/data_info/

Other Related Resources and Tools

For a list of **hydrologic models** that have been used to assess climate change impacts can be found in section see Table 4-1.

The **National Renewable Energy Laboratory** produces maps illustrating renewable resources, including biomass maps, geothermal maps, solar resource maps, and wind resource potential maps.

http://www.nrel.gov/gis

The **Tool for Exploratory Landscape Scenario Analysis** (TELSA) allows modeling of landscape dynamics in a spatially explicit framework. Model scenarios can include natural processes (e.g. succession and disturbance), as well as management scenarios. Monte-Carlo simulation allows for the exploration of sensitivity and variability in modeled outcomes.
http://www.essa.com/tools/telsa/index.html

The **Vegetation Dynamics Development Tool** (VDDT) provides a framework for modeling state transitions in vegetation and modeling of scenarios based on succession, management, and disturbance. In combination with TELSA spatially explicit landscape models can be created.
http://www.essa.com/tools/vddt/index.html

Appendix B

Ecosystem Response to Climate Change:

North Carolina Department of Environment and Natural Resources (DENR)

Assessment of Effects and Adaptation Measures

The assessment of Climate-Sensitive Ecosystems in the Adaptation Sector of the broader DENR climate change initiative is being led by the Natural Heritage Program, with input by scientific staff of other conservation agencies. It addresses in detail the likely effects of climate change on North Carolina's ecosystems and species, compares them to other threats, and recommends adaptive measures that could reduce their impact. Effects are examined separately for each of 42 ecosystem types (see below). An example for Northern Hardwoods is provided below.

To address the potential for complex or differential responses, effects are also considered for several finer levels of biological organization under each ecosystem unit, including natural community types, habitat indicator guilds, and a number of individual, potentially vulnerable, species. Essentially all of the state Wildlife Action Plan focal species are covered, individually or in habitat indicator guilds. Effects of climate change are identified by consistent categories and also described with more detailed text. Effects of climate change are rated for the likelihood and magnitude of effect. Major threats to the ecological units other than climate change are also identified and are rated in comparison to climate change. Information is stored in a database format, which will allow sorting by categories of impact and by recommended actions, as well as output of text content. After the database is initially populated, it will be distributed to conservation partners for additional input, and will eventually be analyzed to identify the most significant effects of climate change to focus on the most important interventions for adaptation.

Suggested citation for this project is: Carolina Natural Heritage Program (NC NHP). 2010. Ecosystem Response to Climate Change: Assessment of Effects and Adaptation Strategies.

For more information contact the North Carolina Natural Heritage Program:

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Northern Hardwood Forests

Theme Description:

Northern Hardwood Forests are found on high mountain slopes with a cool climate and high levels of rainfall. They are dominated by combinations of moist-site hardwoods such as yellow birch, beech, yellow buckeye, and sugar maple. The herb layer is often lush, and may range from low to fairly high diversity. These forests are subject to periodic widespread disturbances, such as ice storms or severe winds, which provide canopy openings, but probably seldom or never remove the whole canopy at once. The name refers to the resemblance of these forests to those in the northeastern United States, which have similar canopies, but the presence of Southern Appalachian endemics makes the community types in North Carolina different from those of the north.

The Beech Gap Subtype occurs in high elevation gaps and peaks, where beech trees stunted by the wind predominate. In the most extreme cases, the tree canopy may be reduced to shrub size. The trees may be quite old, although small, as growth and reproduction are relatively slow.

The Typic Subtype varies in composition and diversity. Some have a lawn-like ground cover of just a few species of sedges and grasses, while others have a lush and diverse herb layer. Three recognized variants of this community type are determined primarily by topography. Soil chemistry is also an important factor, and additional variants will undoubtedly be recognized in the future.

In the Boulderfield Forest, Ice Age freeze-thaw processes have left the ground completely covered with large boulders; very little soil is present. These areas are dominated by yellow birch with a distinctive undergrowth of gooseberries and moss on the rocks.

Ecosystem Level Effects:

<u>Predicted Impacts of Climate Change:</u>

Factor	Likelihood	Effect:	Magnitude:	Comments:
Increased Temperature	High	Neg	Med	Minimum winter temperatures are expected to increase, as well as number of days with freezing temps.
Wind Damage	High	Neg	Med	
Phenological Disruption	High	Neg	Med	
Hot Spells	High	Neg	High	
Fire	High	Neg	Med	
Drought	High	Neg	High	

Expected climate changes include warmer average temperatures, longer growing season, probably more hot spells, more drought, and more intense storms. We don't know the effect on rainfall and fog. Much of the climate in this zone is orographically determined, and may not follow the same patterns as the general regional climate, but this is less so than in the spruce-fir zone. Climatic effects will still be more drastic if fog and orographic clouds become less frequent, while these might mitigate the effect of temperature changes if they persist.

Drought may lead to increased potential for wild fire. Northern hardwood forests are not very flammable under the current climate, but could become so in more severe droughts. Drought may eliminate seepage, which is important in some boulder fields.

Predicted Ecosystem Reponses:

Ecosystem Change:	Likelihood:	Effect:	Magnitude:	Comments:
Increased Fragmentation	Med	Neg	Med	
Elevation change	Med	Neg	Med	
Acreage Change	High	Neg	Med	

Heat or drought stress could lead to mortality of species, including canopy trees. Deeper soils and greater tolerance of plants makes this less likely than in spruce-fir forests, but it is still a threat in these mesophytic communities.

Invasion by species from lower elevations could lead to competitive exclusion of northern hardwood species. However, the canopy species are highly competitive and could hold their own for many years. Under current fire-free conditions, shade-tolerant northern hardwood forest species invade drier oak forests, suggesting they can tolerate drier conditions than currently prevail in these communities. Changes might be slow, resulting from changed reproductive rates, or could be fast if wind or fire destroyed existing canopy. Typic northern hardwood forests may be able to migrate to higher elevation without much change in community composition. Boulder fields can't migrate, and beech gaps may or may not be able to.

Increased wind storm damage might favor some trees species over others, but this is likely to be minor. All characteristic trees have the ability to sprout and all are shade-tolerant enough to exist as advance regeneration.

Fire would likely be harmful to northern hardwood forests, but may not be catastrophic. Hardwood litter and forb-dominated herb layers carry fire poorly. All major plant species can sprout if burned. However, severe fire could kill old trees. Frequent fire would promote the transition to oak forest. If fire became more common, the current topographic relationship of high elevation red oak forest on dry slope aspects and northern hardwood forest on moist might be altered. This could potentially reduce northern hardwood forests more than elevational shifts alone would predict.

Northern hardwood forests in lower mountain ranges could be eliminated if their zone shifts upward too far. Those in higher ranges are unlikely to be eliminated, but their extent will become more limited. Loss of lower elevation portions of patches will increase fragmentation to some degree. Some patches that now are connected may become isolated if the lower elevation limit rises. Patches in different mountain ranges are already naturally isolated by the warmer climate at lower elevations. These communities were presumably shifted upward in elevation during the Hypsithermal period, and those on lower ranges may have been eliminated then. There is likely to be little additional wholesale loss of communities or species until the climate becomes warmer than the Hypsithermal. The Hypsithermal was drier as well as warmer, and if our future climate is not drier, the change may be less. However, having more severe drought and increased fire frequency may be sufficient to cause substantial changes even if the average rainfall does not change.

Effects of reduced area and fragmentation may be significant, reducing some species populations enough to cause demographic problems. Because the current area is limited, some species populations are likely already small enough to be close to demographic problems.

Habitat Level Effects:

Natural Communities:

Third Approximation Name:	Comments:
Boulderfield Forest	Tied to distinctive sites, these communities will generally not be able to migrate at all. A few new examples may develop, where bouldery sites are currently covered with spruce-fir, as at Grandfather Mountain. The distinctive boulderfield environment is occupied by the Boulderfield Subtype of Rich Cove Forest at lower elevations, and this community will spread into some of the lower elevation Boulderfield Forests. Some Boulderfield Forests have substantial seepage. Droughts may be a threat to seepage and disrupt the water-dependent component of the community.
Northern Hardwood Forest (Beech Gap Subtype)	Tied to distinctive microsites -- either high elevation gaps or high elevation peaks that might otherwise have spruce-fir. Both may be particularly vulnerable to warming climate. The most likely community to develop in their place would be typic Northern Hardwood Forest.
Northern Hardwood Forest (Typic Subtype)	Usually occurs in large patches. Patches will likely migrate uphill and shrink but most are unlikely to be eliminated.

LHI Guilds:

Guilds with Significant Concentration in Theme: Comments:

High Elevation Montane Mesic Hardwood and Mixed Forests

The High Elevation Montane Mesic Hardwood and Mixed Forests guild has most of its habitat contained within this theme, although the Spruce-Fir Forests Theme also contributes a small amount. The Spruce-Fir Forests guild, conversely, has some of it habitat contained within this theme, but is otherwise primarily concentrated within the Spruce-Fir Forests Theme.

Species Level Effects:

Plants

Species:	Global Rank	Endemic	Major Disjunct	Extinction Prone	Federal Status:	Federal Comments:
Stachys clingmanii	G2Q	No	No	No		
Scutellaria saxatilis	G3	No	No	No		
Aconitum reclinatum	G3	No	No	No		This species is at the southern limit of its range in NC and TN.
Brachyelytrum aristosum	G4G5	No	No	No		
Robinia hispida var. fertilis	G4T1Q	No	No	No		
Trientalis borealis	G5	No	Yes	No		This species is a long-distance northern disjuct existing in scattered small populations. It is particularly at risk of warmer temperatures.
Streptopus amplexifolius	G5	No	No	No		
Meehania cordata	G5	No	No	No		This species is at the southern limit of its range in NC and TN.
Scutellaria ovata ssp. rugosa var. 1	G5T1?Q	No	No	No		The taxonomy of the Scutellaria ovata group is poorly understood.

Warmer temperatures in the winter may allow new species to invade areas where cold winter temperatures would otherwise be a limiting factor. Where invaders compete with rare species, there could be detrimental effects to populations.

