Chapter 8

Forests and Climate Change in the Southeast USA

CONTRIBUTING AUTHORS

Steven McNulty (steve_mcnulty@ncsu.edu; Eastern Forest Environmental Threat Assessment Center, USDA Forest Service, Raleigh, North Carolina)

Peter Caldwell (Eastern Forest Environmental Threat Assessment Center, USDA Forest Service, Raleigh, North Carolina)

Thomas W. Doyle (National Wetlands Research Center, US Geological Survey, Lafayette, Louisiana)

Kurt Johnsen (Southern Institute of Forest Ecosystems Biology, USDA Forest Service, Research Triangle Park, North Carolina)

Yongqiang Liu (Center of Forest Science Disturbance, USDA Forest Service, Athens, Georgia)

Jacqueline Mohan (Odum School of Ecology, University of Georgia, Athens, Georgia)

Jeff Prestemon (Forest Economics Unit, USDA Forest Service, Research Triangle Park, North Carolina)

Ge Sun (Eastern Forest Environmental Threat Assessment Center, USDA Forest Service, Raleigh, North Carolina)

The forests of the southeastern USA have seen many changes over the past 200 years. From cutting of the virgin forest in the 19th century to the expansion and later contraction of farming and the rise of plantation forestry in the 20th century, the structure and function of southern forests continues to evolve. Climate change represents another factor that is changing Southeast (SE) forests and forestry practices. Current and continued projected warming likely will increase the risk of wildfire, wind, insect, and disease damage to southeastern forests. Increased air temperatures also likely will lead to decreased forest water yield, even as the population of the SE USA continues to expand. Conflicts between maximizing forest carbon sequestration as a mitigation strategy for climate change and need for water likely will continue well into the 21st century. However, scientists are actively working with land managers to address these issues. Although the form of SE forests will continue to change due to old and new pressures, forest managers are becoming increasingly better prepared to cope with these challenges. This chapter examines some of the pressing issues and management options associated with global change in the SE USA.

Key Findings

- Warming air temperatures likely will increase regional drying through increased forest water use via evapotranspiration (ET) regardless of changes in precipitation, and this drying will likely increase wildfire risk across SE USA forests.
- Longer growing seasons will likely increase the risk of insect outbreak and very likely will expand the northern range of some species, such as the southern pine beetle.
- Under most scenarios, increasing temperatures and decreasing precipitation will result in a greater uptake of soil water by forests and lead to reductions in streamflow.
- Despite climate and land use changes, forests in the southeastern USA will likely continue to provide a sink of atmospheric carbon dioxide (CO_2).
- The potential savannafication of the SE, in which forests are converted into more open woodlands due to a combination of hotter and drier conditions, could be one of the most profound potential climate change impacts in the USA

8.1 Historical Perspective

The forests of the Southeast (SE) USA have seen extensive change during the past century. Currently, 60% of the SE landscape is forested (Wear and Greis 2002). In 1860, about 43% of the SE land area was reported as under cultivation, but a substantial part of the farm holdings that remained in forest were used for grazing livestock (Smith and Darr 2009). Timberland continued to decline until the early 1920s due to the continued expansion of settlements. Significant changes in agriculture took place after 1920 that resulted in abandonment of large areas of crop and pasture lands. Some of the abandoned land was planted with trees, but most of the land reverted naturally to forest, leading to increases in timberland acreage (Wear et al. 2007). By the late 1950s and early 1960s, decline of timberland began again in the SE, caused primarily by the clearing of forests for soybean and other crop production. Much of this timberland reduction occurred in bottomland hardwood forest areas of the Mississippi Delta.

Throughout the 1970s, timberland was cleared for agricultural use and for an expanding export market. The decade beginning in 1982 marked a slowing of forest cover loss with the National Resources Inventory reporting roughly a half million-acre loss (less than 1%) in forestland in the SE (Wear et al. 2007). That trend has continued into the 21st century as softwood pulp prices have fallen by 50% since 1998, and the forest products industry divested approximately 75% of its timberland holdings (Butler and Wear, In Press). Although market prices will likely continue to be a driving factor in forest land area, other ecosystem services such as climate change, wildlife protection, drinking water supply, and recreation may increasingly influence the distribution and composition of SE forests (Wear and Greis 2002).

8.2 Southeastern Forest Types

The southeastern USA is not comprised of a single forest type, but of many. This assessment of forests and climate change focuses on six distinct forest areas within the SE: the Atlantic and East Gulf Coastal Plain, Piedmont, Appalachian/Cumberland, Mid-South, Coastal, and the Mississippi Alluvial Valley. Current inventory data shows that more than 30 million hectares of upland hardwood forests dominate the SE, followed by more than 15 million hectares of planted pine, approximately 13 million hectares of natural pine and bottomland hardwoods, and more than 3 million hectares oak-pine forest types (Butler and Wear 2012). These forest ecosystems provide a multitude of goods and services including clean water and air, wildlife habitat, recreation and aesthetics, timber and fiber production, and CO_2 sequestration. This chapter reviews current and future stresses on services provided by SE forests, and examines how forest management could be used to cope, adapt, or mitigate negative impacts.

Atlantic and East Gulf Coastal Plain. Historically, most of the southeastern Coastal Plain was dominated by fire-dependent longleaf pine (*Pinus palustris*) savannas (Christensen 2000). However, upland closed-canopied forests occur in mesic areas protected from frequent fire or where fire suppression has occurred. Notable examples of old-growth mesophytic beech-magnolia forests are present in the Apalachicola National Forest of the Florida panhandle. Other Coastal Plain broadleaved forests include those dominated by southern oak species such as swamp chestnut oak (*Quercus michauxii*), cherry bark oak (*Quercus pogoda*), and live oak (*Quercus virginiana*), as well as hickories (*Carya spp.*) and loblolly pine (*Pinus taed*a). American holly (*Ilex opaca*), spice bush (*Lindera benzoin*), and pawpaw (*Asimina triloba*) are common in the understory and subcanopy (Christensen 2000).

