13 Summary of Findings, Management Options, and Interactions

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CONTENTS

Forests in the Southern United States are likely to be very different in the coming decades as a result of climate change. Maintaining resilience and restoring forest ecosystems to ensure a continuing supply of ecosystem services will be a major challenge in the twenty-first century. Fortunately, most forests have inherent resistance and resilience to climatic variability and disturbances. Historically, land managers have been able to leverage these characteristics, shaped by management and on-the-ground experiences, to buffer the effects of climatic stresses and disturbances on forest health and productivity. As noted in the previous chapters, the natural resource community in the Southern

United States is not operating in a vacuum of scientific knowledge or management experience. Clear examples include the use of prescribed fire and tree breeding for insect and disease resistance. Despite this history and decades of practical experience, the rapid pace and magnitude of climate change may exceed the inherent resistance and resiliency of forest ecosystems and pose new management challenges that go beyond current knowledge and experience. Among those challenges will be identifying areas where forests are most vulnerable, determining where the effects of change could be the greatest and the most detrimental, and developing and implementing management activities to increase resilience and resistance or to facilitate a transition to a new condition (Millar et al. 2007).

As discussed in Chapter 7, initial progress for making forest stands more resistant and resilient to climate change will most likely occur as modest modifications of forest management activities currently being practiced on forest industry and timberland investment ownerships, on nonindustrial private forest ownerships already under active management, and on government lands such as national and state forests. For these forests, managing forest stands with attention to the possibility of climate change will not be much different in principle than decisions foresters have been making over the past century, but perhaps with different treatment prescriptions based on stand management objectives that address and emphasize the potential impacts of a changing climate. In many ways, this is essentially a risk-reducing strategy, but where management decisions consider the implications of climate change along with all of the other factors considered when planning and implementing management activities. In other cases, the pace of change, the complexity of highly fragmented landscapes and multiple co-occurring stressors, and the consequences of economic and ecological impacts could be so severe that management actions focusing on historical conditions are likely to fail. In these cases, new management approaches may be required to anticipate and respond to climate change and guide development and adaptation of forest ecosystem structures and function, thereby sustaining desired ecosystems services and values over large landscapes and multiple decades. Examples include facilitating migration of and managing future habitat for impacted species (Chapters 10 and 11), selectively managing for "water-wise" species to maintain streamflow and groundwater recharge (Chapter 9), and developing new breeding programs that favor species resistant to climatic change and variability (Chapter 8). In some cases, management actions will involve facilitating the transition to a different or new mix of species and stand structures that can continue to provided ecosystem services. As such, some of these new management activities may challenge long-held management practices aimed at maximizing productivity per unit area or restoring ecosystems to historic conditions.

To address forest–climate interactions in the Southern Region, chapter authors were provided with a common framework (Chapter 1), consistent definitions (Chapter 3), and down-scaled projections of a range of future temperature and precipitation values (Chapter 2) as starting points. Although the approach to utilizing this information varied from chapter to chapter, all chapters provide a comprehensive analysis and discussion of anticipated climate change impacts on forest threats and values in the Southern Region and discuss potential management options to mitigate those impacts. Most climate change impacts, and subsequent management activities to adapt to or mitigate them, would interact with multiple threats and values simultaneously. Some interactions may occur more quickly than others, and may be either positive or negative, and may be either short- or long term. For example, thinning to reduce the threat of wildfire might also have impacts on water resources, wildlife habitat, recreation experience, forest growth, and carbon storage—suggesting the importance of an interdisciplinary and multifactor approach that identifies and evaluates trade-offs among adaptation and mitigation choices. An important first step is to identify the most important interactions. Here, we highlight the major findings from each of the values and threats chapters, summarize management options, and identify key interactions among effects and management options. For details and scientific references to support the key findings and management options, readers are referred to the specific chapters.