Terrestrial Animals

Species:	Global Rank:	Endemic	Major Disjunct	Extinction Prone	Federal Status:	Comments:
Plethodon welleri	*G3*	*Yes*	*No*	*No*		
Desmognathus imitator	*G3G4*	*Yes*	*No*	*No*		
Desmognathus wrighti	*G3G4*	*Yes*	*No*	*No*	*FSC*	
Desmognathus santeetlah	*G3G4Q*	*Yes*	*No*	*No*		
Desmognathus imitator pop. 1	*G3G4T1Q*	*Yes*	*No*	*Yes*		*Taxonomic status needs to be resolved*
Contopus cooperi	*G4*	*No*	*No*	*No*	*FSC*	
Itame subcessaria	*G4*	*No*	*No*	*No*		
Carduelis pinus	*G5*	*No*	*No*	*No*		
Lithophane georgii	*G5*	*No*	*Yes*	*No*		*Disjunct from New England and Canada.*
Certhia americana	*G5*	*No*	*No*	*No*		
Polygonia progne	*G5*	*No*	*No*	*No*		
Troglodytes troglodytes	*G5*	*No*	*No*	*No*		
Glaucomys sabrinus coloratus	*G5T1*	*Yes*	*No*	*No*	*LE*	*Likely to face increased competition from southern flying squirrels*
Loxia curvirostra pop. 1	*G5TNR*	*Yes*	*No*	*No*	*FSC*	*Endemic subspecies?*
Poecile atricapillus practica	*G5TNR*	*Yes*	*No*	*No*	*FSC*	*Likely to face increased competition from Carolina chckadees*
Aegolius acadicus pop. 1	*G5TNR*	*Yes*	*No*	*No*	*FSC*	*Endemic subspecies? major disjunct as sp*
Eulithis propulsata	*GNR*	*No*	*No*	*No*		
Erora laeta	*GU*	*No*	*No*	*No*		

There is a major concern about salamanders, as this is a key theme for rare and southern Appalachian endemic species. On the other hand, the bird species are all more common and widespread farther northward, though a few species may become rare in the state. At least six taxa are endemic to this Theme in the Southern Appalachians; three others may also fall in this

category, but have not yet been formally described as separate subspecies. Additionally, one moth appears to be a major disjunct from the Northern Appalachians and several others are likely to have a similar distribution but are presently too poorly known. All species listed for this Theme are likely to be strongly affected by climate change, including the effects of increased fragmentation.

Combined Threats and Synergistic Impacts:

Importance of Climate Change Factors Compared to Other Ecosystem Threats:

Threat:	Rank Order:	Comments:
Climate Change	1	
Development	2	
Logging/Exploitation	2	

The majority of Northern Hardwood Forests are on public lands and many are in protected status. Development on private lands, and logging on private and some public lands remain threats, and are likely the most immediate and greatest threat to a significant number of good examples. Climate change, particularly associated drought and wild fire, is the greatest threat to protected examples. However, the threat of climate change is less severe than in Spruce-Fir Forests and the threat of logging and development are relatively greater.

Recommendations for Action:

Intervention Measures:

Intervention:	Importance:	Feasibility:	Comments:
Restore/Maintain Landscape Connections	Medium	Medium	
Protect/Expand Remaining Examples	High	High	
Protect from Wildfire	High	High	

For unprotected examples, protection from development and logging is the most important action needed. While many areas are protected, many good examples are unprotected, and some portions of the mountains have little protected area. Warmer winters and more hot spells may fuel increasing desire for housing development at the higher elevations where these communities occur. Effort should particularly be made to protect examples at the higher elevations, where the community is likely to persist and where the seed source for migration to higher elevations will primarily come from. Because the overall extent of the community and of individual patches will decrease, loss of these areas will become more important than at present. There are some opportunities to restore and expand these communities into areas where they have been lost, but the overall loss and potential for restoration has been less significant than in Spruce-Fir Forests.

Protecting examples from wild fire, especially severe fires under drought conditions, would help prevent catastrophic loss of these communities or would allow them to persist longer and migrate more slowly. However, in lower elevation areas where a transition to oak forest is inevitable, prescribed burning in the near future, before severe conditions develop, would promote a more gradual and less disruptive transition. It would allow more fire-tolerant and drought-tolerant species to become established.

Some areas that appear to be young Northern Hardwood Forests at present are actually successional communities. Some developed after the destruction of Spruce-Fir Forest. Others developed where exclusion of fire shifted canopy dominance away from oak species. In both cases, where this can be documented, restoration to the original communities rather than attempting to retain them as Northern Hardwood Forests is desirable.

Theme Summary:

Communities and species associated with this theme are all highly likely to be affected by changes in temperature and moisture associated with climate change. Although occupying a larger area and probably somewhat more resilient than the Spruce-Fir Forests theme, this theme contains a similar high proportion of endemics and major disjuncts, the loss of which cannot be replaced. Along with the Spruce-Fir Forests, this theme should be considered as one of the most threatened by climate change and should receive a high priority for intervention. Like the Spruce-Fir Forests, a substantial amount of the acreage of this theme is located on public lands or on other conservation lands. Consequently, intervention should be easier to implement for this theme than for many others.

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Draft List of ecosystem units used for evaluating Ecosystem Response to Climate Change: DENR Assessment of Effects and Adaptation Measures

1. Blackwater Coastal Plain Floodplains
2. Brownwater Coastal Plain Floodplains
3. Coastal Plain Depression Communities
4. Coastal Plain Large River Communities
5. Coastal Plain Marl Outcrop
6. Coastal Plain Nonalluvial Mineral Wetlands
7. Coastal Plain Stream/Ditch Communities
8. Coastal Plain Swamp Communities
9. Dry Longleaf Pine Communities
10. Estuarine Communities
11. Freshwater Tidal Wetlands
12. General Hardwood and Mixed Forests
13. Granitic Flatrocks
14. Grass and Heath Balds
15. High Elevation Rock Outcrops
16. Low Elevation Cliffs and Rock Outcrops
17. Mafic Glades and Barrens
18. Maritime Grasslands
19. Maritime Upland Forests
20. Maritime Wetland Forests
21. Montane Cold Water Stream Communities
22. Montane Cool Water Stream Communities
23. Montane Oak Forests
24. Mountain Bogs and Fens
25. Mountain Cove Forests
26. Natural Lake Communities
27. Northern Hardwood Forests
28. Peatland Pocosins
29. Piedmont and Coastal Plain Mesic Forests
30. Piedmont and Coastal Plain Oak Forests
31. Piedmont and Mountain Dry Coniferous Woodlands
32. Piedmont and Mountain Floodplains
33. Piedmont Headwater Communities
34. Piedmont Large River Communities
35. Piedmont Small River Communities
36. Sparsely Settled Mixed Habitats
37. Spruce Fir Forests
38. Streamhead Pocosins
39. Successional and Ruderal Uplands
40. Successional Wetlands
41. Upland Seepages and Spray Cliffs
42. Wet Pine Savannas

Appendix C

Regulatory Context for Wind Facility Development in North Carolina and Five Other States

This report was developed by Erin Kimrey for the North Carolina Conservation Network, as an in-depth review of the regulatory context for wind development in North Carolina. This resource is particularly helpful for understanding how wind development interacts with existing environmental regulations in the state. A brief review of additional states (MN, OR, WA, CA, VA) is also provided. All Appendices from this report have been removed for this publication. The full report can be found at: http://h2o.ehnr.state.nc.us/admin/emc/documents/RegulatoryContextforWind-Kimrey.pdf

This report can be cited as: Erin Kimrey, A Regulatory Framework for Wind Energy in North Carolina, Nicholas School of the Environment and Earth Sciences (2006) (unpublished masters degree project, Duke University).

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This paper attempts to lay out the current state-level regulatory context for utility-scale wind facility development in North Carolina. In recent months, several North Carolina counties have also adopted local ordinances regulating wind facility siting, and the North Carolina Wind Working group is drafting a model ordinance for local governments; this paper touches on those local efforts but does not discuss them in detail. At the end of the paper, five states' rules and regulations governing wind energy siting are summarized: Minnesota, Oregon, Washington, California and Virginia. Detailed footnotes provide reference documents for further information and details on the laws and regulations discussed herein. The Appendix includes a map of wind resources in North Carolina and an overlay of windy counties with local zoning regulations.

REGULATORY CONTEXT FOR WIND ENERGY IN NORTH CAROLINA

In North Carolina, there are four distinct settings in which wind energy facilities might be built: in the mountains, on the coastal plain, in state waters of the sound or offshore, or offshore in federal waters.[1] Each location carries with it different state regulatory requirements for siting. This section will explore the key existing regulations that would govern the siting of wind facilities in North Carolina in each of these locations. There are some existing state regulatory barriers to wind development both in the mountains and at the coast that will also be discussed.

I. State Context in North Carolina

A. Mountain Ridge Protection Act

In 1983 the General Assembly passed the North Carolina Mountain Ridge Protection Act, which restricted building on North Carolina's mountain ridges.[2] The law, commonly referred to as the Ridge Law, states that buildings and structures over 40 feet in height cannot be built along, or within 100 feet of, ridges that are over 3,000 feet in elevation. Among its stated purposes, many of which are non-aesthetic, is an intention to protect the natural beauty of the mountains. The law gave counties and cities a small window of opportunity to either opt out of the law or pass their own ordinances governing building on mountain ridges; if such action was not taken by January 1, 1984, the law would become effective. Even if a local government adopted its own ordinance, however, consideration to "protecting the natural beauty of the mountains" must be a permitting requirement in the local ordinance. With interest in wind energy growing, there has been quite a bit of debate in North Carolina about whether the Ridge Law prohibits the construction of wind turbines in the mountains. Wind energy advocates argue that the law contains an exemption for wind turbines. The law states that "tall buildings and structures" do not include "water, radio, telephone or television towers or any equipment for the transmission of electricity or communications or both" or "structures of a relatively slender nature and minor vertical projections of a parent building, including chimneys, flagpoles, flues, spires, steeples, belfries, cupolas, antennas, poles, wires, or windmills."[3] Wind proponents argue that the exemption specifically exempts "windmills" and that this applies to modern day wind turbines as well. An attorney for Watauga County recently argued in a legal memo that windmills meet the exemption because they are "naturally slender."[4] She further argued that the presence of a single wind turbine[5] on a peak near Boone in 1983 indicates that windmills were specifically exempted "to avoid de-legitimizing" this project, and thus the term "windmill" in the exemption was intended to apply to large wind turbines. North Carolina Attorney General Roy Cooper, on the other hand, proffered a different interpretation in a 2002 memo to the Tennessee Valley Authority regarding a proposed wind energy facility near the North Carolina border.[6] Mr. Cooper wrote the memo as a comment during the Environmental Assessment process for the facility. In the memo, Cooper argues that a wind farm with thirteen 300 foot high turbines along 2 miles of ridgeline could not be considered "slender in nature" and would *not* fall under the exemption in the Ridge Law. Further he states that the intention of the legislature in 1983 was to exempt "the traditional solitary farm windmill which has long been in use in rural communities" and not large utility-scale wind farms. He also notes that the exemption for electric transmission lines does not apply to wind turbines since turbines are generating equipment and are distinct from transmission equipment. Cooper has since declined to issue a formal opinion on the law, indicating that interpretation of the exemption is up to individual counties.

