1 Introduction to Climate Change Adaptation and Mitigation Management Options

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CONTENTS

Climate is a critical factor shaping the structure and function of forest ecosystems in the Southern United States. Human induced changes in climate systems have resulted in an increase in the global average air temperature of about 0.8°C since the 1900s (Pachuri and Reisinger 2007). Data from long-term weather stations show that overall, the continental United States has warmed during the past century, but that the magnitude and direction of change vary by geographic area (Backlund et al. 2008). The primary driving force behind this overall warming is an increase in carbon dioxide (CO_2) and other greenhouse gas emissions, a trend that is likely to continue over the next century (Karl et al. 2009). For example, by 2100, further warming in the United States is expected to range from 2.5°C to 5.3°C relative to the 1971 to 2000 time period (Kunkel et al. 2011).

While warming and elevated CO_2 are important aspects of climate change, projections of increased climate variability and extreme weather events—such as drought, heat waves, heavy rains, tornados, and hurricanes (Easterling et al. 2000; Huntington 2006)—are expected to have an even greater impact on forest ecosystems than increases in CO_2 and temperature alone (Dale et al. 2001; Kunkel et al. 2011; Vose et al. 2012). Indirect effects may be equally or more significant, as the frequency, magnitude, and severity of wildfires, insect and pathogen outbreaks, and the spread of nonnative invasive species may be amplified by climate change (Vose et al. 2012). Combined, these direct and indirect effects of climate change are likely to create conditions that have not as yet been observed and may shape ecosystems in ways that have no historical analog (Williams and Jackson 2007). Some of these effects may be already occurring (Parmesan and Yohe 2003). For example, forest dieback, large insect outbreaks, and large wildfires during the past decade (Bentz et al. 2009; 2010; Breshears et al. 2005, 2009; Turetsky et al. 2010) may be signals of the potential effects of a rapidly changing climate on forest ecosystems (Vose et al. 2012).

The history of forestry in the South is one of managing disturbances, whether from early unsustainable logging practices or from wildfires, insects, and diseases. Almost a century of federal, university, and private industry research has produced an abundance of silvicultural studies, long-term data on trends in forest conditions and environmental changes, and expertise in modeling the effects of disturbances ranging from wildfires to insects to climate change. This science served to reforest the almost completely cutover landscapes at the beginning of the twentieth century and to establish the most productive forest region in the world (Prestemon and Abt 2002). Land managers are now being challenged to sustainably manage forest ecosystems in an increasingly uncertain, but likely very different, set of future climate conditions and disturbance regimes. The task becomes even more difficult because of co-occurring increases in landscape fragmentation, greater numbers of invasive species, changing social and economic conditions, and greater demands for ecosystem services from a growing population (Wear and Greis in press). Hence, land managers will need to consider multiple risks as they make decisions about activities on forest lands.

Land managers often look to past experiences and well-established scientific knowledge for guidance before deciding how to manage their forests. For example, restoration activities are often guided by the structure and function of historical stand types and conditions such as longleaf pine (*Pinus palustris*). Commercial forest management proceeds from an understanding of historical growth and yield coupled with an understanding of the risks of forest damage or mortality. In some circumstances, these historical conditions may be useful analogs for contemporary and future management; in others, change occurs at such a fast pace and broad scale that historical analogs provide poor guidance (Hobbs et al. 2011). In these circumstances, how does a land manager develop, evaluate, and implement the appropriate management actions? Scientists and managers have begun to develop some general guidelines, principles, and tools (e.g., Millar et al. 2007; Peterson et al. 2011) to help land managers begin incorporating climate change considerations into planning, management, and decision making. Management responses to climate change can generally be classified into three categories: adaptation, mitigation, and no action. Mitigation, which reduces or offsets CO_2 emissions, includes increasing storage (in forest systems or long-lived wood-based products) or offsetting fossil fuel use. Adaptation includes activities that help ecosystems resist the effects of climate change, be more resilient to the effects of climate change, or facilitate the transition to a new state after ecosystems have been subjected to the effects of climate change (Millar et al. 2007). The longevity of forests creates challenges not shared by other managed ecosystems such as agricultural crops, where changing species or genotypes and other management practices can be quickly modified when conditions change, new technologies are introduced, and new best management practices are adopted. Instead, forest management is a long-term investment—management actions implemented today can greatly constrain management possibilities over the next several decades. Although this long-term aspect of forest management does not preclude change, it does impart restrictions on "nimbleness," increasing the urgency for basing today's decisions on the best available information.