THREATS TO SOUTHERN FORESTS

Wildfires

Key Findings

- The South will face the challenge of potentially increased wildfires this century because of projected warmer temperatures and more frequent droughts resulting from climate change.
- Future fuel loading is projected to decrease in the western areas of the South and increase in the eastern areas based on a global dynamic vegetation model and a dynamic downscaled climate change scenario.
- The area with the largest increase in future fire potential is expected to occur along the eastern Gulf of Mexico coastal areas in the early spring, extending to the central area in the late spring, and further to the Atlantic coast in summer and early autumn. The length of the spring and autumn fire seasons is likely to increase and the extent of the drying would be more severe.
- Projected increased dryness during summer may introduce a summer fire season to parts of the South (or at least a later end to the spring season and earlier start of the autumn season). Fire seasons would increase in duration by about 1–5 months in eastern areas of the South with the largest increase in the Appalachian Mountains, and by about 1–3 months in western areas with the largest increase in the Mid-South.
- Wetter weather, which may accompany climate change in some places, would result in less frequent, smaller, and less intense wildfires in those areas.
- The continued population growth of the South increases the potential threat that wildfires pose to life and property.
- Human populations are positive risk factors for wildfire; human-ignited wildfires tend to be clustered around places with human populations, confirming that as human populations grow, wildfire ignitions by people are more frequent, all things being equal. Increased fires in the future will likely increase occurrence of smoke and lead to more severe air quality impacts.
- Public tolerance of smoke has diminished over time, and complaints about smoke impacts from prescribed burning, wildland fire use, and wildfires are frequent.
- The number of days when a prescribed burn is unlikely to become an uncontrolled burn or a wildfire in the South could be reduced by about 40–60% during summer and autumn, 30% during winter, and 10% during spring.

Management Options

- Increase public awareness and education about the potential impacts of climate change on wildfire risk.
- Increase the use of prescribed burning to reduce accumulation of understory fuels and therefore reduce wildfire risk.
- Reduce wildfire risk indirectly by expanding the acreage of fire-resistant species such as longleaf pine.
- Increase focus on arson-prevention efforts.

Insects, Diseases, and Invasives

Key Findings

- Changes in environmental factors including temperature, precipitation, and associated factors, may affect the occurrence and impacts of forest diseases, native and nonnative pest insects, and nonnative plant species in several ways, some of which are difficult to predict.

- Long-term drought events may result in increased host stress and lead to an increase in the severity and mortality attributed to root disease. Conversely, tree mortality associated with drought can reduce stand density, thus reducing the opportunity for root contact, contagion, and demand for nitrogen.
- Increasing air temperature may decrease the incidence of stem rust pathogens because of their exacting requirements for infection and spore survival on plant surfaces.
- Warming from climate change will likely hasten proliferation of potentially harmful insect species such as bark beetles, defoliators, sap-sucking insects, borers, and weevils (all of which would likely see increased numbers of generations per year).
- Climate-change-driven warming could expand the northern ranges for many invasive insect species in the United States.
- In addition to increased insect metabolism during the growing season, warmer temperatures could also reduce insect mortality from the extreme cold winter season, resulting in thriving insect populations through the spring into summer.
- Climate change could also indirectly affect insect populations through impacts on natural enemies, important insect symbionts, host physiology, and host range distributions.
- Future warmer winter temperatures could remove existing range barriers for some native species. This could result in spread into places where hosts are currently abundant and result in competition between native and nonnative insect species.
- Even within the past few decades, invasive species of all kinds have moved higher in latitude and elevation, threatening the native plant species with small population sizes and distribution ranges.
- Climate change will likely influence the establishment of new invasive species and the effectiveness of control strategies. Invasive plants that are fast growing and responsive to resources would be favored by environmental changes that increase resource availability, which would jeopardize the existence of invasive species.

Management Options

- Implement preventive measures such as thinning to reduce stand density—removing infested, damaged, and weakened trees, and harvesting before trees become over mature.
- Replant impacted stands with resistant varieties and species.
- Apply early detection and rapid response systems to prevent the establishment of, or mitigate damage from, new invasive species.
- Plan for monitoring and prompt management of insect outbreaks at higher elevations, and prepare for management of large-scale mortality events and altered fire regimes.
- Promote silvicultural practices that increase seedling regeneration and genetic mixing.
- Reduce homogeneity of stand structure and synchrony of disturbance patterns by promoting diverse age classes, species mixes, and genetic diversity.

VALUES OF SOUTHERN FOREST

Forest Productivity and Carbon Sequestration

Key Findings

- The South's forest sector produces approximately 60% of the total United States' wood production–climate change could have major implications for the nation's wood supply.
- Southern forests play an important role in carbon (C) storage, accounting for 36% of the carbon sequestered in the conterminous United States.
- The primary effects of climate change will likely occur as exogenous or endogenous disturbance events of as-yet unknown duration, frequency, or intensity in southern forest stands and landscapes.