B. Certificates from the North Carolina Utilities Commission

In North Carolina, any electric generation facility or transmission line must apply for and obtain a certificate from the North Carolina Utilities Commission (Commission).[7] Primarily, the Commission's role is to ensure the provision of "adequate, reliable and economical utility service to all of the citizens and residents of the state." However, the Public Utilities Act which created the Commission also lists among its purposes "to encourage and promote harmony between public utilities, their users and the environment."[8] The law and the Commission's rules lay out slightly different procedures for generation facilities and transmission lines. While this paper focuses on generating facilities, it can be helpful in this case to understand the Commission's role in transmission line siting since it includes some level of environmental consideration. The role of the Commission in addressing environmental impacts from siting generation facilities or transmission lines is somewhat vague and decidedly weak.

1. Certificate of Public Convenience and Necessity.

North Carolina law requires anyone constructing an electric generation facility to apply for a "certificate of public convenience and necessity" from the NC Utilities Commission. In 2007 the General Assembly passed a Renewable and Efficiency Portfolio Standard (REPS) (Session Law 2007-397), and in doing so exempted renewable energy facilities under 2 megawatts from the Certificate requirement, though they still must file a report with the Commission.[9] In February, 2008, the NC Utilities Commission adopted rules implementing the REPS. These rules spell out information that is to be contained in the application for a Certificate from a renewable energy facility[10], including business ownership information, costs, the site in relation to roads, streams and other landmarks, and a list of all federal and state licenses and permits. The application does not request any environmental information, and only minimal site layout information.

Applications for Certificates for renewable energy facilities are to be sent to the State Clearinghouse in the Department of Administration for distribution to agencies having an interest, including environmental agencies and commissions, who are then given an opportunity to comment on the application.[11] The new rules also require public notification in a local paper and a public hearing if any complaints are received.[12] For generating facilities of 300 MW or more, the Commission's rules do require the applicant to submit site information as well as "preliminary information concerning geological, aesthetic, ecological, meteorological, seismic, water supply, population and general load center data…" and a statement of "proposed environmental evaluation program to meet the applicable air and water quality standards" 120 days prior to filing an application.[13] There is nothing in the rules, however, about whether more definitive information will be required or how this information is to be considered in the Commission's decision.

2. Certificate of Environmental Compatibility and Public Convenience and Necessity

For electric transmission lines, North Carolina law provides for some level of environmental consideration by the Commission. The statute requires entities to obtain a "certificate of environmental compatibility and public convenience and necessity" for any new transmission line over 161 kilovolts.[14] The application for such a certificate includes site information as well as an environmental report discussing the environmental impact, mitigation measures and alternatives.[15] Furthermore the law states that the Commission shall grant the certificate if it meets several criteria regarding necessity and cost, and if "the impact the proposed transmission line will have on the environment is justified considering the state of available technology, the nature and economics of the various alternatives, and other material considerations…"[16] There are two additional provisions in this section of the law that are worth noting. The requirement for a certificate can be waived if the transmission line has undergone licensing by the Federal Energy Regulatory Commission (FERC).[17] FERC has jurisdiction over interstate transmission lines, so if a line were to be built to connect a wind facility in western North Carolina to Tennessee, this exception might apply. Additionally, the Commission's decision preempts local ordinances, although local governments are given an opportunity to present their case as a party to the proceeding.

3. Public involvement

The application for a certificate for generating facilities triggers a public notice in the local paper and, if requested, the Commission must hold a public hearing to determine whether a certificate should be issued.[18] There is also a process for appeal of the Commission's decision, although the appellant is required to post a bond to compensate the applicant for damages for project delays if the appeal is lost.[19] The requirements for certificates for transmission lines are slightly different, but similar in spirit.[20]

C. North Carolina Environmental Policy Act

North Carolina has a state level version of the National Environmental Policy Act (NEPA) – the North

Carolina Environmental Policy Act (NCEPA) - which provides a process for environmental review of projects in which the state is involved.[21] An environmental review under NCEPA, however, would not always be triggered by development of a wind facility. NCEPA environmental review is required for projects that meet three criteria: (1) where there is an expenditure of public monies or use of public land (including submerged lands), *and* (2) a state action (such as a permit), *and* (3) a potential environmental effect "upon either natural resources, public health and safety, natural beauty, or historical or cultural elements of the state's common inheritance."[22] Tax incentives that are available after a facility is operating do not trigger NCEPA.[23] The state Renewable Energy Tax Credits and the Federal Production Tax Credit for Wind would, therefore, not trigger NCEPA, but it is possible that the State Renewable Energy Grant program would.[24] Under the North Carolina Coastal Area Management Act (CAMA), the primary permitting program for coastal development, which is discussed in more detail below, most activities requiring a CAMA permit are explicitly exempt from NCEPA review unless they meet certain criteria established by the Department of Environment and Natural Resources (DENR).[25] For projects requiring a CAMA major permit or Dredge and Fill permit, DENR has established minimum criteria that must be met in order to trigger NCEPA; projects that do not meet this minimum threshold are exempt from NCEPA even if they otherwise would be subject to NCEPA.[26] One criterion may be applicable to wind farms: excavation of materials from aquatic environments for non-navigational projects *does* trigger NCEPA.[27] Installation of wind turbines in state waters, either the sound or up to 3 miles offshore, would involve excavation, and thus, would meet the minimum criteria. Since projects in state waters would meet the excavation criteria, and would meet the three basic triggers of NCEPA review – public funds or land (including submerged land), permits, and potential environmental impact - wind energy projects in state waters would be subject to NCEPA.

Projects that require a CAMA permit but are located on land, however, would be exempt from a NCEPA review. Another provision in the rules allows an agency Secretary, in this case the NC Department of Environment and Natural Resources (DENR), to require an environmental document when the proposed activity does not meet the agency's minimum criteria but may have potential for significant adverse effects.[28] It is not clear whether this provision only applies to projects that fall under the scope of NCEPA in the first place – i.e., involve public money or land, require a permit, and have potential environmental impacts, so it is unclear whether the Secretary's discretion to require an environmental review for CAMA-permitted projects would apply to wind farms on private land. General permits, which are granted for routine projects with little or no environmental impact, under the Coastal Area Management Act (CAMA), as well as under air pollution and water discharge laws, are exempt from NCEPA.[29] Also noteworthy is an exemption in the rules from NCEPA for sampling and research activities, which could include the installation of an anemometer to gather wind speed data.[30]

D. Coastal Area Management Act

As authorized by the federal Coastal Zone Management Act, the state developed its own Coastal Management Program, which was federally approved in 1978. As part of this program, the state adopted the Coastal Area Management Act (CAMA).[31] CAMA established the Coastal Resources Commission (CRC), required local land use planning in the 20 coastal counties and created a program for regulating development through a permitting process.[32] The statute authorizes the CRC to establish rules for protection and conservation of natural resources (including scenic vistas), economic development, recreation; preservation of cultural aspects, and protection of public rights.[33] In terms of regulating development, the CRC has the authority to issue permits for development inside "areas of environmental concern" (AEC), which the CRC is authorized to define.[34] Within the CAMA counties, AECs encompass most navigable waters of the state but only three percent of the land area.[35] The CRC has established rules to define four categories of AECs and has established general and specific use standards in each AEC.[36] Permits are required only if a project falls within or affects an AEC and does not meet one of the exemptions.

1. When a CAMA permit is req uired.

There are two types of permits, "major permits" and "minor permits." A "major permit" is required if the project (1) falls under the definition of "development", *and* (2) is in an AEC, *and* (3) meets one of the following 3 criteria: (a) requires any other state or federal action, (b) involves construction on over more than 60,000 square feet, or (c) involves alteration of more than 20 acres of land or water.[37] All other projects – a house for example - within an AEC would require a "minor permit."[38] Local governments are delegated authority by the CRC to issue minor permits.[39] There is one provision in CAMA that could potentially exempt wind generating facilities or transmission lines from requiring a CAMA major permit. The statutory definition of "development" provides an exemption for energy facilities under certain circumstances: "Work by any utility and other persons for the purpose of construction of facilities for the development, generation, and transmission of energy to the extent that such activities are regulated by other law or by present or future rules of the state Utilities Commission regulating the siting of such facilities (including environmental aspects of such siting) … [shall not be deemed to be development]."[40] Current Utilities Commission rules do not, I believe, regulate siting enough to trigger this exemption; however how possible future Environmental Management Commission rules would interact with CAMA is an area that would need further exploration.

2. Application of CAMA in the Coastal Plain.

On land, the CAMA permitting structure covers very little area in the 20 coastal counties.[41] Unless it is being proposed very near the sound or ocean such that it falls within the boundaries of an AEC, a wind facility on the coastal plain would likely not trigger a CAMA permit, and thus be subject only to local zoning and ordinances. The statute does allow for CRC permitting jurisdiction in areas that "affect" AECs, although it is unclear how this standard would be determined for wind farms or if it includes, for instance, consideration of effects on birds.[42] CAMA establishes a cooperative program between local and state governments in which the state acts "primarily in a supportive standard-setting way."[43] It requires counties to prepare local land use plans,[44] and requires these plans to be consistent with state guidelines;[45] it conversely requires CAMA permits to be consistent with local land use plans.[46] It is unlikely, however, that individual county land use plans in North Carolina address wind power specifically.[47] Thus, although most of the coastal wind resources are located on the water, it is feasible that a major wind facility could be sited on coastal land with no specific requirement for state permitting through CAMA, and no environmental review or public notification.

