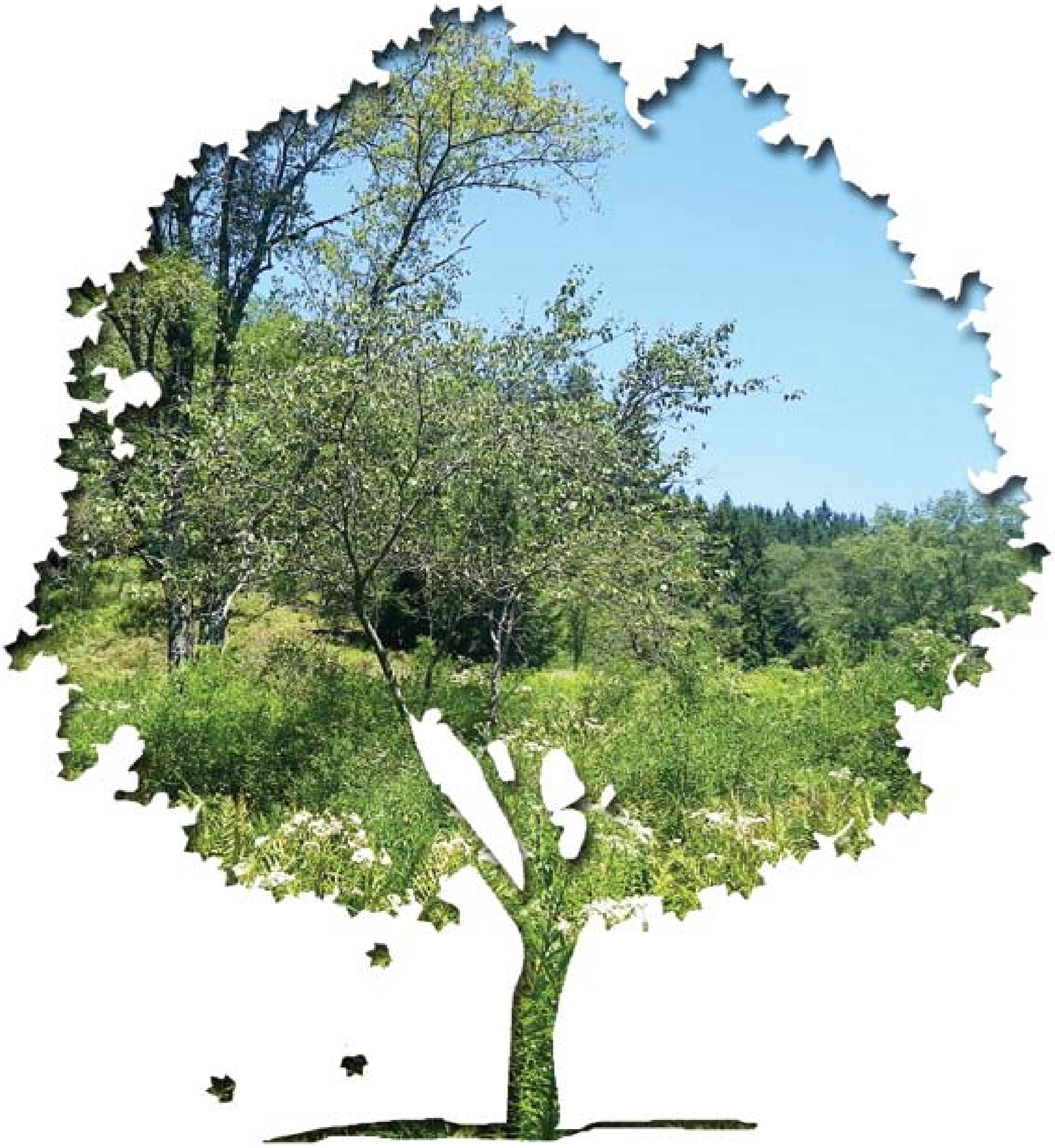
United States Department of Agriculture

# Central Appalachians Forest Ecosystem Vulnerability Assessment and Synthesis:

## A Report from the Central Appalachians Climate Change Response Framework Project



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# ABSTRACT

Forest ecosystems across the Central Appalachians will be affected directly and indirectly by a changing climate over the 21st century. This assessment evaluates the vulnerability of nine forest ecosystems in the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow and Eastern Broadleaf Forest Provinces of Ohio, West Virginia, and Maryland for a range of future climates. We synthesized and summarized information on the contemporary landscape, provided information on past climate trends, and described a range of projected future climates. This information was used to parameterize and run multiple vegetation impact models, which provided a range of potential tree responses to climate. Finally, we brought these results before a multidisciplinary panel of scientists, land managers, and academics familiar with the forests of this region to assess ecosystem vulnerability through a formal consensus-based expert elicitation process.

The summary of the contemporary landscape identifies major forest trends and stressors currently threatening forests in the region. Observed trends in climate over the past century reveal that average minimum temperatures have increased in the area, particularly in summer and fall. Precipitation has also increased in the area, particularly in fall. Projected climate trends for the next 100 years using downscaled global climate model data indicate a potential increase in mean annual temperature of 2 to 8 °F for the assessment area. Projections for precipitation indicate increases in winter and spring precipitation, and summer and fall precipitation projections vary by scenario. We identified potential impacts on forests by incorporating these future climate projections into three forest impact models (DISTRIB, LINKAGES, and LANDIS PRO). Model projections suggest that many mesic species, including American beech, eastern hemlock, eastern white pine, red spruce, and sugar maple may fare worse under future conditions, but other species such as eastern redcedar may benefit from projected changes in climate. Published literature on climate impacts related to wildfire, invasive species, and forest pests and diseases also contributed to the overall determination of climate change vulnerability.

We assessed vulnerability for nine forest ecosystems in the assessment area. The assessment was conducted through a formal elicitation process of 19 science and management experts from across the area, who considered vulnerability in terms of the potential impacts on a forest ecosystem and the adaptive capacity of the ecosystem. Appalachian (hemlock)/northern hardwood forests, large stream floodplain and riparian forests, small stream riparian forests, and spruce/fir forests were determined to be the most vulnerable ecosystems. Dry/mesic oak forests and dry oak and oak/pine forests and woodlands were perceived as less vulnerable to projected changes in climate. These projected changes in climate and the associated impacts and vulnerabilities will have important implications for economically valuable timber species, forest-dependent wildlife and plants, recreation, and long-term natural resource planning.

## Cover Photo

Small stream riparian forest with a red spruce forest in the background. Photo by Patricia Butler, Northern Institute of Applied Climate Science and Michigan Tech, used with permission.

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## A Report from the Central Appalachians Climate Change Response Framework Project

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# PREFACE

## CONTEXT AND SCOPE

This assessment is a fundamental component of the Central Appalachians Climate Change Response Framework project. The Framework is a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. Six Framework projects are currently underway, covering approximately 250 million acres in the northeastern and midwestern United States: Northwoods, Central Appalachians, Central Hardwoods, Mid-Atlantic, New England, and Urban. Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects.

We designed this assessment to be a synthesis of the best available scientific information on climate change and forest ecosystems. Its primary goal is to inform forest managers in the Central Appalachians region, in addition to people who study, recreate, and live in these forests. As new scientific information arises, our understanding of climate change and forest ecosystems will be strengthened. Most importantly, this assessment does not make recommendations about how this information should be used.

The scope of the assessment is terrestrial forest ecosystems, with a particular focus on tree species. Climate change will also have impacts on aquatic systems, wildlife, and human systems, but addressing these issues in depth is beyond the scope of this assessment.

The large list of authors reflects the highly collaborative nature of this assessment. The overall document structure and much of the language was a coordinated effort among Leslie Brandt, Patricia Butler, Maria Janowiak, Stephen Handler, and Chris Swanston. Danielle Shannon conducted much of the data analysis and developed maps for Chapters 1, 3, and 4. Louis Iverson, Stephen Matthews, Matthew Peters, and Anantha Prasad provided and interpreted Tree Atlas information for Chapter 5, and assisted with the data processing for the climate data presented in Chapter 4. Frank Thompson and William Dijak provided results and interpretation of the LINKAGES and LANDIS PRO models. All modeling teams coordinated their efforts impressively. Kent Karriker, Jarel Bartig, and Stephanie Connolly provided substantial input throughout the document.

Among the many others who made valuable contributions to the assessment, Scott Pugh (U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis [FIA] Program) provided technical and analytical support for querying FIA databases. We also thank Kevin Potter (North Carolina State University), James Rentch (West Virginia University), and an additional reviewer, who provided formal technical reviews of the assessment. Their thorough reviews greatly improved the quality of this assessment.

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# CONTENTS

# EXECUTIVE SUMMARY

This assessment evaluates key vulnerabilities for forest ecosystems in the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow and Eastern Broadleaf Forest Provinces of Ohio, West Virginia, and Maryland across a range of future climate scenarios. This assessment was completed as part of the Central Appalachians Climate Change Response Framework project, a collaborative approach among researchers, managers, and landowners to incorporate climate change considerations into forest management.

The assessment summarizes current conditions and key stressors and identifies past and projected trends in climate. This information is then incorporated into model projections of future forest change. These projections, along with published research and local knowledge and expertise, are used to identify the factors that contribute to the vulnerability of nine major forest ecosystems within the assessment area through the end of this century. A final chapter summarizes the implications of these impacts and vulnerabilities on a variety of forest-related ecological, social, and economic topics across the region.

## CHAPTER 1: THE CONTEMPORARY LANDSCAPE

This chapter describes the forests and related ecosystems across the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow and Eastern Broadleaf Forest Provinces of Ohio, West Virginia, and Maryland and summarizes current threats and management trends. This information lays the foundation for understanding how shifts in climate may contribute to changes in forest ecosystems, and how climate may interact with other stressors on the landscape.

### Main Points

- The assessment area of the Central Appalachians region contains about 29 million acres, of which 18.9 million acres are forest land. Private individuals and organizations own more than 85 percent of forest land.
- Current major stressors and threats to forest ecosystems in the region are:
  - Fragmentation and land-use change
  - Shifts in natural disturbance regimes (e.g., shifts in drought or flood frequencies)
  - Forest diseases and insect pests
  - Nonnative plant species invasion
  - Shifts in fire regime
  - Mineral, gas, and wind energy development
  - Erosion and sedimentation
- Repeated periods of warming and cooling over the last 15,000 years have resulted in multiple waves of species retracting and expanding from the south and from climatic refuges along the Atlantic coast.
- Historical land use and past management practices (17th century onward) have resulted in second-growth forests that have been rebounding from large-scale deforestation and wildfire. Secondary forests are largely even-aged with poor structure and reduced species diversity.
- The forest products and forest-related recreation industries are major contributors to the region's economy, and an increasing amount of the forest land in the assessment area is managed according to at least one sustainability certification standard.

## CHAPTER 2: CLIMATE CHANGE SCIENCE AND MODELING

This chapter provides a brief background on climate change science, models that simulate future climate change, and models that project the effects of climate change on tree species and ecosystems. This chapter also describes the climate data used in this assessment.

### Main Points

- Temperatures have been increasing at a global scale and across the United States over the past century.
- Climate scientists attribute this increase in temperature to human activities.
- Major contributors to warming are greenhouse gases from fossil fuel burning, agriculture, and changes in land use.