The distribution of current and potential future droughts and associated fire risk varies as does the potential impacts on trees species. Several dendrochronological analyses of Coastal Plain longleaf pine trees demonstrate the impact of growing season drought severity in relationship to reduced tree growth rates, as well as positive impacts of warmer winter temperatures (Bhuta et al. 2009, Henderson and Grissins-Mayer 2009). Less climatic research has been conducted in closed-canopied upland forests, but increasing fire frequencies in these Coastal Plain forests, due to ongoing and potential future droughts, may be a major impact on the distribution of some forests of this region (Wade et al. 2000). However, a recent study by Gruhn and White (2011) examined the northward range expansion of southern magnolia by comparing establishment success with climatic and topographic variables. Although minimum winter temperatures and the number of frost-free days were important determinants of establishment success, precipitation was not.

In addition to drought and fire, Coastal Plain forests and other ecosystems are also particularly vulnerable to hurricanes. Hurricane Isabel in September 2003 damaged 15% of trees, particularly canopy trees, in a maturing hardwood forest of the Virginia Coastal Plain (Prengaman et al. 2008). Hurricane Isabel was only a Category 2 storm, so increased frequencies of Category 4 and 5 hurricanes as a consequence of climate change likely will have even more profound effects (Webster et al. 2005, Knutson et al. 2011). Hurricane Katrina is an example of the damage caused by a strong hurricane (MIFI 2005).

Southern Appalachians. These forests cover much of the high elevation areas of the north-central southern region that includes eastern Tennessee and Kentucky, western North Carolina and Virginia, and northern Georgia. The southern Appalachian forests are some of the most diverse in North America (Clark et al. 2011). Both unique species and commercially important species can be found within the region. The diversity of these forests is controlled by regional and local weather patterns that can be highly variable due to the mountainous terrain (Clark et al. 2011). As with other mountain systems, the high elevation forests of the southern Appalachian ecosystems are at particular risk from a warming climate. A 3^{o}C increase in July temperature would raise climate-elevation bands by about 480m, resulting in the extirpation of the rare red spruce-Fraser fir (*Picea rubens* and *Abies fraseri*) alpine forests growing at the highest elevations in North Carolina and harboring federally threatened animal species, including the North Carolina flying squirrel (Delcourt and Delcourt 1998). Many of the mid-elevation “cove” forests, which are currently dominated by mesic, fire-intolerant tree species, are extremely diverse in terms of canopy trees, spring ephemeral wildflowers, and amphibians. Since the early 1980s this region has warmed and precipitation variability has increased. If these trends continue, they could lead to substantial change in the structure and function of future southern Appalachian forests.

In addition to determining biodiversity, climate variability also controls forest growth. For example, the annual growth rate of five dominant oak species can be severely affected by growing season drought intensity (Speer et al. 2009). During drought years, observed oak forests showed diminished productivity and accumulated 40% less carbon compared to a year of average precipitation (Noormets et al. 2008). If projected temperature increases are accompanied by decreased growing season precipitation, the combined changes may reduce the competitiveness of oaks in the southern Appalachians and elsewhere in the SE (Ibáñez et al. 2008).

Wildfires also shape the structure and function of forests within the southern Appalachians. A recent study suggested that fires occurred fairly frequently over the past 4,000 years in a variety of southern Appalachian forest types including those now dominated by mesic hardwoods, including tulip poplar (*Liriodendron tulipifera*) (Fesenmyer and Christiansen 2010). These researchers found that fire return intervals appear to have been of centuries-scale duration in the time period 4,000 to 1,000 years before present, and were likely often severe. Fires became more frequent approximately 1,000 years ago and were thus likely less severe due to less accumulated fuels build-up. The increased frequency of fire coincided with the occupation by Woodland Tradition Native Americans. If drought and drought-induced fires become more common in the southern Appalachians, fire-tolerant oak and hickory species may become more abundant over less-tolerant tulip poplar, maple (*Acer spp.*), basswood (*Tilia americana*), birch (*Betula* spp.) and magnolia (*Magnolia* spp.) species, potentially reducing diversity in currently highly-diverse mesic forests (Fesenmyer and Christiansen 2010).

Piedmont. The Piedmont region lays southeast of the Appalachian region and stretches from east-central Alabama through central Georgia, northwestern South Carolina, and central North Carolina and Virginia. These forests are dominated by a mixture of pine and deciduous species (Figure 8.1) of high commercial importance (Van Lear et al. 2004). Dale et al. (2010) used ecosystem models and an ensemble of general circulation model (GCM) scenarios to project that in the southeastern Piedmont and Appalachians, southern mixed hardwoods and pine forests on the Piedmont were the most susceptible to changes induced by warmer, and particularly drier, climates. Under the driest of the three climate scenarios considered by Dale et al. (2010), a southern mixed forest transitioned from very high tree species diversity with 14 commonly co-dominant species to very low forest diversity, dominated by loblolly pine, southern red oak (*Quercus falcata*), and Shumard's oak (*Quercus shumardii*). Dale et al. (2010) also found that the less-diverse forests may be more susceptible to insect and pathogen pests, and that hickory (*Carya spp.*) species tended to increase in relative importance under the climate change scenarios considered. Conversely, under those projections the biomass of chestnut (*Quercus prinus*) and black oaks (*Quercus velutina*) tended to decline across Tennessee, as the hickories appeared to be better able to grow in the warmer, drier climate relative to the oak species.

Research from the Duke Free-Air CO_2 Enrichment (FACE) experiment and the Oak Ridge FACE experiment in the southern Appalachians suggests that an approximate doubling of atmospheric CO_2 increases the productivity of the canopy loblolly pine and sweet gum (*Liquidambar styraciflua)* trees by 23% to 27% (DeLucia et al. 2005, Norby et al. 2005). However, when examining the juvenile tree species most likely to comprise the future forests, elevated CO_2 conditions favored the population biomass growth of less productive, shade-tolerant tree species southern sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and black cherry (*Prunus serotina*) as well as woody vines such as poison ivy (*Toxicodendron radicans*) (Mohan et al. 2006, 2007, and 2008) and exotic Japanese honeysuckle (*Lonicera japonica*) (Belote et al. 2004). So, increased atmospheric CO_2 levels may benefit a variety of species, but it is unclear from these few studies how elevated CO_2 levels coupled with other potential stresses may affect the composition of future forests as a whole.