- Climate change may stimulate growth in many areas of the Southern United States; however, lower precipitation and nitrogen (N) availability may alter or negate the growth response.
- Predicted warming over the next century may cause accelerated decomposition of soil C and reduce C storage in southern forests.

Management Options

- Increase the frequency of thinning and manage at lower basal area to maintain individual tree vigor.
- Expand and intensify pine plantation management to increase productivity and C sequestration.
- Plant and manage species less susceptible to extreme weather conditions such as longleaf pine.
- Breed for more climate change resilient ideotypes.
- Manage to create forests with greater genetic diversity and multiple age cohorts.
- Conserve at risk species via *in situ* and *ex situ* genetic conservation.
- In wet or seasonally inundated forests, maintain hydrologic regimes to ensure continued C retention.
- Extend rotations and increase initial planting density to increase net C storage.

Water Resources

Key Findings

- Water resources in the Southern United States are at risk of degradation from climate change, land conversion from forests to urban uses, increasing water demand from growing population, and sea level rise.
- Droughts, floods, and water quality problems are likely to be amplified by climate change.
- As species distributions change in response to climate change, especially if large areas of forests experience catastrophic mortality, streamflow and water quality are also likely to change.
- Decreases in water supply and increases in water demand as a result of population growth would combine to increase water supply stress to humans and ecosystems.
- A warming climate may elevate water temperature, diminishing surface-water value for consumptive and habitat uses.
- Changes in precipitation amount or storm intensity can affect soil erosion and sediment loading by altering the amount of runoff, the kinetic energy of rainfall, or the ability of vegetation cover to resist erosion.
- Future climate change is likely to aggravate the problems of salt-water intrusion in the east coast of the United States by increasing air temperatures, changing regional precipitation regimes, and raising sea level.

Management Options

- Consider the water demands of tree species when planning restoration and afforestation activities. “Water-wise” choices may help maintain streamflow during droughts and reduce flood risk after high precipitation events.
- Natural wetlands should be protected to maintain their hydrologic functions and buffer disturbances.
- The resilience and vulnerability in artificially drained, managed forests should be evaluated based on projected future climatic and hydrologic conditions in the region.
- To mitigate salt-water intrusion, management practices in these areas should include timing of withdrawals to coincide with outgoing tides, increasing storage of raw water, adjusting

the timing of larger releases to move the saltwater–freshwater interface downstream, and blending higher conductance surface water with lower conductance water from an alternative source such as groundwater.

- Mitigating climate change impacts on low flows would require implementation of management practices that help to reduce water use, reclaim wastewater, and enhance infiltration and groundwater discharge to streams.
- Mitigation of increases in stream temperature and greater overland flow would require stable or increased shading from solar radiation through riparian buffer retention, expansion of riparian buffer widths, and restoration of degraded riparian zones.
- To compensate for higher runoff volumes: (1) adjust the relationship between road grade and separation distances for broad-based dips and other water diversion features, (2) increase culvert diameter for a given drainage area, and (3) use hooded inlets on culverts to increase storm water-carrying capacity for a given culvert size.
- Develop and implement new best management practices for road design and construction that more effectively disconnect the road system from the stream network.
- Develop and implement storm water structural best management practices such as rain gardens and other sediment basins, and sustainable urban drainage systems that encourage infiltration, minimize exceeding treatment facility capacity, and ultimately reduce the risk of degraded surface water.

Plant Species and Habitat

Key Findings

- Climate models vary in their forecasts of future climates, but generally predict a warmer and drier environment for much of the South. Vulnerability assessment for common tree species indicates that some, that is, those with relatively high moisture requirements, will decrease their areas of distribution.
- Vulnerability assessments varied considerably among the four climate predictions, particularly when comparing the MIROC3.2 A1B scenario (the general circulation model that projects the warmest and driest future) to the other three model and scenario combinations.
- Vulnerability of tree species to climate change in the Southern Region is potentially highest (measured by number of tree species predicted to decrease their range) in the Mid-Gulf-West of the Coastal Plain, the Central Appalachian Piedmont, and the Ozark-Ouachita Highlands section of the Mid-South. In contrast, the ranges may expand northward for species in the Southern Appalachian Piedmont, Blue Ridge and Northern Ridge and Valley, which are rapidly expanding their northern ranges in response to warming climates.
- The overall effect of climate change on diversity of southern trees was predicted to result in small reductions of species richness in most of the 21 ecological sections studied, although the number of species may remain constant or increase slightly in several sections by the year 2060.
- Although the magnitude of results varied somewhat among climate scenarios, the overall trends were generally consistent: tree diversity could decrease throughout the Southern Region by the year 2060, with the highest risks occurring in certain sections of the Coastal Plain, Piedmont, and eastern zone of the Mid-South.