## CHAPTER 3: OBSERVED CLIMATE CHANGE

Many of the climatic changes that have been observed across the world over the past century are also evident in the assessment area. This chapter summarizes our current understanding of observed changes and current climate trends in the assessment area and across the Central Appalachians region, with a focus on the last 100 years.

### Main Points

- Annual minimum temperatures increased over the past century, with summer and fall minimum temperatures warming the most rapidly. April, June, July, August, and November had the greatest increases in minimum temperature. Maximum temperatures decreased during July, September, and October. Hot days are occurring more frequently.

Hemlock on the Monongahela National Forest, West Virginia. Photo by Patricia Butler, Northern Institute of Applied Climate Science (NIACS) and Michigan Tech, used with permission.

- Precipitation patterns have changed across the region, with the most change occurring in fall (increase of 2.3 inches). The number of intense precipitation events has increased.
- Snowfall decreased across the assessment area, and lake ice duration has declined.
- Climate change is also indicated by positive trends in growing season length, shifts in flowering phenology, and changes in wildlife emergence and migration.

## CHAPTER 4: PROJECTED CHANGES IN CLIMATE, EXTREMES, AND PHYSICAL PROCESSES

This chapter describes climate projections for the assessment area over the 21st century, including projections related to patterns of extreme weather events and other climate-related processes. Temperature and precipitation projections are derived from downscaled simulations of climate models. Published scientific literature provides the basis for describing possible trends in a range of climate-driven processes, such as extreme weather events and snowfall.

### Main Points

- Temperatures are expected to increase over the next century, under a range of climate scenarios and in all seasons.
- Precipitation is projected to increase in winter and spring across a range of climate scenarios. Projections of summer and fall precipitation are more variable; depending on the scenario, precipitation is projected to decrease during either summer or fall.
- Late season droughts or localized soil moisture deficits are expected to become more frequent.
- The growing season length is expected to increase by up to a month.
- The number of hot days is expected to increase and the number of cold days is projected to decrease.
- Intense precipitation events are expected to become more frequent.
- Streamflow and flooding potential are expected to increase in the winter and spring, and decrease in the summer and fall.

## CHAPTER 5: FUTURE CLIMATE CHANGE IMPACTS ON FORESTS

This chapter summarizes the potential impacts of climate change on forests in the assessment area, drawing on information from a coordinated series of model simulations and published research.

### Main Points

- Many temperate tree species present within the assessment area are expected to tolerate a mild degree of warming, but are expected to decline under higher rates of warming.
- Many mesic species, including American beech, eastern hemlock, eastern white pine, red spruce, and sugar maple are among those projected to have reductions in suitable habitat, growth potential, and biomass under a high degree of warming over the next century.
- Many species are expected to lose establishment and regeneration potential over the next century, but in the absence of other mortality factors, may persist as mature individuals that continue to grow for much longer.
- Species with ranges that extend largely to the south such as eastern redcedar, post oak, and shortleaf pine may have increases in suitable habitat and biomass. Loblolly pine, currently only in plantations in the assessment area, is also expected to fare well under the future climate.

- The model projections used in this assessment do not account for many other factors that may change under a changing climate. Scientific literature was used to provide additional information on these factors, including:
    - Drought stress
    - Wildfire frequency and severity
    - Acid deposition and carbon dioxide fertilization
    - Altered nutrient cycling
    - Changes in invasive species, insect pests, and forest diseases
    - Effects of herbivory on young regeneration
    - Interactions among these factors

## CHAPTER 6: FOREST ECOSYSTEM VULNERABILITIES

This chapter focuses on the vulnerability of major forest ecosystems in the assessment area to climate change, with an emphasis on shifts in dominant species, system drivers, and stressors. The adaptive capacity of forest systems was also examined as a key component to overall vulnerability. Synthesis statements are provided to capture general trends. Detailed vulnerability determinations are also provided for nine forest ecosystems (Table 1). We consider a system to be vulnerable if it is at risk of a composition change leading to a new identity, or if the system is anticipated to suffer substantial declines in acreage, health, or productivity.

### Main Points

### Potential Impacts of Climate Change on Drivers and Stressors

- **Temperatures will increase (robust evidence, high agreement).** All downscaled climate models project that average temperatures will increase across much of the assessment area.

**Table 1.—Vulnerability determination summaries for forest ecosystems considered in this assessment**

| Forest ecosystem | Potential impacts | Adaptive capacity | Vulnerability | Evidence | Agreement |
|---|---|---|---|---|---|
| Appalachian (hemlock)/ northern hardwood forest | Negative | Low-Moderate | High | Medium | Medium |
| Dry calcareous forest, woodland, and glade | Neutral-Negative | Low-Moderate | Moderate-High | Limited-Medium | Medium |
| Dry oak and oak/pine forest and woodland | Positive | Moderate-High | Low | Medium | Medium-High |
| Dry/mesic oak forest | Positive-Neutral | High | Low- Moderate | Medium | Medium-High |
| Large stream floodplain and riparian forest | Negative | Low | High | Medium | Medium |
| Mixed mesophytic and cove forest | Neutral-Negative | Moderate-High | Moderate | Limited-Medium | Medium |
| North-central interior beech/maple forest | Neutral | Moderate | Moderate | Limited-Medium | Medium |
| Small stream riparian forest | Negative | Moderate | Moderate-High | Medium | Medium |
| Spruce/fir forest | Negative | Moderate | High | Limited-Medium | Medium |

- **Growing seasons will get longer (robust evidence, high agreement).** There is high agreement among evidence that projected temperature increases will continue the current trend of longer growing seasons in the assessment area.
- **The amount and timing of precipitation will change (medium evidence, high agreement).** All downscaled climate models agree that there will be changes in precipitation patterns across the assessment area.
- **Intense precipitation events will continue to become more frequent (medium evidence, medium agreement).** There is some agreement that the number of heavy precipitation events will continue to increase in the assessment area. If so, impacts from flooding and soil erosion may also become more damaging.
- **Severe storms will increase in frequency and severity (medium evidence, medium agreement).** There is some agreement that future climate change will destabilize atmospheric circulation patterns and processes, leading to increased risk of severe weather.
- **Soil moisture patterns will change (medium evidence, high agreement), with drier soil conditions later in the growing season (medium evidence, medium agreement).** Studies show that climate change will have impacts on soil moisture, but there is some disagreement among climate and impact models on how soil moisture will change during the growing season.
- **Climate conditions will increase wildfire risk by the end of the century (medium evidence, medium agreement).** Some national and global studies suggest that wildfire risk will increase in the region, but few studies have specifically looked at wildfire potential in the assessment area.
- **Certain insect pests and pathogens will increase in occurrence or become more damaging (medium evidence, high agreement).** Evidence indicates that an increase in temperature will lead to increases in certain pest and pathogen outbreaks, but research to date has examined few species in the assessment area.
- **Many invasive plants will increase in extent or abundance (medium evidence, high agreement).** Evidence indicates that an increase in temperature and more frequent disturbances will lead to increases in many invasive plant species.

## Potential Impacts of Climate Change on Forests

- **Suitable habitat for northern species will decline (medium evidence, high agreement).** All three impact models project a decrease in suitability for northern species such as eastern hemlock, red spruce, and sugar maple, compared to current climate conditions.
- **Habitat is projected to become more suitable for southern species (medium evidence, high agreement).** All three impact models project an increase in suitability for southern species such as eastern redcedar and loblolly pine, compared to current climate conditions.
- **Species composition will change across the landscape (limited evidence, high agreement).** Although few models have specifically examined how species composition may change, model results from individual species, paleoecological data, and ecological principles suggest that recognized communities may dissolve to form new mixes of species.
- **A major transition in forest composition is not expected until after the middle of the century (2040 to 2069) (medium evidence, medium agreement).** Although some models indicate major changes in habitat suitability, results from spatially dynamic forest landscape models indicate that a major shift in forest composition across the landscape may take 100 years or more in the absence of major disturbances.

- **Climate change is expected to affect early growth and regeneration conditions (medium evidence, medium agreement).** Seedlings are more vulnerable than mature trees to changes in temperature, moisture, and other seedbed and early growth requirements.
- **Increased fire frequency and harvesting will accelerate shifts in forest composition across the landscape (medium evidence, medium agreement).** Studies from other regions show that increased fire frequency can accelerate the decline of species negatively affected by climate change and can accelerate the northward migration of southern tree species.
- **Net change in forest productivity is expected to be minimal (medium evidence, low agreement).** A few studies have examined the impact of climate change on forest productivity, but they disagree on how multiple factors may interact to influence it.

### Adaptive Capacity Factors

- **Low-diversity ecosystems are at greater risk (medium evidence, high agreement).** Studies have consistently shown that diverse ecosystems are more resilient to disturbance, and low-diversity ecosystems are more vulnerable to change.
- **Species in fragmented landscapes will have less opportunity to migrate long distances in response to climate change (limited evidence, high agreement).** Evidence suggests that species may not be able to disperse overthe distances required to keep up with climate change, but little research has been done in the region on this topic.
- **Ecosystems that are highly limited by hydrologic regime or geological features may be topographically constrained (limited evidence, medium agreement).** Our current understanding of the ecology of Central Appalachians ecosystems suggests that some species will be unable to migrate to new areas due to topographic constraints.
- **Ecosystems that are tolerant of disturbance or are disturbance-adapted have less risk of declining on the landscape (medium evidence, high agreement).** Basic ecological theory and other evidence support the idea that systems that are adapted to more frequent disturbance will be at lower risk.
- **Fire-adapted ecosystems will be more resilient to climate change (high evidence, medium agreement).** Studies have shown that fire-adapted ecosystems are better able to recover after disturbances and can promote many of the species that are expected to do well under a changing climate.
- **Ecosystems occupying habitat in areas of high landscape complexity have more opportunities for persistence in pockets of refugia (medium evidence, medium agreement).** The diversity of landscape positions occupied by forest may provide opportunities for natural refugia, for example where cool air and moisture accumulate in valley bottoms.

## CHAPTER 7: MANAGEMENT IMPLICATIONS

This chapter summarizes the implications of potential climate change impacts on important facets of forest management and planning in the Central Appalachians region, such as impacts on wildlife or cultural resources. The process we used to assess the vulnerability of forest ecosystems was not used to consider these topics. Rather, we point out important implications, ongoing research, and sources for more information on how climate change is expected to affect these topics. This chapter does not make recommendations as to how management should be adjusted to cope with these impacts, because impacts and responses will vary by ecosystem, ownership, and management objective.

## Main Points

- Management of endemic plants and animals that depend on forests may face additional challenges as the climate shifts.
- Prevention and eradication of nonnative invasive plant species are expected to become more difficult and require more resources.
- The timing of activities, including prescribed fire, recreation, or timber removal may need to be shifted as temperatures and precipitation patterns change.
- Responses to increased risk of wildfire or large-scale wind and storm events may require reassessing emergency response plans, water resource infrastructure, and available resources.
- Climate change may present opportunities for the forest products industry, recreation, and other sectors if resource managers are able to anticipate and respond to changing conditions.