Coastal wetland forests. Coastal wetland forests exist in the transition between the Coastal Plain and maritime ecosystems and are responsive to changes in climate and freshwater outflow resulting from varying patterns and frequencies of freeze, drought, storm, sea level, and runoff events. Because saltmarshes and mangroves thrive in the

Figure 8.1 Mixed conifer and deciduous Piedmont forest in the southeastern USA.

intertidal zone between land and sea, these systems are expected to undergo the most severe changes from marine effects, such as sea level rise and salinity. They are also affected by freshwater drainage effects (e.g., flooding, elevated nutrient loading, and pollutant discharge), and by extreme climate events (e.g., freezing air temperatures, drought, and hurricanes) (Michener et al. 1997, Erwin 2009). For example, mangroves (*Rhizophora* spp.) are halophytes that thrive along tropical coastlines reaching latitudinal limits along the northern Gulf Coast in Texas, Louisiana, and Florida. Historical lapses in freeze events and extreme drought events may account for the northward establishment of red mangrove, which are cold sensitive (Montagna et al. 2009). Warming sea and surface temperatures under predicted climate change scenarios will likely increase the frequency and severity of drought episodes in western parts of the Southeast (Caldwell et al. 2012), while decreasing the periodicity of hard freezes that cause dieback of frost-intolerant tropical plant species (Montagna et al. 2009). Mangrove populations have persisted in fringe populations along subtropical coastal settings of Texas, Louisiana, and Florida but have been undergoing recent expansion in latitudes above the tropical Everglades region, where mangroves traditionally have dominated the coastal land margin (Michot et al. 2010, Doyle et al. 2010). Local populations of black mangrove *(Avicennia germinans)* in coastal Louisiana have expanded in area, density, and stature since the last damaging freeze two decades ago (Michot et al. 2010). If the period between severe freeze events lengthens under climate changes, mangrove expansion is expected to succeed landward and poleward along the northern Gulf Coast changing the proportion of saltmarsh area (Krauss et al. 2008). Mangroves have the added benefit of possessing unique root structures that may help stabilize coastal areas from erosion (McKee et al. 2007, Cherry et al. 2009). A shift from saltmarsh dominated coastlands to mangrove dominated shores, due to climatic changes, may also lead to shifts in fish species present (Ley et al. 1999), and reductions in some bird populations (e.g., brown pelican, *Pelecanus occidentalis*) (Visser et al. 2005).

Climate change poses some immediate and long-term threats to the health, function, and biodiversity of tidal wetlands along the coastal margin of the SE USA. Tidal forests of the Gulf Coast and elsewhere have been undergoing dieback and retreat from sea-level rise during the 20th century (Montagna et al. 2009). This trend is expected to continue or be exacerbated under projected increases of global sea level rise (Montagna et al. 2009). Coastal ecosystems of the western Gulf of Mexico are even more vulnerable due to the high rates of land subsidence that drive relative sea level rates that equal or exceed high Intergovernmental Panel on Climate Change (IPCC) projections for accelerated global sea level rise expected with climate warming during the 20th century (Doyle et al. 2007 and 2010). In all coastal counties and region-wide, sea level rise of any rate or origin, relative or eustatic, is expected to cause widespread loss or retreat of coastal forests as dictated by local environmental settings (Doyle et al. 2010). Mangrove forests that dominate tropical shores of southern Florida are expected to migrate inland with increasing sea level and increase the proportion of forested habitat in coastal areas.

Mississippi Alluvial Plain and adjacent regions. The Mississippi Alluvial Plain (MAP) forests, which extend up north to southern Illinois and Kentucky, west to Tennessee; and into the western Gulf Coastal Plain, are similar to those of the Atlantic and Eastern Gulf Coastal Plain forests but can include different levels of nutrients and soil types. Alfisol soils, which are more fertile than highly-weathered clay Ultisol soils or sandy Entisols, are common along the alluvial plain of the Mississippi River as well locations in Alabama (Christensen 2000). Seasonal temperature variations increase away from the coast and frost-free growing season durations decline appreciably from south to north. Although covered more extensively in Natural Ecosystems (Chapter 11), the freshwater swamp forests of the MAP in Louisiana are particularly threatened by a combination of drought and intrusion of saltwater triggered by drought conditions (Hoeppner 2008). Drought also has been linked to increased fire frequency and size in Mississippi, particularly in counties dominated by pines in the southern part of the state (Grala and Cook 2010). The importance of drought for this region is underscored by paleo-ecological work examining extended drought impacts during the mid- to late-Holocene period including the Medieval Warm Period (approximately 800 to 1200 CE) that characterized much of the Northern Hemisphere. During these times, vegetation loss was severe enough to coincide with the formation of low mounds and dunelike features that characterize much of the currently forested regions in the south-central USA today (Seifert et al. 2009).

8.3 Changes in Forest Type Across the South

The forests of the SE USA are currently highly diverse but they are not necessarily stable under a changing climate (for discussion of projected changes see Chapter 2). The potential savannafication of the SE, in which forests are converted into more open woodlands due to a combination of hotter and drier conditions, could be one of the most profound potential climate change impacts in the USA. Predictions for the SE include emergence of savanna ecosystems (Hansen et al. 2001, Bachelet et al. 2001), with expansion of Coastal Plain species into the Piedmont and Appalachians (Iverson et al. 2008). However, the SE is also expected to have future climates and vegetation compositions that are currently not found within the region (Williams and Jackson 2007). The combination of future climate, soils, and land cover may not resemble anyplace currently within vegetation dispersal distances (Williams and Jackson 2007). Current Coastal Plain climates are most similar to those expected for the Piedmont, but this region differs in soils, hydrology, and historical fire frequencies (Christensen 2000). Clay soils of the southeastern mountains and Piedmont are more similar to each other than those of the sandy Coastal Plain, and it is unclear how species may shift distributions in response to changes in SE climates.