3. Application of CAMA in State Waters.

In general it is safe to assume that all state waters in the coastal counties fall under the Areas of Environmental Concern;[48] thus a wind facility in the sound or nearshore would require a CAMA major permit. Additionally, and, as discussed above, a wind facility in the water would trigger environmental review under NCEPA due to the fact that it involves state (submerged) land, requires a state permit, has potential impacts on the environment, and would involve excavation of materials from aquatic environments for a non-navigational project and thus exceed DENR's minimum threshold for exemption.[49]

However, here we come to a possible regulatory barrier to coastal wind development in North Carolina. The CRC rules implementing CAMA prohibit development of structures that are not "water dependent" in the estuarine waters of the state.[50] Water-dependent structures include docks and boat ramps, but not currently wind turbines. In 2005, a CRC subcommittee provided an informal ruling that wind turbines would not be considered water-dependent structures and voted not to amend the rules to allow such facilities.[51] An additional barrier is a CRC rule prohibiting any development that would impact or relocate oceanfront dunes or vegetation; this could prohibit running transmission lines from an offshore wind farm to land in North Carolina.[52] This prohibition applies only to the Ocean Erodible Area of Environmental Concern and thus transmission lines from wind turbines behind the dunes in the sound would not trigger this prohibition.[53] CAMA does contain a procedure for applicants to request a variance from the rules, though the standards are rigorous. The applicant must show that the prohibition causes unnecessary hardship, that conditions are peculiar to the specific property, and that the variance would be consistent with the purpose and intent of the rules.[54] It is not clear that a wind development could successfully receive a variance. If the CRC does not grant a variance, the developer can petition for a contested case hearing,[55] and if still unsatisfied, can appeal for judicial review.[56]

E. Other State Permits

Development of a wind facility in state waters would trigger several additional permit requirements. One of the benefits of getting a CAMA permit for coastal development is that it provides a coordinated process for permitting projects in the coastal zone, although the CRC does not have veto power over other permits.[57] The major CAMA permit application serves as the application for several other state and federal permits, including, but not limited to, dredge and fill permits under the NC Dredge and Fill Act,[58] a permit under the NC Archives and History Act,[59] state water and air pollution control permits including a 401 water quality certification, as well as the certificates required by the NC Utilities Commission.[60] A 401 certification is required if a project impacts wetlands or waters and triggers a federal 404 wetlands permit by the Army Corps of Engineers. CAMA permits are reviewed by 10 state and 4 federal agencies through the State Clearinghouse process.[61] Additionally a wind developer in state water will need to obtain a submerged land lease from the North Carolina Department of Administration.[62] A lease will not be considered until all permits and approvals are obtained.

II. Local Jurisdiction

At the local level, a wind facility in North Carolina would probably need to obtain some sort of local approval, although in some cases this could be as minimal as a building permit. As discussed below, local land use regulations may or may not be applicable depending on the county. Additionally, within the last year, several counties in North Carolina have adopted local ordinances governing the siting of wind facilities.

A. Land Use Regulations

Zoning is the primary way that local governments regulate land use, setting out development regulations and standards within pre-defined zones. In North Carolina, counties are not required to adopt zoning ordinances. About three quarters of the 100 counties in the state have zoning ordinances – 60 that apply countywide and 18 that apply to only part of the county.[63] Nineteen counties, however, do not have any zoning regulations.[64] It is worth noting that most of the viable wind resource areas, both coastal and mountains, occur in counties with no or partial zoning.In cases where there is no zoning ordinance or the ordinance does not apply in the proposed location, a wind facility would very likely only be required to obtain a local building permit. As discussed above, state or federal permits may or may not be required, depending on the project, and those permits may or may not require an environmental review or a public input process. It is quite conceivable that a utility-scale wind project on land, either at the coast or in the mountains, could be built with no real consideration of its land use impacts, no environmental review, no design standards or conditions, and no meaningful opportunity for public input.

B. Local Ordinances in NC

In response to recent proposals to build wind facilities, local communities in North Carolina have begun to pass local ordinances regulating the siting of such facilities. These vary in the size of turbines they regulate and the parameters placed on development. Watauga County was the first to adopt such an ordinance in August, 2006 establishing a permitting process, public input process and noise, height, and setback restrictions.[65] Ashe County followed suit in July, 2007.[66] In September, 2007, Camden County adopted a local ordinance[67] and Currituck County adopted an ordinance in January, 2008.[68] Interestingly, the Currituck County ordinance uses authority given to it in the NC Environmental Policy Act[69] to require the applicant to submit an Environmental Impact Statement and for the County to submit that to applicable federal and state agencies, including DENR, the NC Wildlife Resources Commission, the US Fish and Wildlife Service, and the Army Corps of Engineers for comment.

STATE REGULATION IN FIVE STATES

A. Minnesota

Minnesota a consolidated state level permitting processes specifically for wind energy facilities. The state regulations apply to developments over 5 MW, include a thorough environmental review process, and preempt local zoning. The Minnesota legislature passed the Wind Facility Siting Act in 1995,[70] and in 2002 the Minnesota Environmental Quality Board adopted rules for siting Large Wind Energy Conversion Systems, over 5 megawatts, though in 2007 regulatory authority was transferred to the MN Public Utilities Commission. Small wind power systems (under 5 megawatts) are subject to local jurisdiction only. The Wind Siting Act provides for an environmental review process that takes the place of review under the Minnesota Environmental Policy Act. There is no environmental review required for small wind systems under 5 MW.[71] Wind energy systems over 50 MW must also obtain a certificate of necessity from the Public Utilities Commission.[72]

For large wind systems, the state's policy is "to site large wind energy conversion systems in an orderly manner compatible with environmental preservation, sustainable development and the efficient use of resources."[73] The rules for siting large wind systems provide: (1) a clear review process, with permits issued within 180 days; (2) a consolidated permit that includes all other required site approvals; (3) a conditional permitting process in which conditions and standards for turbine design, site layout, construction activities, and operation are included in the site permit; (4) procedures for public notification and hearing; (5) enforcement procedures to respond to violations; and (6) a thorough environmental review as part of the permitting process.[74] The application for a permit must contain a detailed analysis of the potential environmental impacts, proposed mitigative measures, and any adverse environmental effects that cannot be avoided. Review and public comment on this analysis constitutes the environmental review, and a permit with specific conditions is crafted based on this review. This process replaces the environmental assessment worksheet or environmental impact statement under the Minnesota Environmental Policy Act. The site permit issued under the Wind Facility Siting Act preempts all local zoning, building or land use rules, regulations or ordinances.[75]

B. Oregon

In Oregon, wind projects over 105 MW[76] must apply for a site certificate from the Oregon Energy Facility Siting Council (EFSC).[77] Wind facilities under 105 MW are not required to go through the EFSC site certificate process, but may opt to do so.[78] The threshold of when a site certificate is required was raised from 25 MW to 105 MW by the 2001 Oregon legislature.[79]

The EFSC is a seven-member citizen board appointed by the Governor. The site certificate issued by the EFSC is a consolidated state permit and, once issued, state and local agencies must issue their permits; however, federally-delegated air and water permits – for instance Clean Water Act Section 401 water quality permits - are not covered under the site certificate, nor are non-siting related permits.[80] The EFSC must issue or deny a permit within 12 months.[81] Wind facilities under 300 MW are eligible for expedited review, in which case the siting decision must be made within 6 months or 9 months if there are interveners in the contested case hearing.[82] The EFSC also issues certificates for other types of electric generating facilities and transmission lines. Oregon does not have a state environmental policy act, and the EFSC process does not require an EIS. The application, however, is extensive, and projects must meet a set of specific standards, including fish and wildlife habitat, protected areas, threatened and endangered species, noise, scenic, and land use standards.[83] The rules include specific standards for wind facilities.[84] If the project meets the standards, the Council must issue a site certificate, which can be subject to conditions. It may also issue a certificate even if the standards are not met if the Council determines the benefits outweigh the costs. In terms of land use, wind developers have the option of seeking local land use approval or having the Council make the land use determination.[85] This may be a reason for small wind projects to opt into the state level siting process if they expect local opposition, as the Council's decision preempts local authority.[86] The process includes public notification, hearing, a contested case hearing, and procedures for appeal and judicial review.

C. Washington

In Washington, wind developers are exempt from the statewide permitting process for energy facilities, but may opt into it voluntarily.[87] The Energy Facility Site Evaluation Council (EFSEC) serves as a centralized siting agency for nuclear, coal or gas-fired power plants over 350 megawatts. Wind projects are exempt from EFSEC jurisdiction, and, unless they opt into the centralized state process, are permitted through a local land use process. Local permitting, however, triggers an automatic state-level environmental review under the State Environmental Protection Act (SEPA) and the EFSEC becomes the lead agency in the SEPA process.[88] For example, in the case of the Stateline project, a 263 MW project that straddles the Oregon and Washington state line, the 180 MW portion in Washington received a local conditional use permit, with environmental review through a SEPA EIS.[89] The EFSEC is comprised of a Governor appointee, representatives from five state agencies, including the Departments of Ecology, Fish and Wildlife, and Natural Resources, and a local representative from the jurisdiction where the project is proposed. The 12-month long review includes an environmental review under SEPA, which could include an Environmental Checklist or a full Environmental Impact Statement. The EFSEC retains an independent consultant to conduct the environmental review, paid for by the applicant. Energy facilities must meet a set of environmental standards pertaining to noise, fish, wildlife, and wetlands. The EFSEC holds a land use consistency hearing to determine if the project is consistent with local land use laws; if not, the EFSEC has the authority to preempt local zoning. The process includes both public notice and hearings specifically about the EIS, and adjudicative hearings about the application. If the EFSEC determines the project meets all standards, it issues a draft Site Certification Agreement which is either signed or rejected by the Governor.[90] In 2006, the Washington legislature passed a bill authorizing the EFSEC to grant an expedited permitting process if the council finds the environmental impact is not significant or will be mitigated and is consistent with local land use regulations. Under an expedited process, there is no environmental review, nor any adjudicative hearings.[91]

D. California

In California, decisions on siting wind projects are left to local governments, but projects must undergo a state level environmental review, which includes opportunities for public notification and comment. The California Energy Commission does not regulate wind projects because its authority extends only to thermal power plants over 50 megawatts.[92] However, under the California Environmental Quality Act (CEQA),[93] any project that involves state or local government participation, financing or approval, and has the "potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment" must undergo an Environmental Impact Report (EIR). In most cases this would encompass wind projects. Certain projects, including projects located in environmentally sensitive areas or projects that substantially affect wildlife habitats, must also undergo a State Clearinghouse review by other state agencies.[94]

In the case of Altamont Pass, the first and largest U.S. wind project, the Alameda County Zoning Board of Adjustments issued conditional use permits and did not require an Environmental Impact Report under CEQA. The County claimed a categorical exemption from CEQA, although the CEQA guidelines clearly state that a "categorical exemption shall not be used for an activity where there is a reasonable possibility that the activity will have a significant effect on the environment."[95] The Altamont Pass wind project, built in the mid 1980s, has received worldwide notoriety for bird deaths. A 2004 study done by the California Energy Commission found that the Altamont Pass turbines kill an estimated 881 to 1,300 birds of prey each year, many of which are endangered or threatened species.[96] The permits were up for renewal in 2004, and although environmental groups and state and federal wildlife agencies presented substantial evidence on the environmental impacts of the turbines and called for an EIR, the County re-issued the permits in 2005, again without an EIR.[97] Most wind projects in California, however, undergo the EIR process.