Now more than ever, land managers need credible and concrete examples of how to blend expert knowledge, science, and on-the-ground experience (Vose et al. 2012) to address climate change. Some information can be extracted directly from the large body of science that focuses on forest ecosystem responses to disturbance and environmental variability; however, conducting controlled studies of how changes in temperature and other co-occurring factors, such as precipitation amount and variability, impact ecosystem structure and function is extremely difficult, especially at the temporal and spatial scales needed to understand the consequences and implications for forest management. As a result, some of the science and approaches used to develop our current understanding of forests and forest management in southern forests may not fully apply to the future complexities of climate change. To address this knowledge deficit, scientists can combine synthesis of current knowledge, retrospective analyses of long-term data, modeling, and their own experiential knowledge to formulate working hypotheses about climate-change impacts on ecosystems and to help managers develop options to mitigate change or help forests adapt. These working hypotheses can also guide future forest science. That is the approach used in this book.

The objective of this book is to synthesize the best available expert knowledge by combining scientific literature, tools and models, and the experiences of scientists and land managers in the South to answer the question: *Can forest management enhance the sustainability of southern forest ecosystems and their values under climate change?* It provides a comprehensive analysis of the management options that could be used by natural resource managers to help southern forest ecosystems adapt to the impacts of climate change or manage forests to help mitigate climate change.

APPROACH

Providing a scientific framework for managing forests in the face of climate change has been the focus of several recent papers and overviews, including Baron et al. (2008), Joyce et al. (2009), Millar et al. (2007), and Peterson et al. (2011). They have provided the foundation for many of the concepts and definitions used by the authors in this book; however, they provide little direct guidance specific to land managers in the South. To help address this need, we assembled a team of scientists that represented multiple disciplines and many years of experience studying southern forest ecosystems and developing management options for protecting or enhancing their values. Our goal was to develop a comprehensive, cohesive, and integrated analysis of potential climate change impacts and management options to address those impacts. Doing so required developing a common conceptual framework, consistent definitions and data sources, and an overall organization and analytical structure that could span scientific disciplines. Data and knowledge limitations usually required that each of the chapter authors adapt and modify aspects the common conceptual framework to meet their particular needs.

THREATS AND VALUES

We organized the chapters by the values that southern forest ecosystems provide and the threats to the sustainability of those values (Table 1.1), each of which was identified and refined at a stakeholder workshop conducted early in the process. Workshop attendees included scientists, public and private land managers, and nongovernment organizations (NGOs). The list was not intended to be comprehensive of all of the values provided by (or threats to) southern forests; rather, they were collectively identified as critically important, and as areas where sufficient science and expertise were available to characterize risks and vulnerabilities and to develop potential management options.

Decisions about areas of focus were also guided by results from the Southern Forest Futures Project (SFFP) (www.srs.fs.usda.gov/futures/[Date accessed: October 25, 2012]; Wear and Greis in press), which provides a science-based "futuring" analysis for the forests of the 13 southern states. Organized by a set of scenarios (described fully in Chapter 2) and using a combination of computer

TABLE 1.1
Threats and Values of Forest Ecosystems in the Southern United States

Threats	Values
Insects, disease, invasives	Timber, fiber, and carbon sequestration
Wildfire	Water quality and quantity
	Species and habitats
	Plants
	Wildlife
	Recreation

models and science synthesis, the SFFP examines a variety of possible futures and how they could shape forests and their ecosystem services and values. Its ultimate goal was to translate a vast array of science and modeling results into useable information by government, the natural resource community, and other key stakeholders for southern forest management and policy analysis. Indeed, many of the analyses, databases, and findings from the SFFP serve as a foundation for several of the chapters in this book.

ECOLOGICAL SUBREGIONS

The South is a region of highly complex landscapes, ranging from the mountainous areas in the Southern Appalachians and Cumberland, to the Piedmont, the Mississippi Alluvial Valley, the Mid-South, and the flat landscape of the lower Coastal Plain. These subregions vary considerably in biophysical characteristics such as climate, soils, and vegetation; in processes such as water, carbon, and nutrient cycling; and in socioeconomic conditions, land use patterns, and forest management opportunities. We used the subregion classification system (Figure 1.1) developed for the SFFP (Wear and Greis in press) as a framework both for describing this variation in our analyses of risks, vulnerabilities, and impacts, and for developing management options for the chapters in this book. We recognized that a significant level of variation in biophysical and socioeconomic conditions also exists *within* the subregions, but addressing specific site/stand condition or socioeconomic/management constraints was beyond the scope of this book. Also, our experience has been that within the context of climate change, the use of general analyses or simple model predictions at the stand or site level cannot produce meaningful specific recommendations. This means that land managers must continue to blend the best and most appropriately synthesized science with their own experience and professional judgment in making stand-level decisions. To provide the best available science and account for some of this variation among subregions, we described any key vulnerabilities (Schneider et al. 2007) and potential impacts that we were able to identify as specific to each subregion. Authors were encouraged to use case studies to provide specific examples and demonstrate how the concepts, analyses, and potential management options could be applied within the subregions.