Management Options

- Landowners with holdings in areas of the Southern Region that face the highest threat to vulnerability for certain species (such as shortleaf pine in western Arkansas) and high risk to species diversity (such as in the Ozark-Ouachita Highlands section of the Mid-South) will be among those who need relevant information on resource management the earliest.

- To maintain the historic oak component in some ecosystems in the likely event of climate change, land managers may need to reduce basal area and stem density of shade-tolerant competitors, such as invading red maple, in all canopy strata.
- Artificial regeneration of preferred tree species by planting may be required as an alternative to natural methods for resource managers concerned about short-term effects of climate change on species composition.
- Genetic selection from natural variability within a species may allow resource managers to respond to climate change when trends of future temperature and precipitation become more apparent for an area.

Wildlife Species and Habitats

Key Findings

- Major factors contributing to population declines of wildlife species include habitat destruction and fragmentation, isolation, small population sizes, low genetic diversity, water diversions, introduction of nonnative invasive species, acid precipitation and other environmental pollutants, commercial development, human disturbance, and exploitation. Stress from climate change may exacerbate the effects of these factors.
- Based on the processes of extinction and colonization and their ability to disperse, species are expected to shift their distributions or move to higher altitudes in response to a warming climate.
- Increased fire frequency or intensity could alter habitat features required by some wildlife species.
- Because of their ability to regulate body temperature, mammals generally respond to climate indirectly through changes in food supplies, predators, parasites, and habitat. However, human-modified landscapes may affect movements of mammals to more favorable climates.
- Increased variability or reductions in precipitation may affect disease outbreaks, survival, physiology, and nutritional state in mammals. Changes in climate could lead to increased zoonotic disease outbreaks in humans.
- Climate modification also can indirectly affect birds by influencing habitat conditions. Various groups of birds, such as waterfowl, shorebirds, game species, and neo-tropical migratory birds may be affected by habitat conditions that change from climate modification.
- Eventually, even highly adaptive bird species may reach their limits and would be forced to employ other measures to deal with climate change effects. Temporal responses may appear as changes in migratory patterns with birds arriving at breeding grounds earlier.
- For some bird species, warming may have a beneficial effect if it results in a widening of the area within which their habitat requirements are met and they utilize this expanded area. The enlarged area may contain food resources that differ from the current range; hence, the species must be capable of adjusting to the new food resources and possibly a different suite of predators.
- Shorebirds that depend on multiple areas of the South for part of their life cycle may be adversely affected by global warming on their breeding habitat, migration routes, and wintering habitat.
- Shifts in climate can have negative effects on amphibian populations. Temperature and precipitation have major influences on the life cycle of amphibians, particularly their breeding activities. Higher temperatures could cause some amphibians to shift their distributions north because their young are unable to develop in warmer waters. Many mountaintop species may already be approaching their thermal maxima and have limited dispersal ability. Increases in temperature would result in lost habitat for many species. Species with small geographic ranges would be at greater risk of extinction.

- As a group, reptiles may be less vulnerable to climate change than amphibians because their scale-covered skin makes them less vulnerable to desiccation and better able to tolerate predicted drier, warmer conditions. Nonetheless, reptiles would be affected by changes to primary habitats, temperature-driven energetic shortfalls, temperature-dependent sex determination, or changes in food availability.
- Butterflies play a significant, critical role in ecosystem function as pollinators. Climate change, to the extent that it alters butterfly and other pollinator populations, would have cascading effects on entire ecosystems. As a consequence of their complex life cycles, diverse larval hosts, and frequent dependence on a particular suite of nectar resources, butterflies would respond to climate change in very complex ways. Their larvae are also important herbivores in terrestrial ecosystems and critical prey for predators (such as insectivorous birds).
- Changes in butterfly populations resulting from climate change would have consequences for both host plant and predator species. Butterfly species would begin to expand northward but their success would depend on concurrent shifts in host plant distribution. Other species, lacking the ability to colonize new habitats rapidly, would be locally or globally extirpated, with resultant loss of diversity and critical ecosystem services.