Climate envelope models use the climate where a species occurs today to predict where suitable climates will likely occur in the future. However, climate envelop models themselves do not predict the future locations of tree species, as they do not account for rates of migration, habitat fragmentation, and other issues (Iverson et al. 2008). Genetic evidence suggests late Quaternary and early Holocene migration of trees species following the last ice age likely occurred at much slower rates than what would be required to keep pace with current and future climate change (McLachlan et al. 2005, Anderson et al. 2006, Mohan et al. 2009). Molecular work using chloroplast DNA suggests these paleo-rates were much less than 100 m per year, yet current global temperatures are shifting poleward at rates exceeding 1 km per year (McLachlan et al. 2005, Anderson et al. 2006). Migration rates of plant populations depend largely on rare long-distance seed dispersal events (LDD) which may not be frequent enough to result in the rapid migrations needed to keep track with species' current climates. Successful seedling recruitment and colonization after LDD is further limited by successful germination, growth, and survival (Ibáñez et al. 2007, Mohan et al. 2009). Recent work suggests that 59% of the 92 tree species examined were exhibiting range contractions at both the northern and southern boundaries (Zhu et al. 2011). Only 21% of eastern temperate tree species were shifting ranges northward, and 16% were shifting ranges southward (Zhu et al. 2011). This is in contrast to the expectation that juvenile trees of the eastern USA may currently be expanding northward in response to warming over the last several decades (Zhu et al. 2011).

Climate effects on canopy tree mortality rates are highlighted in work by Lines et al. (2010). Using data from across the eastern USA they found that tree mortality was six to nine times lower in areas with an intermediate temperature range (8°C to 10°C) compared to those areas with higher or lower temperatures. Mortality increased with increasing temperatures for species that currently exist in a range where average annual air temperature ranges between 10°C to 15°C. Areas with mean annual temperatures of more than 15°C, which currently includes much of the southeastern Piedmont and most of the Coastal Plain, exhibited much higher rates of tree mortality, suggesting that overall tree survivorship may decline with warmer temperatures. Therefore, northern parts of the SE may also see sharp increases in forest decline with increasing annual temperatures associated with regional warming. Conversely, historical tree mortality was minimized at intermediate amounts of annual precipitation, but mortality rates increases were much greater where annual precipitation was lowest. Therefore, future shifts in precipitation patterns within the region could also impact forest mortality.

8.4 Current and Projected Forest Stresses

Expansion and contraction in forest range and survivorship are often not directly a function of climate or climate change, but indirectly a function of climate impacts on other stressors such as insect populations and wildfire. Drought may weaken a forest, but it may be another biotic or abiotic factor that is the actual cause of death (McNulty and Boggs 2010). Forests in the southeastern USA are characterized by frequent natural disturbances such as fire, wind and ice storms, drought, insects and disease (Dale et al. 2001). Under a changing climate, many of these disturbances are projected to continue and may be amplified by climate change, and a series of disturbances may be required to significantly impact forest mortality. The major types of disturbance across the southeastern USA are outlined in the following sections.

Wildfires

The SE contains some of most productive forest land in the USA (Wear et al. 2007). As forest productivity increases so does fuel for wildfire. The combination of favorable climate and abundant fuel loads create a high fire-return rate of three to five years (Stanturf et al. 2002). The SE leads the nation in number of wildfires per year. The region averaged approximately 45,000 fires per year from 1997 through 2003 (Gramley 2005). Climate change may increase the frequency and intensity of wildfires (Blate et al. 2009).

Wildfires can lead to severe environmental consequences. Emissions from wildfires are an important source of atmospheric carbon. Furthermore, smoke particles are a source of atmospheric aerosols, which affect atmospheric radiative transfer through scattering and absorbing solar radiation and through modifying cloud microphysics (Charlson et al. 1992). These processes can further modify clouds and precipitation and atmospheric circulation (Ackerman et al. 2000, Liu 2005a and 2005b). In addition, wildfires release large amounts of particulate matter (PM) and other air pollutants that can degrade air quality (Riebau and Fox 2001). Wildland fires contribute an estimated 15% of total PM and 8% of CO_2 emissions over the southeastern USA (Barnard and Sabo 2003).

Weather and climate are determinants for wildfires along with fuel properties and topography (Pyne et al. 1996). Fire activities vary from one fire season to another. Fire weather and climate influence wildfire behavior and account for fire variability at various time scales. Under warm and dry conditions, fire seasons become longer and fires ignite more easily and spread more quickly. There is evidence that wildfires, especially catastrophic wildfires, have increased in recent decades in both the USA and other parts of the world (Piñol et al. 1998, Westerling et al. 2006). Among the converging factors were extreme weather events such as extended drought and climate change (Goldhammer and Price 1998, Stocks et al. 2002). Many climate models have projected significant climate change by the end of this century due to the greenhouse effect (IPCC 2007), including an overall increase in temperature worldwide and a drying trend in many subtropical and mid-latitude regions. Thus, wildfires likely will increase in these regions. Fire potential will increase significantly in several global geographic regions, including some areas in the USA (Liu et al. 2009).

Climate change may have various impacts on fires in the SE. Temperature is projected to increase across the South and would contribute to increased fire frequency and intensity, total burned area and longer fire seasons. In addition, temperature change can indirectly impact fires by changing fuel conditions. Increased temperature will reduce fuel moisture due to increased evaporation and, therefore, increase the threat of wildfires. The impact of climate change on fuel loading is more complex. Increased air temperature can increase fuel loading if the growing time is lengthened and there is sufficient soil moisture for tree growth. However, if increased air temperature also reduces soil moisture, tree productivity and fuel loading could *decrease* despite the extended length of the growing season.

The contributions of precipitation and humidity are also complex. Projections for precipitation are less certain than those for air temperature. Projected precipitation change often shows no clear trends even over large areas, including the southeastern USA (McNulty et al. 2012). Model agreement over projected precipitation decrease is higher in many subtropical and mid-latitude ecosystems outside the SE. This reduced precipitation would reduce fuel moisture and therefore increase fire potential in these regions. However, precipitation reduction would reduce available water for plant growth, leading to less fuel and therefore lower fire potential. Nevertheless, most GCMs also project more frequent precipitation anomalies such as drought that in turn could increase fire risk.

Hurricanes

Hurricanes, which are tropical cyclones with sustained winds equal to or greater than 119 km per hour, can cause massive economic damage to forests (see chapter 2 for more detail on future hurricane projections). In 2005, Hurricane Katrina heavily damaged forests along the Louisiana and Mississippi Gulf coasts (Chambers et al. 2007, and Stanturf et al. 2007). McNulty (2002) estimated that a single Category 3, 4, or 5 hurricane can destroy the equivalent of 10% of the annual carbon sequestered in the USA. Owing to its size, intensity and trajectory, Hurricane Katrina may have had 6 to 14 times that impact (Chambers et al. 2007). In 2005, winds from Hurricane Katrina damaged 22 million m^3 of timber estimated at a value of \$1.4 billion to \$2.4 billion dollars. Impacts are not limited to loss of wood volume and quality; ecosystem services provided by these forests also can also be impaired.