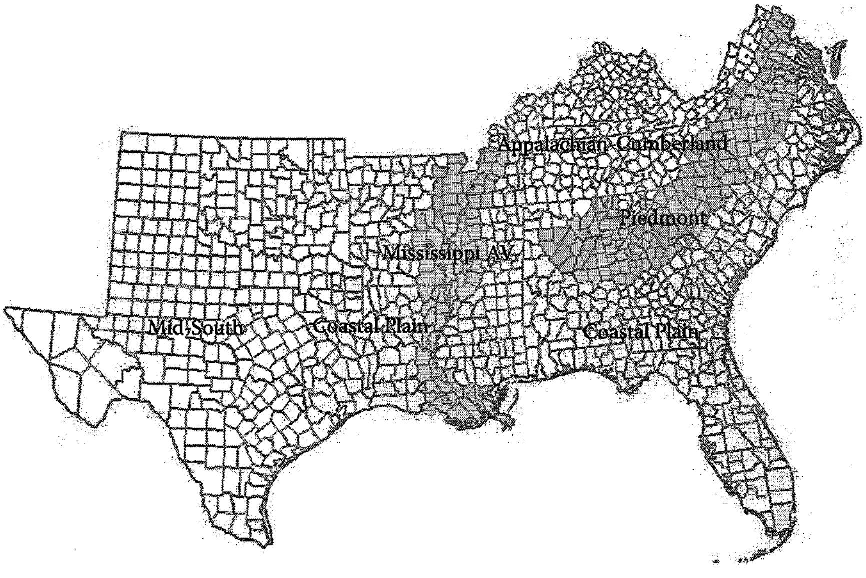

FIGURE 1.1 Ecological subregions of the Southern United States. (Wear, D.N. and J.G. Greis, eds. In press. The Southern Forest Futures Project: Technical Report.)

OVERALL CONCEPTUAL FRAMEWORK

Forest ecosystems are unique among all land uses because of their longevity and relative stability; even so, each has a structure and function that can be substantially altered by forest management. Both managed and unmanaged forest ecosystems frequently experience variability in weather systems (with or without climate change), as well as a myriad of other co-occurring disturbances and stressors. As a result, natural resources managers already have extensive experience managing forests, both to increase resistance and resiliency to historical disturbances and stressors and to restore desired conditions. However, the rate and magnitude of changes in biophysical conditions, as well as in the forest ecosystems that these biophysical conditions influence, will likely test the efficacy of current management approaches and guidelines. Nevertheless, this experience should help enable them to understand and implement "climate smart" management practices.

Despite these challenges, managing in the face of climate change is imperative for ensuring the sustainability of ecosystem services in southern forests. The response of forests to changing biophysical conditions will result from choices to: (1) respond to anticipated changes, (2) react to observed changes, (3) take no action in response to anticipated or observed changes, or (4) combine several of the above options. Indeed, any of these four approaches may be most appropriate based on assessments of critical vulnerabilities and risks. Proactive or reactive approaches to forest management can influence ecosystem responses to climate change by altering structural and functional attributes that determine response thresholds in either a positive manner (undesirable changes are less likely to occur) or a negative manner (undesirable change are more likely to occur).

Structural and functional attributes of forest ecosystems determine their resistance and resilience to historic patterns of climatic variability, and can facilitate long-term persistence of species and community types. As such, large and rapid changes in the structure and function of forest ecosystems usually only occur at the extremes of climate and other physical conditions. The threshold for these rapid, and sometimes permanent, changes varies considerably by ecosystem type and condition. For example, ecosystems that have been substantially degraded may have a narrower threshold of response to climate change than ecosystems that have been subject to less degradation. Conversely, heavily degraded ecosystems may have reached a new level of stability (e.g., they may now have a higher proportion of disturbance tolerant species) that reduces vulnerability to extreme disturbances. More extreme disturbances (such as hurricanes, catastrophic wildfires, and extreme drought) are difficult to predict and are often (but not always) localized. For example, an increase in the number of extended droughts may lead to more frequent and intense ecological disturbances, which in turn would lead to rapid changes in forest composition and dynamics (McKenzie et al. 2004). As a result, managing forests for frequent, unpredictable, and localized events can be very difficult, and in many situations, the severity of the disturbance is so great that preventive management activities are futile. In these situations, postdisturbance restoration or "facilitated transitions" are the only possible responses. Responses to longer-term climate change, such as a gradual warming, can be viewed in the same conceptual framework (see Chapter 3). Gradual changes in average climate or atmospheric environment produce gradual changes in ecosystems. For example, forest species distribution and abundance have shifted over long time scales as individuals respond to variability in temperature and precipitation, and to climatic-induced changes in wildfire and other disturbance regimes (Whitlock et al. 2008; Anderson et al. 2009).