Management Options

- Increase the amount and connectivity of wildlands and minimally disturbed habitats through acquisitions and conservation programs, with particular attention to interconnected habitats that run from north to south, and from higher to lower elevations.
- Consider wildlife movement and road-kill mortality reduction when planning or improving roads and highways; examples include providing (as needed) elevated sections of highways or building wildlife underpasses to allow uninterrupted migration corridors.
- Where possible, manage ecosystems to restore and maintain historical conditions likely to enhance resilience in associated native wildlife species by promoting optimal habitat and larger populations.
- Protect and conserve coastal habitats through strategic planning and implementation of zoning and building codes, particularly in areas of predicted rising sea levels where development plans may need to provide for inland migration of coastal wetlands.
- Use caution when building barriers for construction or flood control, as they can cause the elimination of existing wetlands.
- Make coastal habitats less susceptible to sea level rise, such as by removing ditches to restore the hydrologic regime and limit saltwater intrusion, assisting development of vegetation by planting salt-tolerant species, and building oyster reefs to buffer shorelines from storm events and wave action.
- Protect and maintain wetland and stream water quality, water quantity, flow, hydrologic processes, and temperatures by restoring riparian zones and watersheds.
- Conserve species and special habitats, paying special attention to restoration and management of rare species or ecosystems.
- Aim for representation, resiliency, redundancy—networks of intact habitats that represent the full range of species and ecosystems in a given landscape, with multiple robust examples of each.
- Reduce existing ecosystem stressors, both from climate and other disturbances, such as habitat loss and alteration, pollution, ozone depletion, invasive species, and pathogens.
- Forge or foster partnerships among agencies, organizations, scientists, and local communities to develop science-driven, landscape scale strategies to maximize the use of scarce resources.
- Monitor, model, and implement adaptive management in response to unforeseen responses or trophic cascades resulting from climate change.

- Increase management for species in areas where they are expected to advance, such as the northern limits of their ranges.
- Consider short-distance, human-facilitated movements of species across artificial and natural impediments to migration, such as areas dominated by intense agriculture and large rivers.
- Consider, *ex situ* gene conservation options for species at risk of extinction. One option could be translocation of species to geographic areas or habitats (assisted migration) where they do not naturally occur.

Recreation

Key Findings

- Outdoor recreation opportunities rely heavily on natural settings and conditions, thus negative impacts on settings like forests and water bodies could negatively impact the quality and availability of these resources, and their long-term potential in providing recreational opportunities.
- Climate may affect recreation in direct and indirect ways including the effects of weather on recreationists' physical comfort or convenience and the effect of varying the length of seasons on the availability/suitability of certain outdoor opportunities. In addition, more frequent and damaging severe weather events could pose risks to recreationist safety.
- Climate change could gradually alter the natural resource base on which outdoor activities depend. For example, increasing temperatures will likely affect the distribution of plant and animal species that are fundamental to maintaining fish and game populations.
- In the coming decades, population growth will be the overriding factor influencing outdoor recreation. The effects of climate change on recreation demand by southerners appear to be moderately mitigating insofar as use density measures (like participants per forest and rangeland acre and activity days per acre) are concerned.
- Increased congestion and possible declines in the quality of the outdoor recreation experience are likely to present important challenges to management.

Management Options

- Management activities that maintain forest settings, provide stable water resources (e.g., streamflow and lake water levels), and provide wildlife habitat will help to ensure quality recreation opportunities.
- While climate change will impact outdoor recreation, managers will need to be more concerned about increased congestion and possible declines in the quality of the outdoor recreation experience. This will probably have to be accomplished through creative and efficient management of site attribute inputs and plans, rather than through any major expansions or additions to the natural resource base for recreation.