There are four main factors that determine the extent and severity of wind damage on forests: climate, soils, topography, and stand conditions (Wilson 2004). Hurricanes obviously represent an extreme climatic event. Trees growing in soil conditions that restrict root growth and depth are consistently more prone to uprooting. Variation in wind-throw along topographical gradients is more complicated and is often confused with damage due to species type and soil variation. There are many stand attributes that help determine tree susceptibility to wind-throw. These include height to diameter ratios, height, spacing, recent thinning, and impacts of previous disturbance on creating exposed edges that contain trees more vulnerable to wind-throw. Tree species composition may also impact the degree of damage from hurricanes. Therefore, stand composition and stocking levels represent stand attributes that can be manipulated by forest managers to reduce hurricane impacts.

Some evidence suggests that longleaf pine (*Pinus palustris*) might also be more tolerant to high winds than either slash pine (*P. elliottii*) or loblolly pine (*P. taeda*). In a study of the Hobcaw Forest, in coastal South Carolina after Hurricane Hugo, Gresham et al. (1991) reported that longleaf pine suffered less damage than loblolly pine. It was noted that species native to the Coastal Plain may be adapted better to the disturbance regimes found there. For example, longleaf pine, baldcypress (*Taxodium distichum*), and live oak (*Quercus virginiana*) suffered less damage than forest species with broad distribution ranges Gresham et al. (1991).

Johnsen et al. (2009) found that following hurricane Katrina, longleaf pine suffered less mortality (7%) than loblolly pine (26%). In addition to being potentially more resistant to wind-throw, longleaf pine is also more drought and fire resistant than the commonly planted loblolly pine (Landers et al. 1995). Wind damage increases with tree size, but the frequency and severity varies with species, site, wind parameters, and stand characteristics, specifically canopy evenness and age distribution, making it difficult to distinguish those tree species that appear to be more or less susceptible to wind damage (Gresham et al. 1991). The southeastern USA Coastal Plain is highly prone to hurricane events (Stanturf et al. 2007), and intense hurricanes occur two out of every three years across the region (McNulty 2002). Similar to historical natural fire regimes, the selection pressure of frequent high velocity winds has been a driving factor in forest composition.

Insects

Many types of insects damage southeastern forests, but the southern pine beetle (*Dendroctonus frontalis Zimm*.) is the most commercially destructive. Southern pine beetles caused more than $900 million in damage to SE pine forests between 1960 and 1990. Higher winter air temperatures are expected to increase over-wintering beetle larva survival rate, and higher annual air temperatures are expected to allow the beetles to produce more generations per year (Ayres and Lombardero 2000). Both of these factors could increase beetle populations. Other climate changes may work to reduce beetle populations. On the one hand, field research has demonstrated that moderate drought stress can increase pine resin production and, therefore, reduce the colonization success rate of the beetle (McNulty et al. 1998). However, severe drought stress reduces resin production and greatly increases the susceptibility of trees to beetle infestation (McNulty and Boggs 2010).

In addition to length and timing of the breeding season, other factors will likely impact the amount of insect caused damage under future climate conditions including the minimum winter air temperature and the prompt removal and destruction of infected timber (Rodriguez 1966). However, another factor closely linked to climate change may also impact insect success. Although it is one of the principle drivers of rising global air temperatures, CO_2 also increases forest productivity. Gan (2004) used an ecosystem model in conjunction with climate scenarios to predict that climate change would increase forest production by more than 7% during this century. The increase in productivity was a function of increased air temperature, longer growing season, and elevated atmospheric CO_2. However, southern pine beetle damage is also projected to increase by 4 to 7 times current levels, which would cause damage estimated at $500 to $800 million year per year (Gan 2004).

Potentially, some of the challenging impacts of climate change will be those conditions for which we have not considered or prepared for, such as previously unobserved combinations of environmental conditions that interact in new and unique ways. This concern is not unique to science. One such event occurred in the high elevations red spruce (*Picea rubens*, Sarg.) forests of western North Carolina. From 1999 until 2002, the area around Mt. Mitchell was in a period of extended heat wave and drought (McNulty and Boggs 2010). This southerly section of the Appalachian Mountains received some of the highest rates of acidic deposition in the eastern USA and contain remnant species present from the last glaciation, such as red spruce or hemlock that may be most at risk of extirpation. In 2001 some of the red spruce stands in the area began to die in large numbers while other stands of red spruce survived within the area (Figure 8.2). An examination of the sites found that stands with predominantly live trees and sites with predominantly dead trees had very different site characteristics. The sites with predominantly dead trees had much faster growth rates and higher soil nitrogen concentrations prior to the drought, compared to the historically slower growth rates and lower soil nitrogen concentrations from sites that largely survived the drought. In addition to the drought, there were signs that all the sites were attacked by southern pine beetles, a species that does not normally inhabit high elevation areas (Williams and Liebhold 2002). All the trees were attacked, but the trees that survived successfully repelled the phloem eating beetles. These were the trees from the poorer quality (i.e., lower soil nitrogen content) sites. Conversely, the trees that were unable to repel the beetles came from the higher quality (i.e., high soil nitrogen content) sites. The authors suggested that those factors that allowed stands to have the most vigorous growth under average climatic conditions also made these stands the most susceptible to mortality once those conditions changed. In combination, insects, drought, and nitrogen deposition ultimately combined to cause the observed forest mortality. If any one of these factors were not present, the trees may not have died. While in retrospect, the mechanisms for decline seem clear, forest managers have historically not been taught to consider vigorous forest stands as unhealthy. However, under a changing climate the definition of forest health, resilience, and resistance may need to be reevaluated (Thompson et al. 2009).

Elevated Atmospheric CO_2

Although CO_2 is not considered a disturbance factor for forests, atmospheric CO_2 could impact forest structure and function. Atmospheric carbon dioxide (CO_2) levels have increased nearly 35% since preindustrial times, from about 280 ppm to more than 380 ppm (IPCC 2007). Depending on the growth and emissions scenario used, atmospheric CO_2 may rise as high as 850 ppm by 2100 (IPCC 2007).