COMMON DATABASES

One of the challenges of making "climate smart" management decisions is the variation (in space and over time) in projections of climatic future conditions. Uncertainty poses challenges to decision making in any context, but land managers will need to make decisions and management choices within the context of largely uncertain projected future climate conditions, as well as uncertain anticipated impacts. This variation in future projections is driven by a variety of factors, such as the choice of general circulation models, assumptions about future carbon dioxide emissions, and differences in approaches used to downscale coarse scale models to finer spatial scales (statistical vs. dynamic downscaling). To reduce the variability associated with model choice, emissions futures, or downscaling approaches across chapters, authors were provided with common databases and projections of future climatic conditions to 2060. We used the climate futures developed by the SFFP, which included four general circulation models (CSIROMK2, CSIROMK3.5, HadCM3, and MIROC3.2) and two emissions storylines (A1B and B2) from the Intergovernmental Panel on Climate Change (2007). These scenarios resulted in a range of possible futures derived from both model performance and emissions scenarios, and were intended to bracket "low" and "high" projections of future temperature and precipitation across the South. In addition, we developed an "ensemble"-based approach to develop temperature and precipitation projections using four general circulation models (CGCM3, CCSM3, HadCM3, and GFDLCM2.1) and three IPCC emission scenarios (B1, A1B, and B2). This ensemble approach averages variability in projections associated with differences in model performance, but maintains variation associated with emissions scenarios (Chapter 2).

ORGANIZATION

We used a series of workshops to develop a conceptual framework and identify key databases, afterward establishing a common framework for each chapter organized around the following questions:

1. In the Southern United States, where are social or biological systems most vulnerable to climate change?
2. Where will the consequences of climate change be the greatest (what areas have the greatest risk)?
3. What management options can be implemented to reduce vulnerability and risk (how can we manage to increase resistance and resilience to climate change)?
4. What are the key unknowns and uncertainties?

Teams of expert scientists for the threats and values identified in Table 1.1 were asked to synthesize the best available science, implement new syntheses and analyses, and use their best professional judgments to answer these questions (Chapters 3 through 12). In some cases, chapter authors used case studies to highlight specific geographic areas or species of concern. There is considerable overlap among many of these threats and values, as well as interdependencies and positive and negative interactions. For example, a management recommendation intended to mitigate a threat to one value could also have either a positive or negative impact on another value. Implications for some of the most significant interactions are discussed in Chapter 13.

CONCLUSIONS

Ensuring the sustainability of southern forest ecosystems and their values under climate change will require management decisions informed by the best available science. Our hope is that this book will serve as a valuable resource for both long-term planning and day-to-day forest management activities. Managing southern forests in response to or in anticipation of disturbance is nothing new for the southern natural resources community. Although uncertainty exists about the location, magnitude, and timing of climate-change effects on southern forest ecosystems, sufficient scientific information and tools are available to begin taking action now. The anticipated rapid pace of climate change, coupled with changes in disturbance regimes and other co-occurring stressors, will challenge the applicability of present-day best-management practices. The authors of this book have attempted to provide a linkage between current management actions and future management options that would anticipate a changing climate. Establishing this foundation of knowledge now could ensure a broader range of options for managing southern forests and protecting their values in the future. This approach requires strong partnerships between land managers and the science community, with successes and failures shared and evaluated, new science rapidly translated into management implications, and adaptive management embraced and implemented.

REFERENCES

Anderson, T., Carstensen, J., Hernandez-Garcia, E., and Duarte, C. 2009. Ecological thresholds and regime shifts: Approaches to identification. *Trends in Ecology and Evolution.* 24:49–57.

Backlund, P., Janetos, A., Schimel, D. et al. 2008. *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States.* Washington, DC: U.S. Department of Agriculture. 362 p.