E. Virginia

In Virginia, wind energy projects must receive local approval as well as a state certificate which entails some level of environmental review. The State of Virginia does not specifically regulate wind power facilities; however, wind facilities fall under State Corporation Commission (SCC) regulation of electric generation facilities. In general, these regulations require the SCC to issue a Certificate of Public Convenience and Necessity (certificate) for construction of electric facilities.[98] The SCC's review must consider the effect of the proposed facility on the environment[99] and establish conditions to minimize adverse environmental impacts. To this end, the Department of Environmental Quality coordinates the environmental review,[100] which consists of analysis of 14 items.[101] DEQ makes recommendations to the SCC regarding conditions that may be necessary to minimize impacts based on input from various agencies; however, there are no clearly stated criteria that are to be applied to this review. The SCC must notify the public and provide an opportunity for a hearing,[102] but there is no requirement for the SCC to consider the input and the timing of the hearing is unspecified. Upon finding that it will not negatively impact reliability or rates and that it is not contrary to the public interest, the SCC must permit construction of a facility. The SCC certificate does not serve as a consolidated state permit, and projects must also obtain other necessary state or federal permits, in addition to local permits.

Outer Continental Shelf Lands Act (OCSLA) 43 U.S.C. § 1301 (2004). States have control over submerged land extending three nautical miles from shore and the federal government controls submerged land from 3 to 200 nautical miles offshore.

[2] NC Gen. Stat. §113A-205 et seq.

[3] NC Gen. Stat. §113A-206(3).

[4] Andrea N. Capua, Esq., di Santi Watson Capua & Wilson (memorandum to the Watauga County Planning Board, May 15, 2006).

[5] Jens Vestergaard, et. al., "Industry Formation and State Intervention: the Case of the Wind Turbine Industry in Denmark and the United States," *Academy of International Business* (Southeast USA Chapter) Conference Proceedings, November 2004, http://www.hha.dk/man/cmsdocs/publications/windmill_paper2.pdf#search=%22how%20big%20is%20a%20mod-1%20turbine%3F%20%22 (accessed December 1, 2006); the memo (ibid.) indicates the turbine was a Mod-I, which Vestergaard (p. 13) indicates would have been 1.8 MW.

[6] Roy Cooper, NC Attorney General, (memorandum to Anita Rose, Tennessee Valley Authority, February 4, 2002).

[7] NC Gen. Stat. §62-110.1(a).

[8] NC Gen. Stat. §62-2(a).

[9] NC Gen. Stat. §G.S. 62-110.1(g).

[10] NCUC Rule R8-64(b)

[11] NCUC Rule R8-64(c)(2).

[12] NCUC Rule R8-64(c))(3).

[13] NCUC Rue R8-61(a).

[14] NC Gen. Stat. §62-101(a).

[15] NC Gen. Stat. §62-102(a)(4).

[16] NC Gen. Stat. §62-105.

[17] NC Gen. Stat. §62-101(c)(3).

[18] NC Gen. Stat. §62-82.

[19] NC Gen. Stat. §62-82.

[20] NC Gen. Stat. §62-101 and 104.

[21] NC. Gen. Stat. § 113A, Article 1.

[22] NC Administrative Code, 01 NCAC 25 .0108(a)

[23] NC Department of Environment and Natural Resources, "State Environmental Policy Act," http://www.envhelp.org/html/state_environmental_policy_act.html (accessed 10-5-05). Note: I could not find a regulatory basis for this information.

[24] For information on state incentives for renewable energy, visit the DSIRE website, http://dsireusa.org/library/includes/map2.cfm?CurrentPageID=1&State=NC.

[25] NC Department of Environment and Natural Resources, "North Carolina Environmental Policy Act Requirements for Projects Requiring a CAMA Permit," Version 2.2, April 13, 2005, 1, http://dcm2.enr.state.nc.us/Rules/sepa.pdf (accessed November 11, 2006).

[26] 15A NCAC 01C .0400. Statutory authorization at NC Gen. Stat. § 113A-11(b).

[27] 15A NCAC 01C .0408(2)(e)(iii) and 15A NCAC 01C .0410(8)(c). See also NC DENR, op. cit. 106, 2.

[28] 15A NCAC 01C .0306

[29] NC Gen. Stat. § 113A-12(2).

[30] NC Gen. Stat. § 113A-12(2)..

[31] NC Gen. Stat. § 113-A Article 7.

[32] NC Department of Environment and Natural Resources, "CAMA Handbook for Development," November 5, 2002, http://dcm2.enr.state.nc.us/Handbook/contents.htm (accessed November 11, 2006).

[33] NC Gen. Stat. § 113A-102(4).

[34] NC Gen. Stat. § 113A-103(5)a

[35] NC Department of Environment and Natural Resources, "CAMA Permits: Will My Project Require a Permit?, http://www.nccoastalmanagement.net/Permits/aecs.htm (accessed November 11, 2006). In general, AECs encompass areas that are either: in or on navigable waters within the 20 CAMA counties; on a marsh or wetland; within 75 feet of the mean high water line along an estuarine shoreline; near the ocean beach; near an inlet; within 30 feet of the normal high water level of areas designated as inland fishing waters by the N.C. Marine Fisheries Commission; or near a public water supply.

[36] 15A NCAC 7H. The four categories are the Estuarine System, Ocean Hazard Areas, Public Water Supplies, and Natural and Cultural Resource Areas.

[37] NC DENR, op. cit. 113, Section 1.

[38] Ibid.

[39] NC Department of Environment and Natural Resources, "Types of permits," http://dcm2.enr.state.nc.us/Permits/types.htm (accessed November 6, 2006).

[40] NC Gen. Stat. §113A-103(b)(3).

[41] NC DENR, op. cit. 116.

[42] NC DENR, op. cit. 113, Section 1.

[43] NC Gen. Stat. § 113A-101.

[44] NC Gen. Stat. § 113A-110.

[45] NC Gen. Stat. § 113A-108.

[46] NC Gen. Stat. § 113A-111.

[47] It should also be noted, that though local governments can opt to be the lead agency for permits and enforcement (§113A-116), CAMA pre-empts local control for energy facilities by requiring those permits to be issued by the Coastal Resources Commission rather than by local governments (§113A-118(e)).

[48] NC DENR, op. cit. 113, Section 1.

[49] 15A NCAC 01C .0408(2)(e)(iii); 15A NCAC 01C .0410(8)(c).

[50] 15A NCAC 07H .0208.

[51] Patricia Smith, "Tilting at windmills for CRC," *The Daily News*, Jacksonville, NC, June 17, 2005.

[52] 15A NCAC 7H .0306.

[53] Renewable Energy Policy Project, op. cit. 72.

[54] NC Gen. Stat. § 113A-120.1.

[55] NC Gen. Stat. § 113A-121.1.

[56] NC Gen. Stat. § 113A-123.

[57] NC Gen. Stat. § 113A-125(b).

[58] NC Gen. Stat. §113-229.

[59] NC Gen. Stat. §121.

[60] NC Gen. Stat. § 113A-125. Also NC DENR, op. cit. 113, Section 5.

[61] NC DENR, op. cit. 113, Section 5. Agencies include: Departments of Administration (Property Office), Cultural Resources (Archives and History). Commerce, (Community Assistance), Transportation (Division of Highways), Environment and Natural Resources (Divisions of Environmental Health, Water Quality, Land Resources, Marine Fisheries, Water Resources), NC Wildlife Resources Commission, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, National Marine Fisheries Service, and U.S. Fish and Wildlife Service.

[62] 01 NCAC 06B.

[63] David W. Owens and N. Branscome, "Inventory of Local Land Use Ordinances in North Carolina," UNC School of Government Special Series No. 21, May, 2006, Chart A. Note: the data in Chart A is more complete than that reported on the map in Figure 1 of the report, as the map represents only counties responding to the survey.

[64] Ibid. The counties with no zoning are: Alamance, Ashe, Bertie, Cherokee, Clay, Duplin, Gates, Graham, Greene, Haywood, Hyde, Jones, Macon, Martin, Mitchell, Pamlico, Rutherford, Swain, Transylvania, Tyrrell, Vance, Yancey.

[65] Watauga County, Ordinance to Regulate Wind Energy Systems, August 2006. http://www.wind.appstate.edu/reports/WataugaCountywindordinance.pdf

[66] Ashe County, An Ordinance to Regulate Wind Energy Systems in Ashe County, NC, July 2007. http://www.ashecountygov.com/PDFs/Ashe%20Co%20Windmill%20Ordinance071607.pdf

[67] Camden County Ordinance 2007-09-01 http://www.dsireusa.org/documents/Incentives/Camden_wind_ordinance.pdf

[68] Currituck County Unified Development Ordinance, amended January 2008. http://www.dsireusa.org/documents/Incentives/Camden_wind_ordinance.pdf

[69] NC Gen. Stat. §113A-8.

[70] *Wind Facility Siting Act,* Minnesota Statutes §§216F.01 et. seq., (2006), http://www.revisor.leg.state.mn.us/revisor/pages/statute/statute_chapter_toc.php?year=2006&chapter=216F (accessed December 3, 2006).

[71] Minn. Rules 4410.4600(3), http://www.revisor.leg.state.mn.us/arule/4410/ (accessed November 11, 2006).