A riparian hemlock community in West Virginia. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

# INTRODUCTION

## CONTEXT

This assessment is part of a regional effort called the Central Appalachians Climate Change Response Framework (Framework; www.forestadaptation.org). The Framework project was initiated in 2009 in northern Wisconsin with the overarching goal of helping managers incorporate climate change considerations into forest management. To meet the challenges brought about by climate change, a team of federal and state land management agencies, private forest owners, conservation organizations, and others have come together to accomplish three objectives:

1. Provide a forum for people working across the Central Appalachians to effectively and efficiently share experiences and lessons learned.
2. Develop new user-friendly information and tools to help land managers factor climate change considerations into decisionmaking.
3. Support efforts to implement actions for addressing climate change impacts in the Central Appalachians.

The Framework process is designed to work at multiple scales. The Central Appalachians Framework is coordinated across the region, but activities are generally conducted at the state or local level to allow for greater specificity. Additionally, regional Framework projects are underway in several other regions: Central Hardwoods, Mid-Atlantic, New England, Northwoods, and an Urban pilot project in Chicago.

The Central Appalachians Framework is an expansion of the original northern Wisconsin effort, and has been supported in large part by the U.S. Forest Service. Across the Central Appalachians region, the project is being guided by an array of partners with an interest in forest management, including:

- Northern Institute of Applied Climate Science
- U.S. Forest Service, Eastern Region
- U.S. Forest Service, Northern Research Station
- U.S. Forest Service, Northeastern Area State & Private Forestry
- Trust for Public Land
- The Nature Conservancy
- NatureServe
- Natural Resources Conservation Service
- Ohio Department of Natural Resources
- West Virginia Division of Natural Resources
- Maryland Department of Natural Resources

This assessment is designed to provide detailed information for forest ecosystems across the Central Appalachians region. Several independent efforts related to climate change, natural ecosystems, and human well-being are also occurring at the state level. This assessment complements other assessments that have been created for the assessment area and for the broader Central Appalachians region. The Framework project will also work to integrate the results and outcomes from other projects related to climate change and natural resource management.

This assessment bears some similarity to other synthesis documents about climate change science, such as the National Climate Assessment (Melillo et al. 2014) and the Intergovernmental Panel on Climate Change (IPCC) reports (working group contributions to the Fifth Assessment at http://www.ipcc.ch/report/ar5/). Where appropriate, we refer to these larger-scale documents when discussing national and global changes. However, this assessment differs from these reports in many ways. This assessment was not commissioned by any federal government agency nor does it give advice or recommendations to any federal government agency. It also does not evaluate policy options or provide input into federal priorities. Instead, this report was developed by the authors to fulfill a joint need of understanding local impacts of climate change on forests and assessing which tree species and forest ecosystems may be the most vulnerable in the Central Appalachians region. Although it was written to be a resource for forest managers, it is first and foremost a scientific document that represents the views of the authors.

## SCOPE AND GOALS

The primary goal of this assessment is to summarize potential changes to the forest ecosystems of the Central Appalachians region under a range of possible future climates, and determine the vulnerability of forest ecosystems to these changes during the next century. Included is a synthesis of information about the current landscape as well as projections of climate and vegetation changes used to assess these vulnerabilities. Uncertainties and gaps in understanding are discussed throughout the document.

This assessment covers about 18.9 million acres of forest land in Ohio, West Virginia, and Maryland (Fig. 1). The assessment area boundaries are defined by the Eastern Broadleaf Forest (Ecological Province 221) and the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow (Ecological Province M221) (McNab and Avers 1994, McNab et al. 2007). In addition to these state and ecological boundaries, we used county-level information that most closely

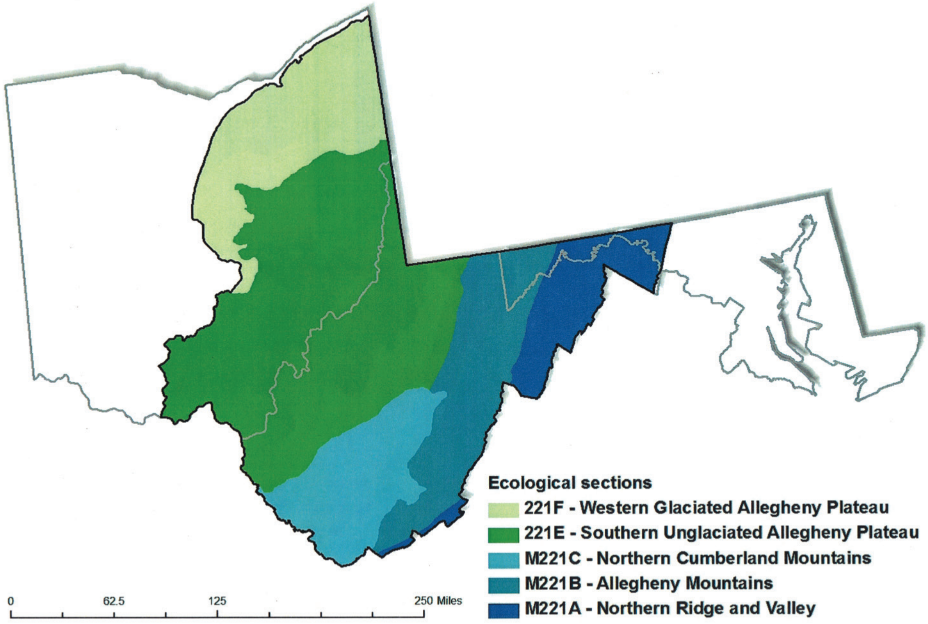

Figure 1.—The assessment area overlaps two sections of the Eastern Broadleaf Forest Province (green) and three sections of the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow Province (blue) within Ohio, West Virginia, and Maryland (Cleland et al. 2007a).

represented the assessment area when ecoregional data were not available, limiting our selections to the counties that are most analogous to the assessment area (21 Ohio counties, all West Virginia counties, and 3 Maryland counties).

Land ownership is fairly similar across the three states. Overall, more than 85 percent of forest land in the assessment area is owned by private individuals and organizations. Approximately 8 percent of land is federally owned, with the Wayne and Monongahela National Forests administering the bulk of federal lands. State agencies own 5 percent of forest land; and county, municipal, and local governments own 1.4 percent. This assessment synthesizes information covering all forest lands in the assessment area in recognition of the area's dispersed patterns of forest composition and land ownership.

## ASSESSMENT CHAPTERS

This assessment contains the following chapters:

**Chapter 1: The Contemporary Landscape** describes existing conditions, providing background on the physical environment, ecological character, and broad socioeconomic dimensions of the assessment area. It defines the nine forest ecosystems we refer to in later chapters.

**Chapter 2: Climate Change Science and Modeling** contains background on climate change science, projection models, and impact models. It also describes the techniques used in developing climate projections to provide context for the model results presented in later chapters.

**Chapter 3: Observed Climate Change** provides information on the past and current climate of the assessment area, summarized from the interactive ClimateWizard database and published literature. This chapter also summarizes some relevant ecological indicators of observed climate change.

**Chapter 4: Projected Changes in Climate, Extremes, and Physical Processes** presents downscaled climate change projections for the assessment area, including future temperature and precipitation data. It also includes summaries of other climate-related trends that have been projected within the assessment area and the broader Midwest and Northeast.

**Chapter 5: Future Climate Change Impacts on Forests** summarizes ecosystem model results that were prepared for this assessment. Three modeling approaches were used to simulate climate change impacts on forests: a species distribution model (DISTRIB of the Climate Change Tree Atlas), and two forest simulation models (LINKAGES and LANDIS PRO). This chapter also includes a literature review of other climate-related impacts on forests that the models did not consider.

**Chapter 6: Forest Ecosystem Vulnerabilities** synthesizes the potential effects of climate change on the forest ecosystems of the assessment area and provides detailed vulnerability determinations for nine major forest ecosystems.

**Chapter 7: Management Implications** draws connections from the forest ecosystem vulnerability determinations to a wider network of related concerns shared by forest managers, including forest management, recreation, cultural resources, and forest-dependent wildlife.

# CHAPTER 1: THE CONTEMPORARY LANDSCAPE

The Central Appalachians region is home to some of the most biologically diverse forests in North America. The diverse forests of the Central Appalachians provide many environmental, cultural, and economic benefits. This forested landscape sustains the people of the region by providing economically important forest products, outdoor recreation opportunities, and other services. This chapter includes a brief introduction to the complex factors that shape the forests in the region and provides context for the modeling results and interpretations provided in later chapters.

## LANDSCAPE SETTING

The assessment area covers nearly 29 million acres, and is defined by a combination of ecological and political boundaries. The area is bounded by Ecological Provinces M221 (Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow) and 221 (Eastern Broadleaf Forest) of the National Hierarchical Framework of Ecological Units, and by the state boundaries of Ohio, West Virginia, and Maryland (McNab et al. 2007). Provinces are broad geographic areas that share similar coarse features, such as climate, glacial history, and vegetation types. Provinces are divided by sections that are based on similarities in geologic parent material, elevation, plant distribution, and regional climate (McNab et al. 2007). To gain a better understanding of differences in forest ecosystems across the landscape, we focused on the five sections within these two provinces (Fig. 1). The major physical and biological features of the sections are summarized below.

### Physical Environment

### Climate

The existing climates within the Central Appalachians are strongly influenced by atmospheric circulation patterns, latitude, topography, and abrupt changes in elevation. The primary factors influencing the climate are latitude and proximity to Lake Erie in the glaciated and gently dissected northern and western sections, and elevation and complex topography in the mountainous eastern sections. Three major air masses move through the assessment area. Hot, dry air from the southwest and cold, dry air from the north affect much of Ohio and West Virginia. Warm, moist air from the Gulf of Mexico sweeps east of the Allegheny Mountains to affect the eastern panhandle of West Virginia and Maryland (U.S. Geological Survey [USGS] 1989). Occasional easterlies can also sweep moist air from the Atlantic Ocean across Maryland to the Allegheny Mountains.

The Allegheny Mountains (M221B) and Western Glaciated Allegheny Plateau (221F) have cooler and wetter climates than the rest of the assessment area, although microclimates within these sections are highly variable due to the effects of topography and relief. Average annual temperatures are 49 °F, with winters averaging 28 to 30 °F and winter minimum temperatures averaging 20 °F. Summers are also cooler in these sections, averaging 67 to 69 °F, with average maximum temperatures of 78 to 81 °F. In the highest elevations of M221B, daily minimum temperatures are the most extreme in the region, and can reach -15 to -20 °F (U.S. Department of Agriculture 2012). The freeze-free growing season is less than 150 days, and can be shorter than 100 days in valleys that are subject to frost pocket effects (Koss et al. 1988). Annual precipitation may reach 70 inches in the high-elevation and lake-effect areas, whereas low-elevation and inland areas may get as little as 30 inches (National Oceanic and Atmospheric Administration [NOAA] 2014c). Annual snowfall is included in these averages and follows a similar pattern, with the high-elevation and lake-effect areas averaging more than 72 inches and lower elevation and inland areas receiving as little as 24 inches (NOAA 2014c).

The warmest parts of the assessment area are Sections 221E, M221A, and M221C, where average annual temperatures range from 51 to 52 °F (Appendix 2). Winter average temperatures range from 32 to 34 °F, and minimum temperatures range from 22 to 24 °F. Summers are relatively hot, with average temperatures ranging from 70 to 71 °F, and maximum summer temperatures ranging from 82 to 83 °F.