INTERACTIONS AMONG MANAGEMENT OPTIONS

In this section, we identify and discuss management options within the context of multiple benefits or conflicts among values and threats (Table 13.1). Management actions can have positive impacts on multiple resource values or threats. For example, increased use of prescribed burning is a management option to reduce wildfire risk; however, it is also recommended for maintaining wildlife habitat and reducing threats from certain insects, diseases, and nonnative plants. On the other hand, expanding the use of prescribed fire into less frequently burned areas in anticipation of future wildfire risk could substantially change current species composition and wildlife habitat. Referring to Table 13.1, other management options with multiple benefits include increased thinning of current stands and managing future stands for lower stocking (recommended by 3 values, 2 threats); increased vegetative, genetic, and age class diversity (recommended by 3 values, 1 threat);

TABLE 13.1
Climate-Change Mitigation Alternatives and Their Potential Impacts (Each Designated by Δ Symbol) on Multiple Forest Values and Threats

	Values					Threats	
Management Options	**Water**	**Species**	**Forest Productivity**	**Carbon Sequestration**	**Recreation**	**Wildfire**	**Invasives**
Improve landscape connectivity, especially south to north		Δ			Δ		
Increase vegetative, genetic age-class diversity		Δ	Δ		Δ		Δ
Increase use of prescribed fire		Δ			Δ	Δ	Δ
Increase thinning, keep stocking levels low	Δ	Δ			Δ	Δ	Δ
Lengthen rotation age				Δ	Δ		
Shorten rotation age			Δ		Δ	Δ	Δ
Redesign road best management practices for larger storms	Δ				Δ		
Increase culvert size for larger storms	Δ				Δ		
Fertilize established stands			Δ	Δ	Δ		
Plant/encourage species that are resistant and resilient to disturbance and stress			Δ		Δ	Δ	Δ
Restore hydrologic function in drained forests and wetlands; maintain or enhance hydrologic function elsewhere	Δ	Δ		Δ	Δ		
Restore and widen riparian buffers	Δ	Δ			Δ		
Manage destinations for species' migrations		Δ			Δ		
Implement facilitated migration		Δ			Δ		
Incorporate water use characteristics of tree species in decision making	Δ				Δ		
Increase and intensify plantation management			Δ	Δ	Δ		
Implement coastal zone water management to abate sea level rise	Δ	Δ			Δ		

restoration, maintenance, and enhancement of hydrologic function (recommended by 4 values); and planting or encouragement of species resistant or resilient to disturbance or stress (recommended by 2 values, 2 threats). As climate change management adaptation and mitigation activities are evaluated and planned for public lands, the identification of management options that provide multiple benefits may help with prioritizing and funding activities that garner the biggest "bang for the buck." This is not to imply that management activities that only benefit a single value or threat are less important or lower priority. Indeed, it is likely that some very specific management activities may be required for activities such as protecting rare and endangered species or addressing high risks such as flood severity or frequency. Management for commercial production will need to translate these threats (Table 13.1) into financial risk profiles for investment alternatives. Increased risks would likely favor shortened rotations and intermediate treatments and possibly increased diversification of management across species and locations.

Specific management options may also have negative impacts on other resource values of threats. For example, maintaining forests at lower stocking levels through thinning and lower initial stand density to increase tree vigor may reduce overall stand productivity and decrease C sequestration potential in the short term. However, if these actions prevent catastrophic wildfire or severe insect outbreaks, then the impacts would be positive in the long term. In contrast, extending rotation lengths to enhance C storage may increase the potential for exposure to insect outbreaks or storm damage that could offset C storage gains. These interactions and trade-offs suggest the need for a broad vision and large-scale approach for implementing "climate smart" management practices. For example, extending rotation ages may not be desirable for all species in all locations. Extending rotation ages in areas where climate change is expected to increase the potential for severe storms or insect outbreaks would increase the risk of tree mortality and reduce productivity and C storage. In areas where future risks are greatest, decisions could be made to shorten rotations and/or favor species more resistant to climate extremes and insect outbreaks.

As noted, evaluating risk (Chapter 3) and landscape scale approaches are at the core of this type of decision making. Risk management has been used by resource managers for many years, but typically not in the context of climate change. The most recent National Climate Assessment (Vose et al. 2012) has advanced a risk-based approach for evaluating climate change impacts and evaluating management options to reduce risk (Yohe and Leichenko 2010), where risk is framed by the likelihood of an impact occurring and the magnitude of the consequence of the impact (Yohe 2010). Figure 13.1 provides an example application of the risk-based framework for a management option to reduce flood risk. Landscape scale planning andmanagement activities will be especially challenging in the Southern United States because of the complex and mixed ownership pattern of the southern forests. Due to the large acreage of private forest land (about 89%), management activities on private forests will be critical in order for many adaptation and mitigation activities to have an impact at meaningful scales. A proactive approach will require working across institutional and ownership boundaries to exchange information and potentially coordinate landscape level approaches.