[72] Minn. Stat. §§216B.243(2), http://www.revisor.leg.state.mn.us/stats/216B/243.html (accessed November 11, 2006).

[73] Minn. Stat. §§216F.03, http://www.revisor.leg.state.mn.us/revisor/pages/statute/statute_chapter_toc.php?year=2006&chapter=216F (accessed December 3, 2006).

[74] Minn. Rules Chapter 4401, http://www.revisor.leg.state.mn.us/arule/4401/ (accessed November 11, 2006).

[75] Minn. Stat. §§216F.07, http://www.revisor.leg.state.mn.us/stats/116C/ (accessed November 11, 2006).

[76] This is peak generating capacity; the statute references 35 MW average generating capacity, which is peak capacity of 105 MW divided by a factor of 3. Peak capacity is used here to allow consistent comparison with other states.

[77] Oregon Rev. Stat. 469.300.11(a)(J), http://landru.leg.state.or.us/ors/469.html (accessed November 11, 2006).

[78] Oregon Admin. Rules 345-021-0000(2), http://oregon.gov/ENERGY/SITING/rules.shtml (accessed November 11, 2006). Again note that the statute references a threshold of 35 MW average generating capacity, which is 105 MW peak capacity divided by a factor of 3.

[79] P. Mostow and A. Linehan, CH2M Hill, "An Assessment of Wind Project Siting Regimes," date uncertain, but probably June 2002, http://www.stoel.com/resources/articles/environment/enf_031.shtm (accessed on 7/28/06.

[80] Oregon Rev. Stat. 469.401(3).

[81] Oregon Rev. Stat. 469.370(9)(d).

[82] Oregon Rev. Stat. 469.370(10). Peak generating capacity; the statute references 100 MW average generating capacity, which is peak capacity divided by a factor of 3.

[83] Oregon Energy Facility Siting Council, "Need Standard for Nongenerating Facilities," http://egov.oregon.gov/ENERGY/SITING/standards.shtml#Need_Standard_for_Nongenerating_Facilities (accessed December 3, 2006). See also Oregon Admin. Rules 345-021-0010 for contents required in an application.

[84] Oregon Admin. Rules 345-024-0015.

[85] Oregon Rev. Stat. 469.504(1). See also Oregon Admin. Rules 345-022-0030(2)(a).

[86] Oregon Administrative Rules 345-022-0030

[87] Washington Energy Facility Site Evaluation Council, "Certification Process," http://www.efsec.wa.gov/cert.shtml (accessed November 4, 2006).

[88] Washington Department of Ecology,"Frequently Asked Questions about SEPA," http://www.ecy.wa.gov/programs/sea/sepa/faq.htm (accessed November 4, 2006).

[89] Mostow and Linehan, op. cit., 181.

[90] Washington EFSEC, op. cit. 189.

[91] Washington House Bill 2402, Chapter 205, 2006 Laws, 59th Legislature, http://apps.leg.wa.gov/billinfo/summary.aspx?bill=2402&year=2006 (accessed November 4, 2006).

[92] Cal, Code Reg., Title 20, http://www.energy.ca.gov/siting/title20/index.html (accessed November 20, 2006).

[93] California Statutes §§21000-21177. See also State of California, "California Environmental Quality Act," California Environmental Resource Evaluation System (CERES), http://ceres.ca.gov/ceqa/ (accessed November 20, 2006).

[94] State of California, CERES, "California State Clearinghouse Handbook," Appendix A, http://ceres.ca.gov/planning/sch/appen_a.html#anchor983652 (accessed November 20, 2006).

[95] Cal. Code Reg., Title 14 § 15300.2

[96] Linda Spiegel, "Developing Methods to Reduce Bird Mortality In the Altamont Pass Wind Resource Area," California Energy Commission, Publication 500-04-052, August, 2004, Table 3-11, http://www.energy.ca.gov/pier/final_project_reports/500-04-052.html (accessed November 11, 2006).

[97] Center for Biological Diversity, "Altamont Pass Wind Resource Area," http://www.biologicaldiversity.org/swcbd/Programs/bdes/altamont/altamont.html (accessed November 11, 2006).

[98] Code of Virginia §56-265.2, http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+56-265.2 (accessed November 11, 2006).

[99] Code of Virginia §56-46.1, http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+56-46.1 (accessed November 11, 2006).

[100] Code of Virginia §10.1-1186.2:1, http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+10.1-1186.2C1, (accessed November 11, 2006). Memorandum of Agreement between Virginia State Corporation Commission and Virginia Departmet of Environmental Quality, PUE-2002-00315, August 14, 2002, http://www.scc.virginia.gov/caseinfo/pue/e020315.htm (accessed November 11, 2006).

[101] Virginia Admin. Code 20VAC5-302-20.12, http://leg1.state.va.us/cgi-bin/legp504.exe?000+reg+20VAC5-302-20.

[102] Code of Virginia §56-265.2A.

[103] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "NC Wind Resources Map," http://www.ncsc.ncsu.edu/programs/The_Coastal_Wind_Initiative.cfm (accessed November 11, 2006).

[104] Map created by Erin Kimrey and Tamara Gagnolet, Nov. 28, 2006. Data on zoning from David W. Owens and N. Branscome, "Inventory of Local Land Use Ordinances in North Carolina," UNC School of Government Special Series No. 21, May, 2006. Data on wind potential from NC State Energy Office, "onemap_test.SDEADMIN.wndpwr," NC Center for Geographic Information and Analysis, Raleigh, NC, September 8, 2005, in NC OneMap database, http://www.nconemap.net/data.html (accessed November 6, 2006).

[105] Ibid.

Appendix D

Invasive Exotic Species List and Related Resources

The following list of invasive species comes from the North Carolina Native Plant Society, *whose purpose is to promote enjoyment and conservation of North Carolina's native plants and their habitats through education, protection, propagation, and advocacy* (http://www.ncwildflower.org/). This list is available on their website and was compiled by Misty Franklin, with review and input from biologists in the following agencies: NC Natural Heritage Program, NC DENR Aquatic Weed Control Program, NC Exotic Pest Plant Council, US Fish &Wildlife Service, The Nature Conservancy, NC Zoo, NC Botanical Garden, and UNC Herbarium.

Rank 1 - Severe Threat

Exotic plant species that have invasive characteristics and spread readily into native plant communities, displacing native vegetation.

Scientific name	Common name
Ailanthus altissima (Mill.) Swingle	Tree of Heaven
Albizia julibrissin Durz.	Mimosa
Alliaria petiolata (Bieb.) Cavara & Grande	Garlic-mustard
Alternanthera philoxeroides (Mart.) Griseb.	Alligatorweed
Celastrus orbiculatus Thunb.	Asian bittersweet
Elaeagnus angustifolia L.	Russian olive
Elaeagnus umbellata Thunb.	Autumn olive
Hedera helix L.	English ivy
Hydrilla verticillata (L.f.) Royle	Hydrilla
Lespedeza bicolor	Bicolor lespedeza
Lespedeza cuneata (Dum.-Cours.) G. Don	Sericea lespedeza
Ligustrum sinense Lour.	Chinese privet
Lonicera fragrantissima Lindl. & Paxton	Fragrant honeysuckle
Lonicera japonica Thunb.	Japanese honeysuckle
Microstegium vimineum (Trin.) A. Camus	Japanese stilt-grass
Murdannia keisak (Hassk.) Hand.-Mazz.	Asian spiderwort
Myriophyllum aquaticum (Vell.) Verdc.	Parrotfeather
Paulownia tomentosa (Thunb.) Sieb.&Zucc. ex Steud.	Princess tree
Phragmites australis (Cav.) Trin. ssp. australis	Common reed
Polygonum cuspidatum Seib. & Zucc.	Japanese knotweed
Pueraria montana (Lour.) Merr.	Kudzu

Rosa multiflora Thunb.	Multiflora rose
Salvinia molesta Mitchell	Aquarium water-moss
Vitex rotundifolia L.f.	Beach vitex
Wisteria sinensis (Sims) DC	Chinese wisteria

Rank 2 - Significant Threat

Exotic plant species that display some invasive characteristics, but do not appear to present as great a threat native communities in NC as the species listed in Rank 1.

Scientific name	Common name
Ampelopsis brevipedunculata (Maxim.) Trautv.	Porcelain-berry
Arthraxon hispidus (Thunb.) Makino	Hairy jointgrass
Bambusa spp.	Exotic bamboo
Berberis thunbergii DC	Japanese barberry
Broussonetia papyrifera (L.) L'Her. ex Vent.	Paper mulberry
Cayratia japonica (Thunb. ex Murray) Gagnep.	Bushkiller
Centaurea biebersteinii DC	Spotted knapweed
Clematis terniflora DC (=C. dioscoreifolia)	Leatherleaf clematis
Conium maculatum L.	Poison hemlock
Coronilla varia L.	Crown vetch
Dioscorea oppositifolia L.	Air-potato
Eichhornia crassipes (Mart.) Solms	Water-hyacinth
Euonymus alata (Thunb.) Sieb.	Burning bush
Euonymus fortunei (Turcz.) Hand. - Mazz	Winter creeper
Glechoma hederacea L.	Gill-over-the-ground, ground ivy
Humulus japonicus	Japanese Hops
Lamium purpureum L.	Henbit
Lespedeza bicolor Turcz.	Bicolor lespedeza, shrubby bushclover
Ligustrum japonicum Thunb.	Japanese privet
Ligustrum vulgare L.	Common privet
Lonicera maackii (Rupr.) Maxim.	Amur bush honeysuckle
Lonicera morrowii A. Gray	Morrow's bush honeysuckle
Lonicera standishii Jaques	Standish's Honeysuckle
Lonicera ×bella [morrowii × tatarica]	Hybrid Bush Honeysuckle
Ludwigia uruguayensis (Camb.) Hara	Creeping waterprimrose

Lygodium japonicum (Thunb. ex Murr.) Sw.	Japanese climbing fern
Lythrum salicaria L.	Purple loosestrife
Mahonia beali (Fortune) Carriere	Leatherleaf Mahonia
Miscanthus sinensis Andersson	Chinese silver grass
Morus alba L.	White mulberry
Myriophyllum spicatum Komarov	Eurasian watermilfoil
Nandina domestica Thunb.	Nandina
Persicaria longiseta (de Bruijn) Moldenke (=Polygonum caespitosum Blume)	Oriental ladies-thumb
Persicaria maculata (Rafinesque) S.F. Gray (=Polygonum persicaria L.)	Lady's thumb
Phyllostachys spp.	Exotic bamboo
Poncirus trifoliata (L.) Raf.	Hardy-Orange
Pseudosasa japonica (Sieb. & Zucc. ex Steud.) Makino ex Nakai	Arrow bamboo
Pyrus calleryana Decne.	Bradford pear
Rhodotypos scandens (Thunb.)	Makino jetbead
Rubus phoenicolasius Maxim.	Wineberry
Solanum viarum Dunal	Tropical soda apple
Sorghum halepense (L.) Pers.	Johnson grass
Spiraea japonica L.f.	Japanese spiraea
Stellaria media (L.) Vill.	Common chickweed
Veronica hederifolia L.	Ivyleaf speedwell
Vinca major L.	Bigleaf periwinkle
Vinca minor L.	Common periwinkle
Wisteria floribunda (Willd.) DC	Japanese wisteria
Xanthium strumarium L.	Common cocklebur
Youngia japonica (L.) DC.	Oriental false hawksbeard

Rank 3 - Lesser Threat

Exotic plant species that spread into or around disturbed areas, and are presently considered a low threat to native plant communities in NC.