Baron, J.S., Allen, C.D., Fleishman, E. et al. 2008. National parks. In: Julius, S.H., West, J.M., eds. *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Responses: A Report by the U.S. Climate Change Science Program and the Subcommittee on Climate Research.* Washington, DC: U.S. Environmental Protection Agency: 4–1 to 4–68.

Bentz, B., Logan, J., MacMahon, J. et al. 2009. *Bark Beetle Outbreaks in Western North America: Causes and Consequences.* Salt Lake City, UT: University of Utah Press. 44 p.

Bentz, B.J., Régnière, J., Fettig, C.J. et al. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. *BioScience.* 60:602–613.

Breshears, D.D., Cobb, N.S., Rich, P.M. et al. 2005. Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Sciences of the United States of America.* 102: 15144–15148.

Breshears, D.D., Myers, O.B., Myer, C.W. et al. 2009. Tree die-off in response to global change-type drought: Mortality insights from a decade of plant water potential measurements. *Frontiers in Ecology and the Environment.* 7:185–189.

Dale, V.H., Joyce, L.A., McNulty, S. et al. 2001. Climate change and forest disturbances. *BioScience.* 51: 723–734.

Easterling, D.R., Meehl, G.A., Parmesan, C. et al. 2000. Climate extremes: observations, modeling, and impacts. *Science.* 289:2068–2074.

Hobbs, R.J., Hallett, L.M., Ehrlich, P.R., and Mooney, H.A. 2011. Intervention ecology: Applying ecological science in the twenty-first century. *Bioscience.* 61(6):442–450.

Huntington, T.G. 2006. Evidence for intensification of the global water cycle: Review and synthesis. *Journal of Hydrology.* 319:83–95.

Intergovernmental Panel on Climate Change. 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.

Joyce, L.A., Blate, G.M., McNulty, S.G. et al. 2009. Managing for multiple resources under climate change. *Environmental Management.* 44:1022–1032.

Karl, T.R., Melillo, J.M., and Peterson, T.C., eds. 2009. *Global Climate Change Impacts in the United States: A State of Knowledge Report from the U.S. Global Change Research Program.* New York, NY: Cambridge University Press. 192 p.

Kunkel, K.E., Stevens, L., and Stevens, S. 2011. *Continental United States Climate Outlook.* Asheville, NC: Cooperative Institute for Climate and Satellites: National Climatic Data Center. Unpublished Draft.

McKenzie, D., Gedalof, Z., Peterson, D.L., and Mote, P. 2004. Climatic change, wildfire and conservation. *Conservation Biology.* 18:890–902.

Millar, C.I., Stephenson, N.L., and Stephens, S.L. 2007. Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Applications.* 17(8):2145–2151. http://www.sgcp.ncsu.edu:8090/ [Date accessed: October 25, 2012]

Pachuri, R.K. and Reisinger, A., eds. 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, Geneva, Switzerland: Intergovernmental Panel on Climate Change. 104 p.

Parmesan, C. and Yohe, G. 2003. A globally coherent fingerprint of climate change across natural systems. *Nature.* 421:37–42.

Peterson, D.L., Millar, C.I., Joyce, L.A. et al. 2011. *Responding to Climate Change on National Forests: A Guidebook for Developing Management Options.* Gen. Tech. Rep. PNW-GTR-855. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109 p.

Prestemon, J.P. and Abt, R.C. 2002. The southern timber market to 2040. *Journal of Forestry*. 100(7):16–22.

Schneider, S.H., Semenov, S., and Patwardhan, A. 2007. Assessing key vulnerabilities and the risk from climate change. In: Parry, M.L., Canziani, O.F., Palutikof, P.J. et al., eds. *Climate Change 2007: Impacts, Adaptation and Vulnerability—Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press: 779–810. Chapter 19.

Turetsky, M.R., Kane, E.S., Harden, J.W. et al. 2010. Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. *Nature Geoscience*. 4:27–31.

Vose, J.M., Peterson, D.L., and Patel-Weynand, T., eds. 2012. *Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector*. Gen. Rech. Rep. PNW-GTR-870. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 265 p.

Wear, D.N. and Greis, J.G., eds. In press. The Southern Forest Futures Project: Technical Report.

Whitlock, C., Marlon, J., Briles, C., Brunelle, A., Long. C., and Bartlein, P.J. 2008. Long-term relations among fire, fuels, and climate in the northwestern U.S. based on lake-sediment studies. *Journal of International Wildfire Research*. 17(1):72–83.

Williams, J.W. and Jackson, S.T. 2007. Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and Environment*. 5(9):475–482.