Figure 8.2 Red spruce (*Picea rubens Sarg.*) mortality in western North Carolina due to a combination of drought, southern pine beetles, and acid rain.

While carbon dioxide is the primary driver of anthropogenic climate change, it is also the basis of plant photosynthesis. Given that plant photosynthesis is not saturated at current CO_2 levels, anthropogenic increases in CO_2 will almost certainly lead to higher rates of photosynthesis if sufficient soil nutrients are available to support the elevated CO_2 induced growth (Oren et al. 2001). However, greater photosynthesis may not translate to significantly greater forest productivity and plant carbon storage, and gains in productivity may not be sustainable over the long term (Norby et al. 2010).

8.5 Ecosystem Services

Southeastern forests have been a major source of ecosystem goods and services for thousands of years (Anderson and Sassaman 1996). Current changes in demographics and climate may change the value of and need for some ecosystem services, but an overall reliance on southeastern ecosystems for societal and economic purposes will remain. In addition to goods and services such as timber and protection of water supplies, southeastern forests are considered important sinks for atmospheric CO_2, and part of a strategy to slow global warming. These services are outlined in the next section.

Forest Productivity and Carbon Sequestration

Large areas in the SE are actively managed for wood production at varying levels of intensity. For example, site preparation; weed control; fertilization; stocking, such as planting density and thinning; and genetic improvement can all impact forest productivity. Attention is being focused on the role forests play in sequestering some of the anthropogenic carbon inputs to the atmosphere in biomass and soils, while conserving existing carbon stocks through informed resource management (Blate et al. 2009).

The role of southeastern forests in providing a steady supply of timber and fiber is of particular importance in meeting current and future timber and fiber needs across the USA because forest harvests have substantially decreased across the other regions. As a whole, the South's forest sector produces approximately 60% of the total wood production in the USA (Prestemon and Abt 2002).

Climate change has the potential to impact forest productivity and carbon sequestration. Increases in forest carbon sequestration (a result of forests storing carbon in soils and woody tissues) can slow down the rate of atmospheric CO_2 increase and therefore help to slow down global warming. Southeastern forests also have been estimated to account for 36% of the carbon sequestered in the conterminous United States (Turner et al. 1995). Han et al. (2007) estimated that each year forests in the SE sequester 13% of regional greenhouse emissions in soils and long-lived forest products, such as lumber. Southeastern forests also contain about 30% of the nation's carbon stock (Mickler et al. 2004) and play a prominent role in the regional and global carbon cycle (Turner et al. 1995).

Forest Water Resources

When compared with other land uses, managed and unmanaged forests provide the cleanest and most stable water supplies for drinking water, recreation, power generation, aquatic habitat, and groundwater recharge. Large acres of forestland in the Appalachians and Piedmont are the headwaters of many river systems in the SE (Sun et al. 2011). These watersheds provide a disproportionately higher amount of the regional water supply than the Coastal Plain because these forests occupy areas with relatively high precipitation and low evapotranspiration (Brown et al. 2008).

The impacts of climate change on forest structure and functions are likely to result in negative consequences on water quantity and quality of forested watersheds through altering key hydrologic fluxes including precipitation and evapotranspiration, and the biogeochemical processes (Sun et al. 2011). An increase in air temperature means an increase in energy availability and atmospheric water demand. Thus for the humid southeastern USA, water shortages are expected to increase. For example, Walter et al. (2004) concluded ecosystem ET has been increasing at a rate of 10.4 mm per decade across six major basins that cover a majority of the watersheds in the USA. As more water is evapotranspired form the soil, less water will flow through the soil, and into streams and rivers. There will also be less water recharging shallow aquifers as tree water use (i.e., ET) increases with increasing air temperature (see Chapter 10. for more details on how forests use and yield water).

Shifts in tree species due to changes in climate, fire regime, and invasive species are likely to increase ecosystem transpiration rates and alter the carbon and nutrient balances. An increase in frequency of high intensity storm events will increase rainfall erosivity thus the potential for increased soil erosion and sedimentation (Marion et al. In press). An example of this increased soil erosion potential was forecast for the

Uwharrie National Forest where severe soil erosion was predicted to increase significantly under future climate changes (Figure 8.3).

Ecosystem model simulations and multiple watershed vegetation manipulation experiments suggest that activities that do not result in a forest type conversion or a coppice stand structure will not substantially alter streamflow responses to extreme precipitation events (Ford et al. 2011). However, based on forest conversion experiment studies, the conversion of deciduous forests (either naturally or by forest management) to pine monocultures in the Appalachians substantially altered the streamflow response to extreme annual precipitation. The pine increased soil permeability and rain fall absorption, but the pines also use more soil water than do the hardwoods. Thus, forest management may reduce flood risk but also exacerbate drought. Tradeoff between managing forests for opposite extremes should be carefully considered by water resource managers for contingency land use planning (Ford et al. 2011).

Increased frequency of heavy rainfall events will likely impact forest communities and increase flood occurrence. If there is an increase spring and summer droughts, it likely will make forest vegetation vulnerable to stresses due to high ET demands in the Coastal Plain region. Forests can also modulate regional climate by controlling energy and water transfers between the atmosphere and forested land-surface (Liu 2011). Forest restoration, afforestation, or both are expected to play important roles in mitigating the impacts of climate change on water resources in these regions.