Precipitation is even more variable across the assessment area. In general, precipitation ranges from 35 inches per year in the lower elevation areas to 65 inches per year in the highest elevations (Chapter 3). The northernmost corner of Ohio's Western Glaciated Allegheny Plateau receives slightly more precipitation because of its proximity to Lake Erie. Precipitation is also slightly higher on the western slopes of the Allegheny Mountains, where it can reach 70 inches per year in the highest elevations. Prevailing winds moving across Ohio and West Virginia pick up moisture, and release it as the air is forced to rise rapidly over the mountains. Moisture-laden air is obstructed by the mountain ridge, which allows precipitation and runoff to enter the western watershed, but not the eastern watershed, resulting in a rainshadow effect. Lake-effect snow from Lake Erie can also generate winter storms, which are more frequent in northeastern Ohio, producing up to three snowstorms per decade with more than 6 inches of snow, and up to five ice storms per decade (Kunkel et al. 2013a). The frequency of these winter storms decreases to the south, with southeastern Ohio receiving an average of one 6-inch snowstorm and three ice storms per decade. Lake effect may combine with local weather processes to generate up to 30 percent of annual snowfall in the northern mountains of West Virginia (Kunkel et al. 2009a, 2009b).

Extreme weather events in the area include high-intensity rains associated with occasional hurricanes, short and infrequent drought periods, heat waves, windstorms and tornadoes, and ice storms (McNab et al. 2007). A more detailed description of past and contemporary climate of the region can be found in Chapter 3.

## Geology, Landform, and Soils

The assessment area comprises both glaciated lands in northern Ohio and unglaciated, elevated lands in Ohio, West Virginia, and Maryland. There is much variation in elevation, from 167 feet in the Maryland portion of the assessment area to 4,681 feet at Spruce Knob in West Virginia (Fig. 2).

Six groups of parent material formed the soils that dominate this assessment area. One group, residuum, developed in place by the weathering of underlying bedrock. Another group, colluvium, weathered from bedrock and was deposited at the base of steep slopes. Alluvium, lacustrine sediments, and outwash materials (e.g., silt, sand, gravel, and clay) were deposited by water. Fine-grained material (loess) was deposited by wind, and glacial till was deposited by ice. The last group of parent material is mine spoil, found in areas that have been strip-mined for coal (McNab and Avers 1994). Soil characteristics for each section are described in general terms below, and information on specific soil types is

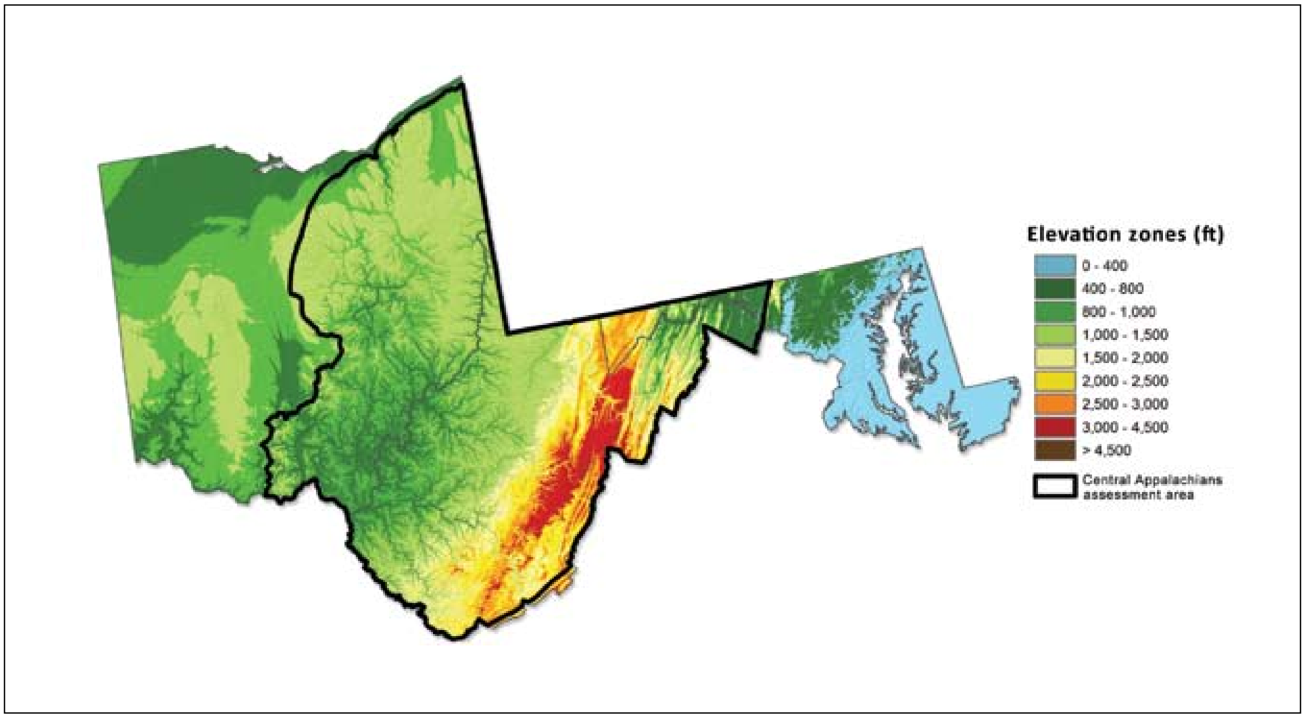

Figure 2.—Elevation zones within Ohio, West Virginia, and Maryland (Danielson and Gesch 2011).

available in the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) Web soil survey portal. Although anthropogenic activities (e.g., agriculture, mining, urban development) have influenced soil characteristics to some degree in many areas, mountaintop removal mining has been primarily responsible for removal of the soil and bedrock from large areas in southern West Virginia (U.S. Environmental Protection Agency [EPA] 2005, 2011; Wickham et al. 2013).

### Section 221F—Western Glaciated Allegheny Plateau

Unlike the rest of the assessment area, the geologic history of this section includes major alteration of the land surface caused by the movement of massive glaciers of the Pleistocene Epoch (Ice Age) (Ohio Department of Natural Resources [ODNR] 2005). The land was scoured and depressed under the weight of glaciers, and subsequent melting released the Earth's crust, deposited boulders and other materials, and carved river beds and other landscape features, such as the rounded hills, ridges, and broad valleys that characterize the area. Glacial features include valley scour, moraines, kames, eskers, and kettle outwash plains. The bedrock consists of shale, siltstone, sandstone, minor conglomerate, and coal (McNab and Avers 1994). The subsurface geology has a generally uniform resistance to erosion, and drainage from smaller streams regularly joins larger streams within a watershed in a regular dendritic pattern. Erosion is caused by two primary geomorphic processes; the first occurs when gravity interacts with moisture on steep slopes to cause slipping of the soil (mass wasting). The second occurs as rivers and streams erode the surrounding earth, transport the soil, and deposit it in a new location (fluvial transport and deposition). Elevation in this section ranges from 650 to 1,500 feet (ODNR 1998).

Ridges, flat uplands, hills, and hummocks in this section are dissected by steep valleys covered by thin glacial till and stratified drift. Lower slopes and valley floors are covered by sediment and unconsolidated glacial materials. Soils are very deep to bedrock, reaching hundreds of feet in some places (ODNR 2013). The glacial deposits range from coarse-textured to fine-textured, with coarser and better drained soils in the south of this section (ODNR 2013). Lowland surfaces in this section are characterized by gently rolling terrain covered by thin to thick glacial drift with frequent areas of poor drainage and extensive wetlands (ODNR 1998).

### Section 221E—Southern Unglaciated Allegheny Plateau

This section of the Allegheny Plateau was not covered by glaciers, but was influenced by proximate glaciers as they melted. Fluvial erosion severely dissected the plateau, now characterized by high hills, sharp ridges, and narrow valleys (McNab and Avers 1994). The bedrock is frequently exposed and consists of limestone, siltstone, sandstone, shale, and numerous coal seams. Three major preglacial streams drained the area until many tributaries were blocked by advancing ice sheets, and the accumulation of water formed lakes and deposited sediment in the valleys. This section now has a high density of streams ranging from high gradient, steep headwater streams to low gradient rivers that flow into the Ohio River. Some streams in the preglacial valleys are underlain by relatively shallow silt, sand, or gravel alluvium, and others are filled with deep glacial deposits. Small springs are numerous, but most are ephemeral. Natural streamflow and topography have been greatly modified by oil, gas, and coal extraction activities in this section. Elevation ranges from 490 to 1,400 feet (ODNR 1998).

Soils in this section are characterized by a relatively high percentage of clay in the subsoil, associated with remnants of an ancient stream system, where economically important sources of clay and coal are located (ODNR 1998). Clay is found extensively in the lowlands, and red or yellowish-brown silt-loams, silt-clay loam colluvium, and lacustrine silt cover the upland areas (ODNR 1998).

### Section M221A—Northern Ridge and Valley

This section is characterized by a series of mountain ranges and narrow valleys created by differential erosion of tightly folded, intensely faulted bedrock. The ridges and valleys run parallel from southwest to northeast. From the base of the Blue Ridge Mountains in the east, this section sweeps west across the Great Valley to the Allegheny Mountains and ends at the Allegheny Front, a steep, high ridge marking the eastern boundary of the Allegheny Plateau (McNab and Avers 1994). The bedrock of the ridges consists primarily of resistant sandstone and limestone, and the valleys consist of less resistant shale and siltstone. Erosion and transport of the water-soluble limestone have resulted in sinkholes, caves, and other karst features common in this landscape, and is responsible for the flat topography of the Great Valley (Box 1) (McNab and Avers 1994). Drainage in this section is constricted by the regular folding of bedrock, which forces tributaries to join the main river at right angles in a trellis-shaped pattern. As a result, streams flow in narrow, steep-sided channels (Bruce and Smith 1921). Mass wasting events (landslides), fluvial erosion, and karst solution are common in this section. Elevation ranges from 300 to 4,000 feet.

The alluvial soils in this section developed from the weathering of underlying bedrock and the subsequent deposition of sediments laid down in floodplains during stream overflow (Bruce and Smith 1921). Soils are relatively shallow over side slopes, back slopes, and ridges, showing frequent outcropping and escarpments of bedrock (Bruce and Smith 1921, McNab and Avers 1994). The shallowness of the soil is due to the erosion of soil as it forms, the slow formation of soils from highly resistant bedrock, and drier conditions resulting from its position in the rainshadow of the Allegheny Mountains (Bruce and Smith 1921).

### Box 1: Karst Topography

Karst landscapes occur where the topography and its distinctive features are formed by the dissolution of soluble rock, especially dolomite and limestone (Fig. 3). The resulting surface features include subterranean drainages, caves, sinkholes, springs, disappearing streams, dry valleys and hollows, natural bridges, arches, and other related features. Sinkholes are karst features that develop as a result of a collapse of surface material into nearby cavities (usually caves). Cold-water springs are characterized by a continuous flow of mineralized groundwater when surface precipitation percolates through fractures in bedrock including sinkholes, losing streams, caves, and bedrock aquifers.