Scientific name	Common name
Ajuga reptans L.	Bugleweed
Allium vineale L.	Field garlic
Artemisia vulgaris L.	Mugwort, common wormwood

Arundo donax L.	Giant reed
Baccharis halimifolia L. (*)	Silverling, groundsel tree
Bromus catharticus Vahl	Bromegrass, rescue grass
Bromus commutatus Schrad.	Meadow brome
Bromus japonicus Thunb. ex Murray	Japanese bromegrass
Bromus secalinus L.	Rye brome
Bromus tectorum L.	Thatch bromegrass, cheat grass
Buddleia davidii Franch	Butterfly bush
Chicorium intybus L.	Chicory
Chrysanthemum leucanthemum L.	Ox-eye daisy
Cirsium vulgare (Savi) Ten.	Bull thistle
Daucus carota L.	Wild carrot, Queen Anne's-lace
Dipsacus fullonum L.	Fuller's teasle
Egeria densa Planch.	Brazilian elodea, Brazilian water-weed
Fatoua villosa (Thunb.) Nakai	Hairy crabweed
Festuca pratensis Huds.	Meadow fescue
Ipomoea quamoclit L.	Cypressvine morningglory
Kummerowia stipulacea (Maxim.)	Makino Korean clover
Kummerowia striata (Thunb.) Schindl	Japanese clover
Lysimachia nummularia L.	Moneywort, creeping Jenny
Melilotus albus Medik.	White sweet clover
Melilotus officinalis (L.) Lam.	Yellow sweet clover
Najas minor All.	Brittle naiad
Pastinaca sativa L.	Wild parsnip
Perilla frutescens (L.) Britt.	Beefsteakplant
Populus alba L.	White poplar
Senecio vulgaris L.	Ragwort
Setaria faberi R.A.W. Herrm.	Nodding foxtail-grass
Triadica sebifera (L.) Small	Chinese tallowtree
Tussilago farfara L.	Coltsfoot
Vicia sativa L.	Garden vetch

Watch List A

Exotic plants that naturalize and may become a problem in the future; includes species that are or could become widespread in North Carolina. At this time, more information is needed.

Scientific name	Common name
Arum italicum P. Mill.	Italian lords and ladies
Buglossoides arvensis (L.) I.M. Johnston (L.) I.M.	Corn gromwell
Bupleurum rotundifolium L.	Hound's-ear, hare's ear
Centaurea cyanus L.	cornflower
Echium vulgare L.	Viper's bugloss
Elaeagnus pungens Thunb	Thorny olive
Hibiscus syriacus L.	Rose of Sharon
Hypericum perforatum L.	St. John's-wort
Ornithogalum umbellatum L.	Star of Bethlehem
Solanum dulcamara L.	Climbing nightshade
Verbascum thapsus L.	Common mullein

Watch List B

Exotic plant species that cause problems in adjacent states but have not yet been reported to cause problems in NC.

Scientific name	Common name
Acer platanoides L.	Norway maple
Akebia quinata (Houtt.) Dcne.	Fiveleaf akebia
Bromus inermis Leyss.	Smooth bromegrass
Cardiospermum halicacabum L.	Balloonvine
Carduus nutans L.	Musk thistle
Cirsium arvense (L.) Scop.	Canada thistle
Commelina benghalensis L.	Bengal dayflower
Elaeagnus pungens Thunb.	Thorny-olive
Hesperis matronalis L.	Dame's rocket
Imperata cylindrica	Cogon grass
Iris pseudoacorus L.	Pale-yellow iris
Lonicera tatarica L.	Tartarian honeysuckle
Melia azedarach L.	Chinaberry

Persicaria perfoliata (Linnaeus) H. Gross (=Polygonum perfoliatum L.)	Mile-a-minute vine
Pistia stratiotes L.	Watter-lettuce
Potamogeton crispus L.	Curly pondweed
Quercus acutissima Carruthers	Sawtooth oak
Rhamnus cathartica L.	European buckthorn
Setaria italica (L.) P. Beauv.	Foxtail-millet
Setaria verticillata (L.) Beauv.	Bur-foxtail
Setaria viridis (L.) P. Beauv.	Green millet
Stachys floridana Shuttlw. ex Benth.	Florida Hedge nettle
Torilis arvensis (Huds.) Link	Spreading hedge-parsley
Tragopogon dubius Scop.	Yellow goat's-beard
Trapa natans L.	Water Chestnut
Tribulus terrestris L.	Puncturevine
Xanthium spinosum L.	Spiny cocklebur

Other Resources

North Carolina Exotic Pest Plant Council http://www.se-eppc.org/northcarolina/

NC EPPC facilitates solutions to problems caused by invasive plants. Our active membership includes public and private land managers, ecological consultants and researchers, planners, volunteer stewards, and concerned citizens. We:

- Provide a focus for issues and concerns regarding exotic pest plants in North Carolina
- Facilitate communication and the exchange of information regarding all aspects of exotic pest plant control and management
- Provide a forum where all interested parties may participate in meetings and share in the benefits from the information generated by Council
- Promote public understanding regarding exotic pest plants and their control
- Serve as an advisory council regarding funding, research, management, and control of exotic pest plants
- Facilitate action campaigns to monitor and control exotic pest plants in North Carolina
- Review incipient and potential pest plant management problems and activities and provide relevant information to interested parties

Southeast Exotic Pest Plant Council http://www.se-eppc.org/
The mission of the Southeast Exotic Pest Plant Council is to support the management of invasive exotic plants in natural areas of the Southeast U.S. by providing a forum for the exchange of scientific, educational and technical information. The Southeast Exotic Pest Plant Council is a non-profit organization and is not a regulatory agency.

North Carolina Department of Environment and Natural Resources Division of Water Resources Aquatic Weed Control Program
http://www.ncwater.org/Education_and_Technical_Assistance/Aquatic_Weed_Control/
The Aquatic Weed Control Act of 1991 directs and regulates the Aquatic Weed Control Program. The purpose of the program is to assist North Carolina citizens and local governments burdened with aquatic weed infestations. The philosophy is that by responding early to localized outbreaks the Division of Water Resources can mitigate the long-term economic and environmental impacts these species impose. Allowing aquatic weeds to spread, as with all invasive species, only exacerbates the problem.

North Carolina Department of Agriculture and Consumer Services Plant Protection Section
http://www.ncagr.gov/plantindustry/plant
The mission of the Plant Protection Section is to enhance the quality of life in North Carolina by protecting agriculture and the environment from injurious plant pests, by promoting beneficial organisms, and by protecting rare native plants of the state.

North Carolina Department of Transportation (NC DOT)
http://www.se-eppc.org/northcarolina/NCDOT_Invasive_Exotic_Plants.pdf
The NC DOT has produced a report on invasive exotic plants of North Carolina
Smith, C. 2008. Exotic Plants of North Carolina. North Carolina Department of Transportation, Raleigh.

U.S. Department of Agriculture National Invasive Species Information Center
http://www.invasivespeciesinfo.gov/
The center is a gateway to invasive species information; covering Federal, State, local and international sources. North Carolina specific information can be found here:
http://www.invasivespeciesinfo.gov/unitedstates/nc.shtml

Appendix E

Climate Change Adaptation Policy and Funding

The climate change adaptation policy and funding landscape is constantly changing. At the time this report was written, the Clean Energy and Security Act was pass in the House, multiple Senate versions of similar legislation has been proposed. Here we review the significant climate change and natural resources legislation as well as the implications for regional coordination, funding for state and federal agencies and future support for adaptation efforts. For more information please visit: http://www.defenders.org/resources/publications/policy_and_legislation/american_clean_energy_and_security_act.pdf.

American Clean Energy and Security Act of 2009

The House Energy and Commerce Committee have approved comprehensive energy and climate legislation, American Clean Energy & Security Act 2009 (H.R. 2454). The bill, introduced by Representatives Henry Waxman (D-CA) and Edward Markey (D-MA), moves America closer to increasing our energy security and tackling global warming and also works to address the impacts of global climate change on wildlife and natural resources. The bill provides one percent of revenues from a cap and trade system to domestic natural resource adaptation over the next 10 years and increases the allocation to four percent by 2027. Ultimately, significantly more dedicated funding (5% of total allowance value from the bill) will be needed to address the impacts of global warming on our wildlife and natural resources. However the funding and language now in the bill will be absolutely critical to protect natural resources for people as well as fish and wildlife in an already warming world.

Important sections

Section 471. Purposes
The purposes of this Act are to establish an integrated Federal program to protect, restore, and conserve the Nation's natural resources in the face of climate change and ocean acidification and to provide financial support and incentives for programs, strategies, and activities that further these goals.

Section 472. Natural Resources Climate Change Adaptation Policy
Establishes the policy of the Federal government, in cooperation with State and local governments, Tribes, and other stakeholders to protect, restore, and conserve natural resources to enable them to become more resilient, adapt to, and withstand the impacts of climate change and ocean acidification.