Robust decision making also requires a full understanding of uncertainty associated with climate change projections (especially for precipitation), climate change impacts on resource values

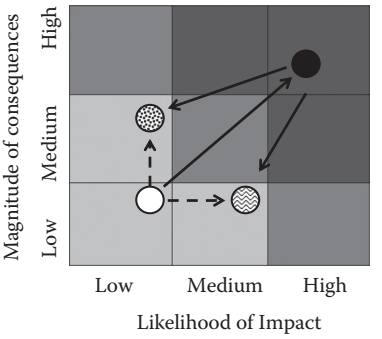

FIGURE 13.1 Example of applying the risk-based framework described in Yohe and Leichenko (2010) to prioritize management decisions and evaluate management options. The *y*-axis is the likelihood of climate change impact (low, medium, high) and the *x*-axis is the magnitude of the climate change impact (low, medium, high). Darker colors indicate greater risk. In this example, we denote the open circle (○) as the flood risk for a watershed under current precipitation regimes. The solid circle (●) represents the future flood risk under a changing precipitation regime that includes more extreme high rainfall events. Management actions can be either proactive (dashed lines) to minimize risk or reactive (solid lines) to reduce risk after changes have occurred. An example of a management action to reduce the likelihood of impacts (◍) would be to increase culvert sizes. An example of a management action to reduce magnitude of impacts (◉) would be to manage for wide riparian zones with species adapted to wet conditions.

and threats, and management actions to reduce impacts or minimize risk. This uncertainty continues to be reduced as new science and observations confirm (or modify) previous predictions and improve model accuracy, and as on-the-ground adaptation activities (such as thinning to reduce wildfire risk) are tested by changes in fire regimes (Vose et al. 2012). Although some level of uncertainty will always exist, sufficient scientific information is available to begin to implement climate smart management activities now, and tools are available to help incorporate climate change science into planning and decision making (Vose et al. 2012). Examples include TACCIMO and ForWarn (see www.forestthreats.org for further information).

Climate change is just one of many considerations that land managers must address when making decisions and choices about specific on-the-ground management activities. These decisions are considered within the context of short- and long-term goals and desired future conditions, the best available science, and the experiences of natural resource professionals. Management actions can be either passive (a decision of no action), reactive, or anticipatory (Carter et al. 1994). The management options advanced by the authors of this book are a mix of reactive and anticipatory actions. Similarly, climate change adaptation management involves a combination of planning (decision making and prioritization in the context of other resource management demands and constraints), strategies (prioritization and decision making of how, where, and when to implement climate change management actions), and tactics (project scale decision making and implementation of climate change management actions). While many of the management options discussed in this book provide guidance for planning, the primary scale of focus is on strategies and tactics.

A few overarching concepts provide broad but useful advice for managers who consider the options described above when developing adaptation strategies and tactics:

- Reduce existing stressors as much as possible early in planning to increase the resilience of the forest ahead of further major climate change impacts. These stressors may include climate impacts, such as more frequent flooding or drought, and others including pollution, habitat loss, alteration, and invasive species. Starting with a healthy ecosystem could provide a greater level of resilience for existing populations.
- Adopt and promote a system of monitoring and implementing adaptive management strategies to accurately assess success and identify areas for improvement. Consistent long-term monitoring will help managers gain valuable information about the ecosystem under a changing climate and adjust their strategies appropriately.
- Develop and enhance existing partnerships with scientists, organizations, agencies and local communities. Such partnerships could enhance the development of science-based management approaches that will provide the essential foundation for managing forests in response to a changing climate.

The rapid pace of new scientific information from observations, models, and experiments; and "on-the-ground" experiences with climate change adaptation activities will place an even greater emphasis on the rapid transfer of new science to land managers and frequent feedback from land managers to scientists. As such, this book serves as a starting point for a dialogue about "climate change adaptation and mitigation and management options" that will be continuously updated and improved through enhanced science–management partnerships.

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