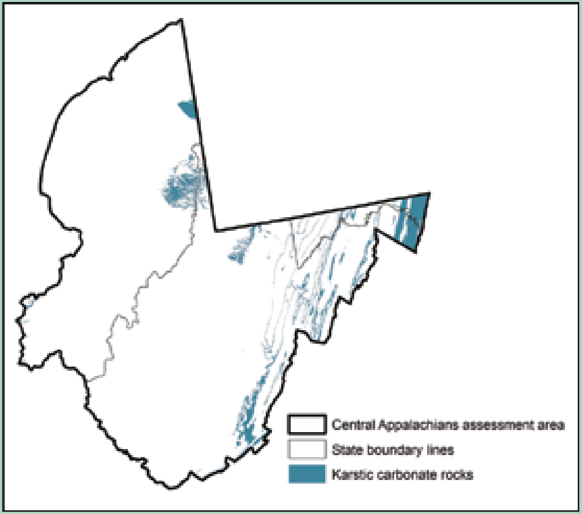

Figure 3.—Potential karst formations in the Central Appalachians. Draft map from Weary (2008).

The Northern Ridge and Valley (M221A) and Allegheny Mountains (M221B) sections contain the assessment area's largest concentration of soluble rock, therefore the largest karst (Weary 2008). The karst caves are simple or complex subterranean networks that trend northeast along the mountains.

Cave and karst systems play an integral role in the area's biological productivity and provide habitat to rare and endangered species. In West Virginia, 3,754 caves are known and 5 percent of those are reported to support cave-obligate species (Schneider and Culver 2004). Approximately 76 known aquatic and terrestrial species that are dependent on caves are recorded in West Virginia. Several species of state or global viability concern also reside in cave and karst habitats in the assessment area (Byers and Norris 2011). The Indiana bat and Virginia big-eared bat are globally threatened, and populations of other bat species also depend on these caves. The Carter Cave spider, eastern cave-loving funnel web spider, and Dry Fork Valley cave pseudoscorpion are some of the invertebrate species occurring only in caves, and in some cases, only in a particular cave in the assessment area (Kovarik 2013). Little is known about the ecology and life history of many of the cave-dwelling species in the assessment area, making it difficult to determine whether they may be affected by a changing climate.

### Section M221B—Allegheny Mountains

This section is characterized by a series of high, sharp ridges, broad plateaus, low mountains, and narrow valleys created by folded and eroded bedrock (McNab and Avers 1994). The parallel ridges and valleys run southwest to northeast. Bedrock consists of shale, siltstone, limestone, sandstone, and coal. The Greenbrier Limestone generally forms a ring midslope in some mountains, and can be seen as an outcrop in the Canaan Valley in West Virginia. Erosion and transport of the water-soluble limestone has resulted in sinkholes, caves, and other karst features common in this landscape. Drainage is primarily dendritic, but trellis drainage occurs where the topography controls the direction of streamflow. Mass wasting, karst solution, and fluvial erosion are the dominant geomorphic processes. Elevation generally ranges from 1,000 to 4,500 feet, but reaches up to 4,861 feet at Spruce Knob, West Virginia.

The alluvial soils in this section developed from the weathering of underlying bedrock and the subsequent deposition of sediments laid down in floodplains during stream overflow (Bruce and Smith 1921). Residuum developed mainly from sandstone, shale, and siltstone (Soil Conservation Service [SCS] 1974). Soils that developed in steeply sloping areas are moderately deep, and have a high rock fragment content (35 percent or greater) with moderately well-drained soils in coves (SCS 1974). Gently sloping soils are moderately well-drained and level soils are generally very poorly drained (SCS 1974). Soils also tend to be nutrient-poor and acidic. Soils at higher elevations tend to be shallow with severe soil erosion and lower forest productivity than lower elevation sites. Most of the soils have a severe erosion potential related often to slope but also to other physical properties. Massive soil loss from erosion and wildfires occurred during the logging era (circa 1930s), when thick organic mats were burned to bedrock in places, and sediment filled stream bottoms. Bituminous coal mining has also disturbed large areas of soil, and erosion is associated with stream siltation and acidification. High-elevation soils (above 3,000 feet) receive greater amounts of atmospheric pollutants, especially sulfate ($SO_4^{-2}$) and nitrate ($NO_3^-$), which has led to the loss of important nutrients (e.g., calcium) and the mobilization of others (e.g., aluminum) (Elliott et al. 2013).

### Section M221C—Northern Cumberland Mountains

This section is characterized by highly dissected uplands and low mountains where less than 20 percent of the area is gently sloping (McNab and Avers 1994). The bedrock consists of shale, coal, sandstone, and limestone. The subsections are named "Eastern Coal Fields" and "Western Coal Fields," reflecting their realized potential for coal extraction. Drainage is primarily dendritic. Primary geomorphic processes include mass wasting, fluvial erosion, and transport and deposition. Elevation ranges from 600 to 3,900 feet.

The soils in this section have formed from residuum on the ridges and mountaintops, colluvium on the slopes, and colluvial and alluvial materials in the valleys. Soils are sandy textured on uplands and loamy on the valley bottoms, where soils are moderately deep to deep and well-drained. Soils can also be shallow and excessively drained in places (NRCS 2006). Adequate soil moisture helps to overcome the limitations of these otherwise nutrient-poor soils.

## Hydrology

The hydrologic characteristics of the Central Appalachians are influenced, depending on location, by past glaciation, topographic complexity, and proximity to Lake Erie or the Atlantic Ocean. Natural lakes are uncommon in this region; many lakes were created by flooding valleys and building reservoirs (Moore et al. 1997). Many streams have been classified as perennial runoff streams with low baseflow and small variations in year-to-year low flow (Poff 1992).

### Section 221F—Western Glaciated Allegheny Plateau

This section covers northeastern Ohio, where dominant drainage basins are Lake Erie and the Ohio River. Temporal variations in streamflow primarily follow precipitation and season; snowmelt in early spring increases streamflow, and evapotranspiration during the growing season reduces streamflow. The hydrology of this section is influenced by the remnants of ancient rivers, buried by glacial till. The landscape is characterized by large rivers and floodplains and relatively low topographic relief, with glacial features including kames, kettles, moraines, flat-bottom valleys, bogs, and deranged stream networks. Agriculture and developed lands make up more of the land base in this section than in any other section, placing greater demand on the area's water resources.

A shallow slow-moving stream, one of many found throughout the assessment area. Photo by Patricia Butler, Northern Institute of Applied Climate Science (NIACS) and Michigan Tech, used with permission.

## Section 221E—Southern Unglaciated Allegheny Plateau

This section covers southeastern Ohio and western West Virginia and contains more than 55,400 miles of streams; 511 lakes, reservoirs, and ponds totaling 27,825 acres; and 162,595 acres of wetlands (Pitchford et al. 2012, West Virginia Department of Environmental Protection [WVDEP] 2013b). Only one lake in West Virginia is natural; the rest were constructed in order to store water. Dominant drainage basins are the Kanawha River and Ohio River basins, which drain westerly to the Gulf of Mexico, and the Potomac River basin, which drains east to the Chesapeake Bay. Streamflow follows the general pattern of growing season and precipitation; intermittent streams are typically dry in late August or early September through early November, when precipitation is low and evapotranspiration is high. Urban and industrial activity is common in valleys along the major rivers. Bituminous coal mining is widespread and has diminished water quality and reduced fish diversity; recent stream quality improvements have occurred in some rivers including the Allegheny, Monongahela, Youghiogheny, and Ohio (Woods et al. 1999).

### Section M221A—Northern Ridge and Valley

Dominant drainage basins in this section are the Youghiogheny River draining west to the Ohio River; the Shenandoah River, which joins with the Potomac River; and the Potomac River, which drains east to the Chesapeake Bay. Temporal variations in streamflow primarily follow precipitation and season; snowmelt in early spring increases flow and evapotranspiration during the growing season (June through September) reduces streamflow.

### Section M221B—Allegheny Mountains

Hydrology varies widely with relief, from flat mountain bogs to steep water gaps. Small ephemeral channels run down ridges to join perennial streams and larger rivers, including the Cheat River, Greenbrier River, and Tygart Valley River. The eastern side of this section is drained by the James River. Steep topography and complex landforms restrict the flow of water so that the swift, actively down-cutting streams run off steep ridges to join the valleys perpendicularly (Woods et al. 1999). Other large rivers such as the Susquehanna River cross ridges, cutting deep gorges in the process (Woods et al. 1999). High-gradient cold-water streams and waterfalls are common in water gaps and on ridge slopes, whereas low-gradient and warmer, meandering streams are common in flatter areas. Because resistant sandstone and shale are not as permeable, surface streams are larger and drainage density is higher than in adjacent limestone areas. Soil erosion is common, and as a result, the stream turbidity can be relatively high and the stream habitat impaired. Bituminous coal mines are common and associated stream siltation and acidification have occurred. Streams do not have much buffering capacity; many reaches, including some not affected by mine drainage, are too acidic to support fish.

### Section M221C—Northern Cumberland Mountains

Hydrology varies widely with relief, from flat mountain bogs to steep water gaps. Small ephemeral channels run down ridges to join perennial streams and larger rivers, including the Greenbrier River, Guyandotte River, New River, and Tug Fork of the Big Sandy River. This section contains rolling, agricultural lowlands in southeast West Virginia, where limestone bedrock results in karst formation. Stream density is low due to the abundance of saucer-shaped sinkholes. Underground solution channels occur, and subsurface drainage feeds the Greenbrier River.

## Land Cover

The Central Appalachians region is dominated by extensive forests, but also contains other natural ecosystems, rich agricultural lands, urban population centers, and industrial mining lands. Satellite imagery from the National Land Cover Dataset estimates forest cover at 67 percent (Fig. 4) (USGS 2011). The remaining land cover is classified as agricultural land (19 percent), developed land (10 percent), grassland (2 percent), water (1 percent), and wetland (1 percent). Shrublands and barren land (containing no vegetation) make up less than 1 percent of the assessment area. Most of the developed land is located in Ohio, which also has a higher concentration of agricultural lands (crops and hay). A similar concentration of agriculture and development is located in the Great Valley region of Maryland's panhandle. The relatively small percentage of agricultural land in West Virginia is primarily limited to mountain valleys and gently rolling terrain. Wetlands are scattered throughout the assessment area, occurring over clay soils at the lowest elevations and in geologic depressions at the highest elevations.