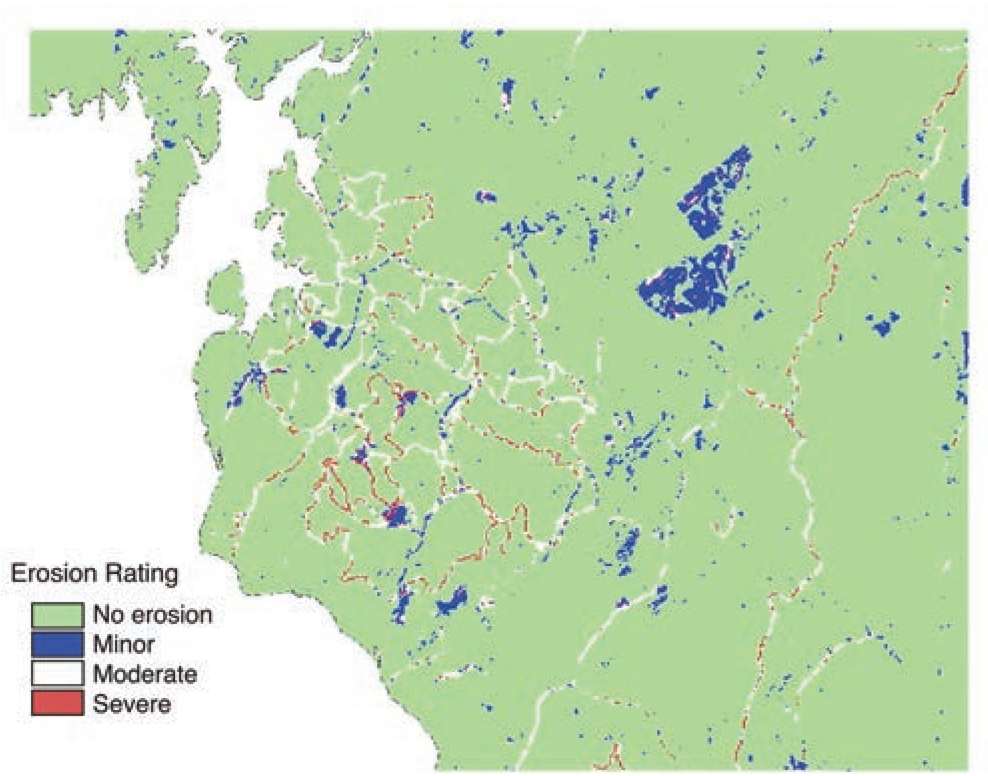

Figure 8.3 Revised Universal Soil Loss Equation predictions of soil erosion areas within the Uwharrie National Forest by 2030.

Regional modeling with a monthly scale water supply and demand model called the Water Supply Stress Index (WaSSI) suggests ecosystem water stress across the eastern USA will likely increase in the next 50 years, especially during the summer and fall seasons, due to increase water demand and reduced water yield (Caldwell et al. 2011).

8.6 Adaptation and Mitigation Options

In general, the biological productivity of SE forests likely will be enhanced by atmospheric carbon enrichment, as long as precipitation does not decline or air temperature does not increase soil moisture stress to a level that would offset potential CO_2 benefits on productivity. Use of forest resources is also anticipated to adapt to changes in productivity (de Steiger and McNulty 1998). For instance, a northward shift in forest productivity (Figure 8.4) is projected to lead to relative increases in the proportion of regional timber harvests that come from the northern reaches of the region. This may compensate for harvest reduction in the southeastern parts, which are projected to be more negatively affected by the biophysical effects of climate change. In addition, landowners are projected to switch land between forestry and agricultural in places and at times where the change in relative productivity warrants it.

There are a variety of other adaptation strategies to address climate trends and extremes. Potential adaptation strategies include genetic and silvicultural system improvements that increase water use efficiency or water availability. Increasing

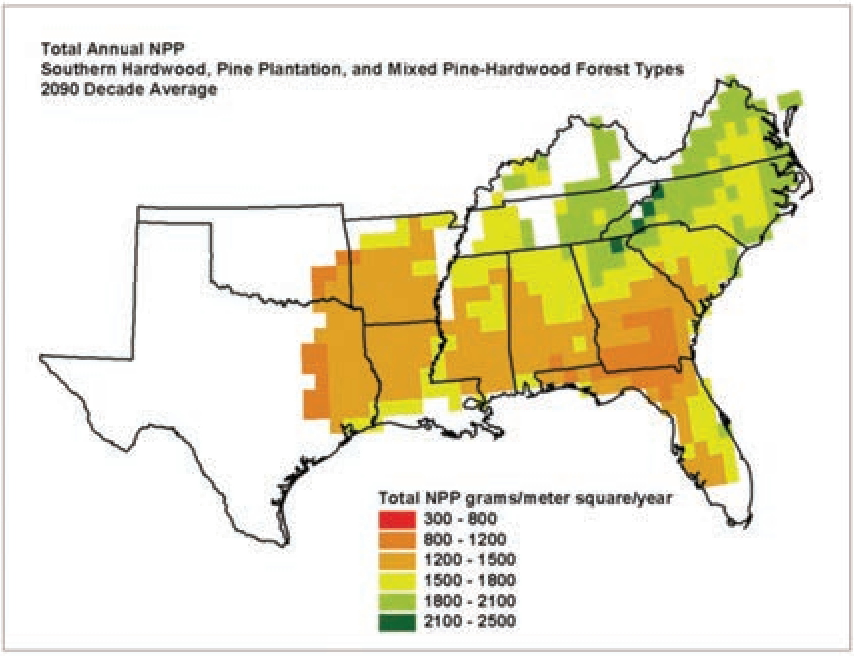

Figure 8.4 Forest model predictions of increased carbon sequestration (measured at net primary productivity, NPP) in the northern sections of the southern USA due to increasing air temperature by the end of this century.

knowledge of the role of fire, hurricanes, droughts, and other natural disturbances will be important in developing forest management regimes and increasing stand productivity in ways that are sustainable over the long term. Under a hotter, drier climate, an aggressive fire management strategy may prove important in this region (Dale et al. 2001). Timber productivity associated with increased temperature, growing season length, and CO_2 enrichment may be further enhanced by improved genetics, bioengineering, use of marginal agricultural land for tree production, and more intensive forest management (Schmidtling et al. 2004, Oren et al. 2004). Reduction of air pollutants, such as ozone and nitrogen oxides, may also be an important strategy for increasing forest productivity due to the potential for synergistic stress impacts (McNulty and Boggs 2010, Figure 8.5).

Increased use of fertilizers may increase forest productivity and carbon sequestration in an effort to partially mitigate greenhouse gas emissions. More than 400,000 ha of pine plantations are now fertilized each year with nitrogen which increases forest productivity (Albaugh et al. 2007). Fertilization can also decrease carbon losses by reducing soil respiration, and thus increasing forest carbon sequestration (Butnor et al. 2003). Other management tools that directly impact carbon sequestration include species selection, modification of initial planting density, and rotation length and thinning.