Section 475. Natural Resources Climate Change Adaptation Panel
Establishes the Natural Resources Climate Change Adaptation Panel, which must be created within 90 days of passage of this act, and serve as the forum for interagency consultation and coordination of the development and implementation of the national strategy. Led by CEQ, the Panel consists of the head, or designee, of NOAA, Forest Service, National Park Service, US Fish & Wildlife Service, Bureau of Land Management, US Geological Survey, Bureau of Reclamation, and Bureau of Indian Affairs, and other Federal agencies with jurisdiction over natural resources.

Section 476. Natural Resources Climate Change Adaptation Strategy
Within one year after enactment, a national strategy to protect, restore, and conserve natural resources in the face of climate change shall be developed. This plan will be developed by the Panel established in Section 6 and be based upon the best available science, be developed in close coordination with States, Tribes and other relevant federal agencies and with the input of other stakeholders, including local governments, conservation organizations, and scientists. This strategy will be revised every 5 years to incorporate new information. This section outlines the contents of the national strategy, including a vulnerability assessment, protocols for integrating climate change adaptation strategies into conservation and management practices, among other items.

Section 478. Federal Natural Resource Agency Adaptation Plans
Calls for Federal agencies represented on the Panel, created under Section 6, to develop agency-specific adaptation plans within a year after completion of the national strategy. These plans are subject to public review and approved by the President. Lays out specific requirements for these plans, including programs to assess impacts, identification and prioritization of strategies and conservation actions to increase resilience, steps to integrate strategies into current plans and programs, methods for assessing strategies' effectiveness, and specific direction to natural resource managers. Plans will be submitted to Congress and reviewed and updated every 5 years.

Section 479. State Natural Resources Adaptation Plans
Establishes a process and requirements for the development of state natural resources adaptation plans. Plans will be developed within a year after completion of the national strategy and approved by the Secretary of the Interior, and, in the case of coastal states (as defined by the Coastal Zone Management Act) the Secretary of Commerce. Lays out the contents of the state plans, which shall be incorporated in state wildlife action plans, and updated every 5 years.

Section 480. Natural Resources Climate Change Adaptation Fund
Establishes the Natural Resources Climate Change Adaptation Account (Table X for funds allocation).

Section 482. Additional Provisions Regarding Indian Tribes
Clarifies that nothing in this act alters or gives priority over Federal trust responsibility to the Tribes. Exempts from FOIA any information related to sacred sites or cultural activities identified as confidential by Tribes.

Area Funded	Percentage
State and territorial fish and wildlife agencies	32.5%
State coastal agencies	6%
Tribal fish and wildlife agencies	3%
Department of the Interior (wildlife programs and lands and waters under DOI's jurisdiction)	17%
Department of the Interior (cooperative grant programs)	5%
Land & Water Conservation Fund (Funding split between DOI and Forest Service for state and federal land protection)	12%
Forest Service	5%
NOAA (coastal, estuarine, coral and marine species and habitats)	7%
EPA	7.5%
Army Corps of Engineers	5%
TOTAL	100%

National Adaptation Strategy

H.R. 2454 calls for the development of a natural resources climate change adaptation strategy (Strategy) to protect, restore, and conserve natural resources to make them more resilient to adapt to and withstand the impacts of climate change and ocean acidification. The Bill calls for the President to complete this strategy through the Climate Change Adaptation Panel, also called for in the bill. The Adaptation Panel will be made up of representatives from the Department of Interior land management agencies, the United States Geological Survey, the Bureau of Reclamation, the Bureau of Indian Affairs, the Environmental Protection agency, the National Oceanic and Atmospheric Administration, the Army Corps of Engineers, and the Chair of the Council on Environmental Quality as well as other federal agencies or departments with jurisdictions over natural resources. The Bill requires that the panel develop the Strategy in coordination and consultation with States and tribes, as well as other Federal agencies, local governments, conservation organizations, scientists and other interested stakeholders.

The bill specifies that such a strategy require several key components:

1. Vulnerability assessment of natural resources to climate change and ocean acidication

2. An inventory of current research and monitoring efforts related to the impacts of climate change and ocean acidification on natural resources at federal, state, tribal, and local levels

3. Identification of natural resources at greatest risk from adverse impacts from climate change

4. Detailed methods for incorporating climate change and ocean acidification strategies into conservation and natural resource management activities carried out by Federal agencies to ensure consistency across jurisdictions and resources

5. Specific adaptation actions Federal departments and agencies shall take to make natural resources more resilient and adaptive in the face of climate change and a timeline to implement these actions

6. Mechanisms for ensuring communication and coordination among federal departments and agencies, and between federal agencies and the state natural resources agencies, U.S. territories, Indian tribes, private landowners, conservation organizations and other nations that share jurisdictions over U.S. natural resources.

7. Specific actions to develop and implement consistent natural resources inventory and monitoring protocols through coordination and collaboration among agencies; and

8. A process for guiding the development of agency- and department-specific adaptation plans to address the impacts of climate change on ocean acidification and natural resources.

National Climate Change Science Center

H.R. 2454 also calls for the National Climate Change Science Center (Science Center), established within the United States Geological Survey, to lead the development and dissemination of a coordinated process to provide science and information that addresses the impacts of climate change and ocean acidification on natural resources. The Science Center and NOAA will provide technical assistance to federal agencies, state and local governments, Indian tribes and interested private landowners as they work to address climate change impacts, conduct research and assist federal departments and agencies in the development of adaptation plans.

The bill further charges the Science Center to collaborate with state and federal natural resources agencies, tribes, universities and other partners to assesses and synthesize current physical and biological knowledge and prioritize research gaps to forecast the ecological impacts of climate change; develop and improve tools to identify, evaluate and forecast the impacts of climate change and adaptation on species and habitats; develop tools to adaptively manage and monitor the effects of climate change on fish and wildlife populations across scales; and built capacities for sharing and synthesizing standardized data.

Federal Natural Resource Agency Adaptation Plans

H.R. 2454 mandates that within a year after bill passage the federal agencies represented on the Natural Resources Climate Adaptation Panel complete an adaptation plan to implement the Natural Resources Climate Adaptation Strategy within their agency. These plans are requires to include the following elements:

1. Detailed methods for incorporating climate change and ocean acidification strategies into conservation and natural resource management activities carried out by Federal agencies to ensure consistency across jurisdictions and resources

2. Plans must establish programs for assessing the current and future impacts of climate change and ocean acidification on natural resources managed by the agency and develop programs to monitor natural resources that are likely to be adversely affected by climate change

3. Plans must identify and prioritize strategies and conservation actions to address the current and future impacts of climate change on ocean acidification on natural resources.

4. Describe the integration of these strategies into plans, programs, actitivites, and actions of the department or agency.

5. Establish methods to assess the effectiveness of strategies taken to protect, restore and conserve natural resources, and respond to new information and changing conditions.

6. Address opportunities and mechanisms to facilitate coordination and cooperation among federal agencies, state and local governments, tribes and non-government stakeholders

7. Include guidance on how managers are expected to address the effects of climate change and ocean acidification, how they will obtain site-specific information to inform management, reflect best practices shared among agencies, and identify and assess data and information gaps.

Upon approval, plans are to be implemented throughout the agency. Although climate change legislation has yet to pass in the Senate, a number of federal agencies have moved forward with national adaptation efforts. Both the USFWS (http://www.fws.gov/nfwcas.html) and the Council on Environmental Quality Adaptation Task Force (http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation) are developing collaborative, multi-sector frameworks for adapting to climate change.

State Natural Resource Agency Adaptation Plans

Similarly, H.R. 5454 would require each state to develop a state adaptation strategy within a year after the bill's passage. This strategy is required to be consistent with the state's Wildlife Action Plan, and will be incorporated into plan revisions, due in 2015. The FWS is responsible for reviewing and approving revisions and addendums to wildlife action plans. As written in the bill, State adaptation plans are to include a strategy for addressing the impacts of climate change and ocean acidification on terrestrial, marine, estuarine, and freshwater fish, wildlife, plants, habitats, ecosystems, wildlife health and ecological processes. This strategy must address the following components:

1. Describe the impacts of climate change and ocean acidification on biodiversity, habitats and ecological processes

2. Establish monitoring programs to track the impacts of climate change on biodiversity, habitats and ecological processes

3. Describe and prioritize proposed conservation actions to help these species and systems adapt to climate change

4. Include specific actions and strategies and a time frame for implementation

5. Establish methods for assessing the effectiveness of these strategies and make changes as necessary

6. Must be incorporated into a revision of the State Wildlife Action Plans

7. Must be developed with participation of the state fish and wildlife agency, the state coastal agency, the state agency responsible for the administration of Land and Water Conservation Fund grants, the State Forest Legacy program coordinator, and other state agencies considered appropriate, as well as coordination with the Secretary of the Interior and where applicable the Secretary of Commerce, as well as other states with jurisdiction over natural resources within the state.

8. Include guidance on how managers are expected to address the effects of climate change and ocean acidification, how they will obtain site-specific information to inform management, reflect best practices shared among agencies, and identify and assess data and information gaps

Coastal states, such as North Carolina would also be required to develop a strategy to address the impacts of climate change and ocean acidification on the coastal zones. This strategy would include similar components. The strategy would require detailed methods for incorporating climate change and ocean acidification strategies into conservation and natural resource management activities carried out by Federal agencies to ensure consistency across jurisdictions and resources. It would also require that plans establish programs for assessing the current and future impacts of climate change and ocean acidification on natural resources managed by the agency and develop programs to monitor natural resources that are likely to be adversely affected by climate change. The strategy needs to identify and prioritize research and data collection needed to address climate change and ocean acidification impacts, such as models of relative sea level rise, and projected habitat loss. The strategy should also identify and prioritize adaptation strategies, establish programs to monitor and improve these strategies, and establish performance measures for assessing the effectiveness of these strategies.

Funding from 2010 annual State Wildlife Grants appropriations

The 2010 Interior Appropriations bill, passed in November, provides $90 million to the state wildlife agencies. This is an increase of $15 million increase over 2009 funding levels. The needed match of funding from the states for implementation projects has been reduced from 50% match to a 35% match. As in the last two years, some of the funding is set aside for competitive grants – $7 million for tribes and $5 million for states – the language asks for a report on how this has worked over the last two years within 90 days of enactment. The conference report does not state that the increase in funding is to be used specifically for updating action plans for climate change or for climate implementation projects. However, the conference report language states that the conferees believe that climate change is an integral part of action plan implementation and that increases should be used for on the ground adaptation projects.