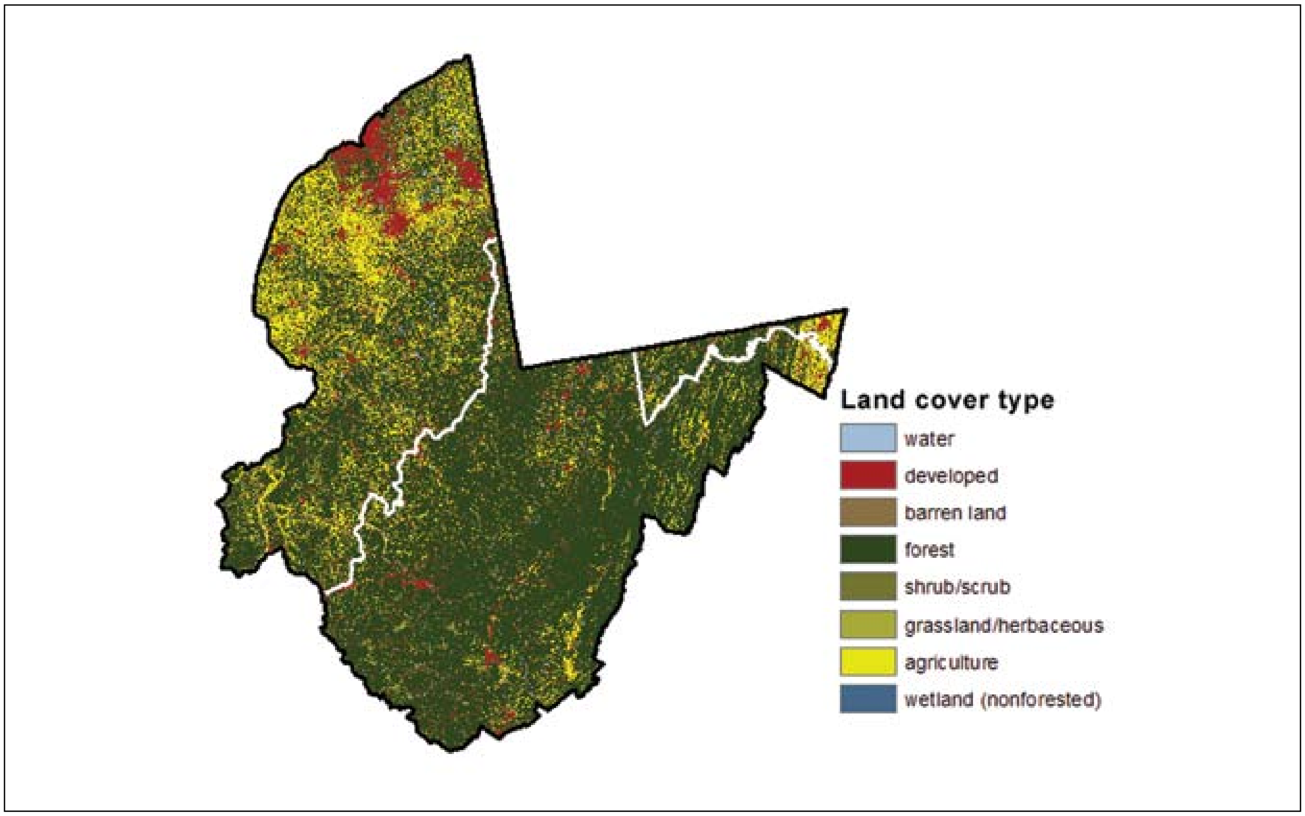

Figure 4.—Land cover classes in the assessment area (USGS 2011).

## DEMOGRAPHIC AND ECONOMIC CONDITIONS

There are some important socioeconomic differences among the states within the assessment area. The highest populations are found near Ohio's lakes and rivers, and in Maryland's Great Valley. West Virginia remains largely forest, with relatively small urban centers spread throughout the state. Approximately 7.5 million people reside within the assessment area (Headwaters Economics 2011). Seventy-two percent of the population is located in the Ohio portion of the assessment area, with 25 and 3 percent residing in the West Virginia and Maryland portions, respectively. The higher population in Ohio reflects the abundance of lands suitable for agriculture, port access to Lake Erie, and a major shipping industry. The population in the whole assessment area has increased 1 percent since 1970. The population in the Maryland portion of the assessment area has increased the most since 1970 (21 percent). The population in the West Virginia portion has increased by 6 percent since 1970, and the population in Ohio has decreased by 2 percent. These trends for larger population growth in Maryland are primarily due to the development of Garrett and Washington Counties. The amount of residential acreage increased by 45 percent in Garrett County from 2000 to 2010, largely due to the development of second homes (an increase of 27 percent from 2000 to 2010).

The economic well-being of people residing in the assessment area varies across the three states. Unemployment has been highest in the Maryland portion over the past 20 years, but only slightly lower in Ohio and West Virginia (Headwaters Economics 2011). In Maryland, growth in employment (57 percent) and personal income (119 percent) over the last 40 years has been greater than in the other two states. Unemployment in the entire assessment area has increased 4 percent since 2007, similar to trends across the United States (Headwaters Economics 2011).

## Economic Sectors

### Forest Products Industry

The forest products industry is measured by grouping census codes from the North American Industry Classification System, and can include logging, forest nurseries, forest products, timber, agriculture and forestry support services, manufacturing of paper and furniture, and other related activities. The forest products industry is important within the assessment area, but the grouping of these codes can vary by state report, and may not be comparable to other states. The forest industry in Maryland is the fifth largest industry in the state; forestry and wood derivatives generated $4.7 billion in 2005 (Maryland Department of Natural Resources [MDNR] 2010). In Ohio, the gross domestic product (GDP) for the manufacturing of wood products and furniture and related products was $2.6 billion, which represented 0.6 percent of Ohio’s total GDP in 2007 (ODNR 2010b). The forest products industry in West Virginia contributes approximately $4 billion to the state economy annually (West Virginia Division of Forestry 2010).

Forests support jobs and revenue in forest management and logging, sawmills and paper mills, and wood products manufacturing. Within the assessment area, more than 25,000 people are employed in the forest sector, accounting for almost 1 percent of total jobs (Headwaters Economics 2011). The proportion of forestry jobs to total jobs is highest in the Maryland portion (1.9 percent), followed by West Virginia (1.3 percent), and the Ohio portion (0.8 percent). Forestry employment has decreased across the assessment area from 1998 to 2010, which is similar to trends for the United States as a whole (Headwaters Economics 2011).

### Agriculture

The agricultural lands of the assessment area are primarily located where the growing season can last up to 175 days: in the Lake Erie floodplains, Maryland’s Great Valley, and the long, narrow valleys of West Virginia (Woods et al. 1996) (Fig. 4). The main agricultural activities are corn, soybean, and beef and dairy livestock farming; Christmas tree plantations; beekeeping; aquaculture; and oilseed and grain farming. Farm employment in the assessment area makes up 1.5 percent of all employment, with a slightly higher percentage of farm employment in West Virginia (2.4 percent) than in other portions of the assessment area. Farm employment has decreased consistently across the assessment area in recent decades, resulting in a net loss of 21 percent of farm jobs from 1970 to 2011 (Headwaters Economics 2011).

Multiple land uses in West Virginia. Agriculture and development dominate the flat valleys. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

## Recreation

The forested lands within the assessment area are a primary destination for recreation opportunities, which are also economically important to the region. The travel and tourism sector generates employment in retail trade, passenger transportation, arts and entertainment, recreation and food, and lodging. In Maryland, increasing demand for forest-based recreation is resulting in increased conflict between motorized and nonmotorized users, and the amount of forest land open to the public is decreasing. Recreation in West Virginia, measured mainly by hunting, fishing, and wildlife viewing receipts, generated $803 million. Tourism in West Virginia generated approximately $4.86 billion, 72 percent of which can be attributed to activities using the state's forests (West Virginia Division of Forestry 2010). National forests are also a major part of the recreation and tourism industry. Common activities in national forests are viewing natural features, hiking, relaxing, viewing wildlife, driving for pleasure, fishing, motorized trail activity, picnicking, nature study, nature center activities, hunting, gathering forest products, camping, and downhill skiing, among many others (U.S. Forest Service [USFS] 2011b). Travel and tourism provide more than 14 percent of all jobs within the assessment area: 18 percent of jobs within the Maryland portion of the assessment area, followed by West Virginia (16 percent) and Ohio (12 percent) (Headwaters Economics 2011). Travel spending in West Virginia totaled $4.25 billion in 2010, and contributed $988 million in job earnings (Headwaters Economics 2011). Travel-related spending, earnings, and employment have all been increasing in West Virginia since 2000 (Runyan 2011). Total spending on local and nonlocal visits to the two national forests within the assessment area are approximately $50 million per year (USFS 2013).

A hiking trail over the Blackwater Falls in the Canaan Valley, West Virginia. Recreation opportunities centered around natural resources may also be affected by climate change. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

## Mining

Mining jobs make up 1.4 percent of all jobs within the assessment area, creating employment in oil and gas extraction, coal mining, metal ore mining, mineral mining, and other related mining work (Headwaters Economics 2011). Coal mining supports the most jobs (27,237 jobs), followed by oil and gas extraction (7,300 jobs), and other related work, such as pipeline construction (3,732 jobs). From 1998 to 2010 mining jobs have decreased in Ohio (-8.2 percent) and Maryland (-19 percent), but increased in West Virginia by 41 percent. Mining is the leading export-oriented industry in West Virginia, generating $6.1 billion in GDP in 2009, an increase from its contribution of $5.6 billion in 2008 (Runyan 2011). Most mining jobs (82 percent) are located in the West Virginia portion of the assessment area (Headwaters Economics 2011).

# ECOSYSTEM COMPOSITION

## Forest Ecosystems

The assessment area is a remarkable landscape of high biodiversity and extensive forests. Many combinations of tree and plant species exist in the variety of habitat conditions that are represented in the area's 18.9 million acres of forest land (USFS 2013). An ecosystem is defined as a spatially explicit, relatively homogeneous unit of the Earth that includes all interacting organisms and components of the abiotic environment within its boundaries (Society of American Foresters 2014). For the purposes of this assessment, the term "forest ecosystem" refers to a specific classification system and is never used to describe ecosystems in general (Table 2). For example, the Appalachian (hemlock)/northern hardwood forest is an ecosystem defined by its species assemblage, its spatial distribution, and other distinct characteristics. Common and scientific names of trees and other species mentioned in this assessment are found in Tables 24 through 26 in Appendix 1.

**Table 2.—Forest classification systems used in this assessment**[a]

| Forest ecosystem used in this assessment | NatureServe ecological systems represented by the forest ecosystems used in this assessment | FIA forest-type groups | Common tree species in forest ecosystem |
|---|---|---|---|
| Appalachian (hemlock)/ northern hardwood forest | Appalachian (hemlock)/northern hardwood forest | maple/beech/ birch, aspen/ birch | sugar maple, American basswood, American beech, white ash, black cherry, yellow birch, sweet birch, red maple, eastern hemlock, red spruce, tulip tree |
| Dry calcareous forest, woodland, and glade | Southern Ridge and Valley/ Cumberland dry calcareous<br>Central Appalachian alkaline glade and woodland<br>North-central Appalachian circumneutral cliff and talus | oak/hickory | eastern redcedar, chinkapin oak, eastern redbud, eastern hophornbeam, white oak, post oak, shagbark hickory |
| Dry oak and oak/pine forest and woodland | Allegheny/Cumberland dry oak forest and woodland<br>Central Appalachian dry oak/pine forest<br>Central Appalachian pine/oak rocky woodland<br>Appalachian shale barrens<br>North-central Appalachian acidic cliff and talus | oak/hickory, oak/ pine, loblolly/ shortleaf pine | white oak, black oak, chestnut oak, mockernut hickory, pignut hickory, scarlet oak, shortleaf pine, pitch pine, Virginia pine, eastern white pine, Table Mountain pine, scrub oak |

(continued on next page)