The effects of silvicultural treatments, such as planting density, thinning and rotation length, on carbon sequestration were analyzed by simulating carbon flux under

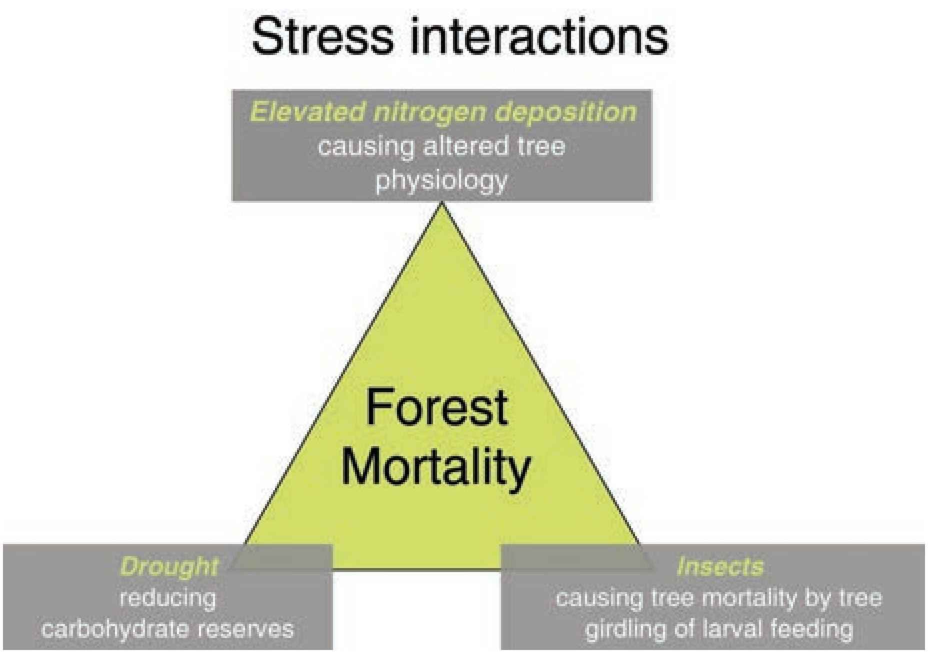

Figure 8.5 Interactions of climate (e.g., drought), biological (e.g., insects) and abiotic (e.g., fire or acid rain) can combine to cause forest mortality. The interactive stresses may be related (e.g., drought and fire) or unrelated (e.g., drought and acid rain). Any single stress may not have caused the mortality, but as climate change continues the potential for more frequent, more severe, and synergistic stress increases.

different climate and management scenarios for loblolly pine and slash pine plantations established in the southeastern USA Lower Coastal Plain (Gonzalez-Benecke et al. 2010 and 2011). Increasing the rotation length increased carbon stock in both species. Canadell and Raupach (2008) cited longer harvesting cycles as a major management strategy for increasing forest carbon stocks.

Improved understanding of climate change impacts and adaptation options are only useful if this information can be conveyed to the land manager. New web-based models and tools are being developed to allow for easier, more site specific climate change assessments. For example, the web-based Distrib/Shift forest species distribution model gives users the ability to examine which tree and bird species will likely become more and less dominant in that area over the coming years and decades (Iverson et al. 2011). Similarly, the web-based WaSSI (Water Supply Stress Index) hydrologic model gives land managers the ability to examine the impacts of climate, population and land use change on water supply and demand on their watersheds. Finally, Web-based tools like TACCIMO (Template for Assessing Climate Change Impacts and Management Options) allow the user to search scientifically reviewed literature on climate change impacts for their area, and then to further use TACCIMO to search for management options to address or adapt to these changes. Significantly improved graphic user interfaces (Figure 8.6), data storage, and internet access speeds have greatly improved the application of these tools.

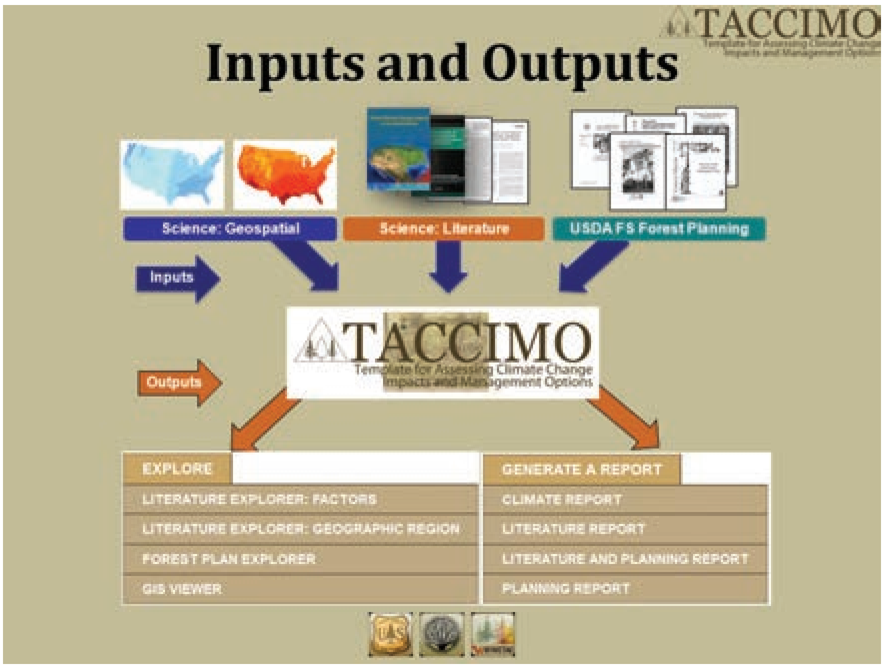

Figure 8.6 Web-based tools such as TACCIMO (Template for Assessing Climate Change Impacts and Management Options) are increasingly being used to easily translate scientific knowledge into the hands of the land manager.

8.7 Conclusions

Southeastern forests are as diverse as the cultures that exist within them. The wide range of tree, plant, and animal species make the region both resistant and susceptible to change. Some species will not be able to adapt to rapidly changing climatic conditions; other species will fill vacated niches that develop. Protecting the overall integrity of the ecosystem will be less of a challenge than protecting all of the parts. Several independent studies suggest that remnant species present from the last glaciation, such as red spruce or hemlock may be most at risk of extirpation. If changes result in warmer, drier conditions in some parts of the SE, conditions could favor more drought-tolerant species such as oaks and long-leaf pine.

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