**Table 2 (continued).**

| Forest ecosystem used in this assessment | NatureServe ecological systems represented by the forest ecosystems used in this assessment | FIA forest-type groups | Common tree species in forest ecosystem |
|---|---|---|---|
| Dry/mesic oak forest | Northeastern interior dry/mesic oak forest<br>Central and southern Appalachian montane oak forest<br>Southern Appalachian oak forest | oak/hickory, oak/pine, white/red/jack pine, aspen/birch | white oak, black oak, northern red oak, scarlet oak, red maple, pignut hickory, mockernut hickory, shagbark hickory, sugar maple, chestnut oak, sweet birch, American beech, blackgum, tulip tree, white ash |
| Large stream floodplain and riparian forest | South-central interior large floodplain<br>Central Appalachian river floodplain<br>Cumberland riverscour<br>North-central interior flood plain | oak/gum/cypress, elm/ash/cottonwood | silver maple, eastern cottonwood, pin oak, red maple, black willow, sycamore, sweetgum, green ash, bur oak, American hornbeam, black walnut, American elm, boxelder, black oak |
| Mixed mesophytic and cove forest | South-central interior mesophytic forest<br>Southern and central Appalachian cove forest | maple/beech/birch | sugar maple, white ash, American basswood, yellow buckeye, tulip tree, red maple, eastern hemlock, cucumbertree, American beech, sweet birch, northern red oak, black cherry, mountain magnolia, black oak |
| North-central interior beech/maple forest | North-central interior beech/maple forest<br>North-central interior wet flatwoods | maple/beech/birch | sugar maple, American beech, northern red oak, American basswood, eastern hemlock, black cherry, tulip tree, red maple, white ash, eastern hophornbeam |
| Small stream riparian forest | South-central interior small stream and riparian<br>Central Appalachian stream and riparian<br>Cumberland seepage forest | elm/ash/cottonwood | sycamore, red maple, silver maple, river birch, boxelder, eastern hemlock, black walnut, pawpaw, American hornbeam, American elm |
| Spruce/fir forest | Central and southern Appalachian spruce/fir forest<br>Southern Appalachian grass and shrub bald<br>High Allegheny wetland | spruce/fir | red spruce, yellow birch, eastern hemlock, red maple, sweet birch, cucumbertree, American mountain ash, black cherry, American beech, mountain magnolia, balsam fir, black ash, sugar maple |

[a] Forest-type groups are used to present broad-scale information on forest trends from U.S. Forest Service, Forest Inventory and Analysis (FIA) data. In this assessment, forest ecosystems are used to describe specific forest communities and associated environments as commonly grouped by local forest management organizations. NatureServe (2013) ecological systems were used to describe forest ecosystems, and in many cases, multiple NatureServe systems were combined to describe forest ecosystems within the assessment area. Forest-type groups are classified differently from forest ecosystems, and the comparison above is a rough cross-walk between the two systems.

## Forest Classification Systems Used in this Assessment

Different organizations describe forests using different classification systems. In this assessment, we describe forests by using two classification systems: (1) USFS Forest Inventory and Analysis (FIA) program (Miles et al. 2006) and (2) forest ecosystems, based on NatureServe ecological systems (NatureServe 2013). These classification systems are used for different reasons and convey different types of information. Although there are some general relationships between the two systems, they are organized differently enough that one cannot be substituted for the other. Both types of information are relevant to this assessment; thus, both classification systems are used. FIA data are used to present trends in forest cover, growth, and mortality for forest-type groups, which are defined by tree species composition. Forest ecosystems are also defined by tree species composition, but include associated understory and wildlife species, hydrologic regime, landscape position, and geographic range. FIA forest-type groups are thereby more broadly defined, and can represent several forest ecosystems (Table 2).

The FIA program was created by the USFS to characterize forests across the nation. In this assessment, we describe acres, ownership categories, and volume of timber by using "forest-type groups" based on FIA data. FIA classifications describe existing vegetation, and only for vegetated areas dominated by trees (i.e., forests). Forest *types* are a classification of forest land based upon and named for the dominant tree species. Forest-type *groups* are a combination of forest *types* that share closely associated species or site requirements. The FIA system measures tree species composition on a set of systematic plots across the country and uses that information to provide area estimates for each forest-type group. However, it does not make any inferences about what vegetation was historically on the landscape and does not distinguish between naturally occurring and modified conditions. Something that is classified as "forest land" by FIA may have been historically a glade or woodland. Likewise, areas dominated by tree species that are not native to the area would still be assigned to a forest-type group based on dominant species.

Throughout this assessment, we also use a classification of "forest ecosystems" as the primary classification system whenever possible because these better describe the forest ecosystems present in the assessment area (Table 2). These forest ecosystems are based upon ecological systems as described by the NatureServe Explorer, a system which is familiar to the Wayne and Monongahela National Forests, state agencies, and other forest management organizations in the assessment area. NatureServe ecological systems describe vegetation as it currently exists on the landscape (NatureServe 2011). An advantage to using the ecological systems is that landforms, soils, and other site features are used whenever possible to help inform the classification. A disadvantage is that the ecological systems have not yet been spatially verified and only rough estimates of abundance are available. In this assessment, we defined our forest ecosystems by combining 24 NatureServe ecological systems into nine forest ecosystems, and then modified the list of dominant species to better reflect the existing vegetation found within the borders of the Central Appalachians assessment area. We used these forest ecosystems to assess vulnerability to climate change (Chapter 6). Common and scientific names of trees and other species mentioned in this assessment are found in Tables 24 through 26 in Appendix 1.

## Forest Ecosystems of the Central Appalachians

The following descriptions of forest ecosystems are based on the ecological systems described by the NatureServe Explorer database, which characterizes terrestrial ecosystems at a broad scale across multi-state regions (Comer et al. 2003, NatureServe

2013). These systems are classified based on vegetation associations, land cover class, spatial pattern, soil type, and geographic distribution. The assessment area is a region of high biodiversity, and therefore contains more than 40 ecological systems represented within the assessment area boundaries. Of these, we identified the 24 most common forest ecosystems (based on area) and merged systems that were similar or commonly occurred together in order to create nine forest ecosystems that could be assessed by a large panel of experts (Table 2, Appendix 5). Descriptions of each forest ecosystem were further modified to better describe the extent and dominant species of the forest ecosystems as they occur within the boundaries of the assessment area. The resulting forest ecosystems were assessed for their vulnerability to climate change (Chapter 6). For original descriptions of NatureServe ecological systems, visit the online database at http://www.natureserve.org/explorer/. Please note that Web addresses are current as of the publication date of this assessment but are subject to change.

### Appalachian (Hemlock)/Northern Hardwood Forest

This forest ecosystem includes only one NatureServe system: the “Appalachian (Hemlock)/Northern Hardwood Forest” system, which extends from southeastern Ohio to the higher-elevation mountains of Maryland and West Virginia. These largely deciduous forests are sometimes mixed with hemlock in the assessment area, distinguishing them from the more montane Southern Appalachian northern hardwood forest. These ecosystems occur on gentle to steep slopes on soils that range from slightly acidic to very acidic with various amounts of nutrients, depending on landscape position and parent material. On colluvial soils, which tend to be on the less acidic end of the spectrum, the canopy is typically dominated by sugar maple, American basswood, American beech, and white ash, with lesser amounts of black cherry, yellow birch, sweet birch, red maple, and tulip tree. Sites on the more acidic end of the spectrum are usually dominated by combinations of yellow birch, American beech, black cherry, red maple, and eastern hemlock, although most sites will not have all five species present as canopy dominants. Minor components on the more acidic sites include sweet birch, red spruce, and tulip tree. On both colluvial and slightly less acidic soils, sweet birch and tulip tree may become dominant in response to heavy disturbance. Wind-driven gap disturbances are the most influential natural disturbance. Historically, this forest ecosystem was probably subject to only extremely rare natural fires. Logging and subsequent slash fires around the turn of the 20th century probably promoted deciduous species at the expense of hemlock and red spruce. Consequently, many examples of this forest ecosystem on more acidic sites are likely successional to the spruce/fir forest ecosystem. The eastern hemlock component is currently being decimated in large parts of its range by the hemlock woolly adelgid, which will likely result in replacement of hemlocks by other canopy trees (Hessl and Pederson 2013). Likewise, the American beech component is being decimated by beech bark disease, which typically results in conversion to broken-canopied stands with a dense understory of beech sucker sprouts.

An Appalachian (hemlock)/northern hardwood forest. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

### Dry Calcareous Forest, Woodland, and Glade

This forest ecosystem is mostly formed by small patches of three NatureServe (2013) systems that occur on thinner circumneutral and calcareous soils over limestone or dolostone. The "Central Appalachian Alkaline Glade and Woodland" system occurs on ridges, summits, and upper to lower slopes and usually grades into closed-canopy forests at low to moderate elevations. Common tree species include eastern redcedar, chinkapin oak, eastern redbud, and eastern hophornbeam. Prairie grasses and forbs dominate the herbaceous layer, with a number of rare forbs. Most existing open patches appear to be maintained by drought and landslides. Fire frequency and intensity influence the relative ratio of deciduous to evergreen trees, with eastern redcedar increasing in the absence of fire (Smith and Johnson 2004). Whether the woodland portion occupied larger areas under a historic regime of frequent fire is debatable. Soils are excessively well-drained, with low water holding capacity. The open canopies and relatively high pH soils make these communities more susceptible to invasive species. On deeper soils in extreme southeast West Virginia, the "Southern Ridge and Valley/Cumberland Dry Calcareous Forest" system may be dominated by white oak and shagbark hickory, and sometimes contains eastern redcedar as a significant component. The "North-Central Appalachian Circumneutral Cliff and Talus" system occurs in small patches on vertical or near-vertical cliffs and steep talus slopes at low to moderate elevations with alkaline soils. Lichens are generally the most abundant vegetation, although stunted northern white cedar may occur on north-facing cliffs. The historic natural disturbance regime included frequent low-intensity fires, but contemporary disturbances include exposure and landslide events.

### Dry Oak and Oak/Pine Forest and Woodland

This forest ecosystem includes major patch-forming forests and woodlands. NatureServe (2013) describes this forest as the "Allegheny/Cumberland Dry Oak Forest and Woodland" on predominantly acidic substrates on southwest-facing slopes in the Allegheny Plateau, where it is dominated by white oak, black oak, chestnut oak, mockernut hickory, pignut hickory, and scarlet oak with small inclusions of shortleaf pine and Virginia pine. The "Central Appalachian Dry Oak/Pine Forest" (NatureServe 2013) occurs in the rainshadow areas of the Ridge and Valley section at low to high elevations, and is dominated by a variable mixture of dry-site oak and pine species including chestnut oak, white oak, scarlet oak, pitch pine, Virginia pine, Table Mountain pine, and eastern white pine. Ericaceous shrubs are common in the understory of both systems. On wooded hilltops, outcrops, cliff faces, and rocky slopes, NatureServe (2013) classifies this forest as "Central Appalachian Pine/Oak Rocky Woodland" and "North-Central Appalachian Acidic Cliff and Talus" systems. These smaller patches are dominated by lichens and stunted trees and may form a woodland with pitch, Virginia, and Table Mountain pines mixed with xerophytic oak species and sprouts of American chestnut. Another patch system, "Appalachian Shale Barrens" (NatureServe 2013), occurs where exposed shale creates extreme growing conditions. Many of these patches occur as open land or as woodland dominated by stunted chestnut oak, Virginia pine, pignut hickory, and scrub oak. As many as 15 endemic herbaceous species may occur on these shale systems. Soils are generally xeric and sandy, and have low water holding capacity. Fire was historically frequent in this forest ecosystem, but contemporary fire suppression has led to shifts in species composition and stand structure.

### Dry/Mesic Oak Forest

This forest ecosystem includes two matrix-forming oak-dominated systems that are only weakly differentiated and occupies more area than any other forest ecosystem in the assessment area. NatureServe (2013) describes this forest as "Northeastern Interior Dry/Mesic Oak Forest" in the north, "Southern Appalachian Oak Forest" in the south, and "Central and Southern Appalachian Montane Oak Forest" in the Allegheny Mountains. The dry/mesic oak forests are drier than the mixed mesophytic and cove forest and more mesic compared to the dry oak and oak/pine forest and woodland. This system is often stunted and wind-flagged on exposed southwest slopes and ridge crests. Common species include white oak, northern red oak, black oak, and scarlet oak. Associated canopy trees also include red maple, pignut hickory, mockernut hickory, shagbark hickory, sugar maple, chestnut oak, tulip tree, sweet birch, white ash, American beech, and blackgum. American chestnut and eastern white pine were historically dominant or codominant species in some areas. Fire is an important driver in this forest ecosystem, but contemporary fire suppression has favored maple species over oaks. Wind and ice storms continue to be important disturbances.

### Large Stream Floodplain and Riparian Forest

This forest ecosystem is found across the assessment area as a complex of wetland and upland vegetation associated with medium to large rivers or streams where topography and alluvial processes have resulted in a well-developed floodplain. NatureServe (2013) describes these forests as "Central Appalachian River Floodplain," "Cumberland Riverscour," and "North-Central Interior Floodplain." There is typically a gradient from moist or periodically dry, somewhat nutrient-enriched conditions upslope to moist and highly enriched conditions downslope. Most areas are inundated with seasonal flooding, most commonly in the spring; microtopography determines how long the various habitats are inundated. Seasonal flooding and flood-scouring contribute to sediment deposition and can be abrasive forces along the riverbanks. Some

Yellow birch and hemlock, common riparian species in the Allegheny Mountains. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

areas are also prone to severe drought periods that may stress or kill vegetation. A variety of alluvial and loess soil types, in combination with various flooding regimes, create a diversity of vegetation communities such as floodplain forests, herbaceous sloughs, shrub wetlands, riverside prairies, and woodlands. The wettest areas are dominated by silver maple, eastern cottonwood, pin oak, red maple, and black willow. Better-drained areas are dominated by sycamore, sweetgum, green ash, bur oak, American hornbeam, black walnut, American elm, boxelder, and black oak. Some common shrubs are hazel alder, common buttonbush, silky dogwood, coastal plain willow, pawpaw, spicebush, and eastern redcedar. Anthropogenic land conversion and invasive plant species are major stressors in this forest ecosystem.

### Mixed Mesophytic and Cove Forest

This forest ecosystem is located entirely south of the glacial boundary, and it is predominantly found in West Virginia within the assessment area. The Allegheny Front separates two similar systems: NatureServe (2013) describes this system as "South-Central Interior Mesophytic Forest" in the west, and "Southern and Central Appalachian Cove Forest" in the east. This forest ecosystem consists of mesophytic hardwood or hemlock-hardwood forests in sheltered topographic positions, often on concave slopes or in areas with high precipitation. Common species include sugar maple, white ash, American basswood, yellow buckeye, tulip tree, red maple, eastern hemlock, American beech, cucumbertree, sweet birch, northern red oak, black cherry, and mountain magnolia. Black oak and black walnut can also occur as minor canopy species. Soils are predominantly colluvial, and range from slightly basic to very acidic, with various amounts of nutrients. Rich coves collect moisture and nutrients from higher positions, and support higher diversity and density in the herbaceous layer and tree layer. Acidic coves often have a dense shrub layer dominated by great laurel and mountain laurel. This system is naturally dominated by uneven-aged forests, with gap-phase regeneration, although current conditions resemble more even-aged second-growth forests. Occasional extreme wind or ice events may disturb larger patches. Natural fires are probably extremely rare and have occurred only in years that were extremely dry. Most of the component species are among the least fire-tolerant in the region. Trees may grow very large in undisturbed areas, but repeated harvesting can result in smaller age-class distributions and favor tulip tree and red maple.

### North-Central Interior Beech/Maple Forest

This forest ecosystem includes the NatureServe (2013) "North-Central Interior Beech/Maple Forest" system on gently rolling uplands to moderate slopes, and the "North-Central Interior Wet Flatwoods" on poorly drained uplands or in clay-lined glacial depressions. This forest ecosystem is primarily found in the glaciated portion of Ohio, where various microtopography and moisture regimes create mixed communities of upland and lowland species. These forests can be composed of deciduous or mixed evergreen-deciduous species including sugar maple, American beech, northern red oak, American basswood, eastern hemlock, black cherry, tulip tree, red maple, white ash, and eastern hophornbeam. On upland sites, soils are loamy over glacial till, limestone, or calcareous shales, and have adequate or abundant levels of nutrients. In wetter locations, soils typically have an impermeable clay layer resulting in ponding and complete saturation during spring and possible drought during summer. The disturbance interval is long, with wind as the primary disturbance, and this forest ecosystem is generally intolerant of fire.

## Small Stream Riparian Forest

This forest ecosystem is a matrix of uplands and wetlands found along creeks, small streams, and medium rivers (e.g., Shaver's Fork) with low to moderately high gradients and oxbows. NatureServe (2013) systems include "South-Central Interior Small Stream and Riparian," "Central Appalachian Stream and Riparian," and "Cumberland Seepage Forest." Flooding and scouring both influence this system, but the nature of the landscape (i.e., steeper side slopes and higher gradients) prevents the kind of floodplain development found along larger rivers. Soils are colluvial and alluvial deposits with moderate inherent fertility, ranging from moist to periodically dry (i.e., poorly to excessively well-drained). The vegetation is a mosaic of forests, woodlands, shrublands, and herbaceous communities. Typical tree species may include sycamore, red maple, silver maple, river birch, boxelder, eastern hemlock, black walnut, pawpaw, American hornbeam, and American elm, as well as many of the tree species that occur in adjacent upland forests. The eastern hemlock component is threatened by the hemlock woolly adelgid, which will likely result in its replacement by other canopy trees. Some characteristic shrubs may include bushy St. Johnswort, coastal plain willow, and hazel alder.

## Spruce/Fir Forest

A red spruce and mixed hardwood forest in West Virginia. Photo by David Ede (retired), Monongahela National Forest.

This forest ecosystem consists of forests, woody wetlands, shrublands, and grasslands on a variety of landforms in the highest elevation zone of the Allegheny Mountains, ranging from 2,400 to 4,600 feet. NatureServe (2013) describes these forests as "Central and Southern Appalachian Spruce/Fir Forest," "Southern Appalachian Grass and Shrub Bald," and "High Allegheny Wetland." Elevation and topography make the climate cool and wet, with heavy moisture input from fog as well as high amounts of rain and snow. Soils are moist year-round, usually acidic, and often very rocky, originating from weathered parent material or from organic deposits over boulders. The forest canopy is typically dominated or codominated by red spruce, with associates including yellow birch, red maple, and eastern hemlock. In some places, sweet birch, cucumbertree, American mountain ash, black cherry, American beech, sugar maple, and mountain magnolia may also appear. The eastern hemlock component is currently being decimated in large parts of its range by the hemlock woolly adelgid, which will likely result in replacement of hemlocks by other canopy trees. Likewise, the American beech component is being decimated by beech bark disease, which typically results in a dense understory of beech sucker sprouts. Balsam fir and black ash can also dominate in wet areas on limestone or calcareous shale. On upland sites, the shrub layer can range from sparse to dense and may include great laurel and southern mountain cranberry. Around the edges of some wetlands, the shrub layer may be dense and may contain a variety of species, including wild-raisin, velvetleaf huckleberry, speckled alder, bushy St. Johnswort, common winterberry, and black chokeberry. The herbaceous layer is generally sparse in upland areas and dense in wetlands. Fine-scale disturbances (e.g., debris avalanches, wind, and ice) are generally the most influential in this forest ecosystem. Red spruce and eastern hemlock are both expanding into portions of their historic niches, recovering from large anthropogenic disturbances at the beginning of the last century.

## Forest Composition and Abundance

Analysis of satellite imagery from the National Land Cover Database estimates forest coverage at 67 percent of the land base. The FIA program, using a network of permanent field plots, estimates that 66 percent of land is forested (Table 3) (USFS 2013). Northern Ohio (221F) is the least forested section (31 percent), and southern West Virginia (M221C) is the most heavily forested section (89 percent). Timberland is forest land that is currently producing or capable of producing more than 20 cubic feet of wood per acre per year. Approximately 97 percent of the forest land in the assessment area is classified as timberland (USFS 2013).

**Table 3.—Acreage (total and forest land) for each ecological section within the assessment area, as determined by FIA (USFS 2013)**

| Ecological section | Total land (acres) | Forest land (acres) | Forest land (%) |
|---|---|---|---|
| 221E | 13,485,413 | 9,056,910 | 67 |
| 221F | 4,961,053 | 1,561,695 | 31 |
| M221A | 2,512,194 | 1,778,653 | 71 |
| M221B | 4,374,448 | 3,366,526 | 77 |
| M221C | 3,504,533 | 3,130,745 | 89 |
| Assessment area | 28,837,641 | 18,894,529 | 66 |

Based on FIA data, the oak-hickory forest-type group is the most common in the assessment area, covering 70 percent of the total forested area (Table 4). The other common forest-type groups across the assessment area are the maple/beech/birch group (19 percent), elm/ash/cottonwood group (4 percent), oak/pine group (2 percent), and loblolly/shortleaf pine group (1 percent). The remaining forest-type groups each equal less than 1 percent of the forest land. There are also more than 8,000 acres of nonnative blue spruce plantation that was classified as the fir/spruce/mountain hemlock forest-type group. Differences among forest types can influence the amount of carbon stored aboveground and belowground (Box 2).

**Table 4.—Forest land by FIA forest-type group (USFS 2013)**

| FIA forest-type group | Total assessment area (acres) | Total assessment area (%) | Ecological section within the assessment area (acres) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 221E | 221F | M221A | M221B | M221C |
| Oak/hickory | 13,311,652 | 70.5 | 6,602,077 | 828,364 | 1,328,991 | 1,926,512 | 2,625,709 |
| Maple/beech/birch | 3,601,227 | 19.1 | 1,461,080 | 424,142 | 149,336 | 1,154,314 | 412,356 |
| Elm/ash/cottonwood | 667,362 | 3.5 | 392,774 | 196,052 | 33,296 | 5,470 | 39,770 |
| Oak/pine | 430,319 | 2.3 | 232,885 | – | 111,333 | 54,373 | 31,729 |
| Loblolly/shortleaf pine | 241,679 | 1.3 | 135,343 | – | 83,496 | 16,179 | 6,660 |
| White/red/jack pine | 162,162 | 0.9 | 62,503 | 12,050 | 27,842 | 57,692 | 2,075 |
| Other hardwoods | 141,683 | 0.7 | 23,396 | 12,611 | 25,320 | 74,987 | 5,370 |
| Nonstocked | 98,697 | 0.5 | 62,566 | 21,662 | 6,397 | 8,072 | – |
| Aspen/birch | 85,235 | 0.5 | 54,007 | 21,024 | – | 10,204 | – |
| Exotic hardwoods | 43,649 | 0.2 | 30,279 | 6,292 | – | – | 7,078 |
| Spruce/fir group | 40,368 | 0.2 | – | – | – | 40,368 | – |
| Exotic softwoods group | 22,031 | 0.1 | – | 18,920 | – | 3,111 | – |
| Other eastern softwoods | 20,945 | 0.1 | – | – | 12,642 | 8,302 | – |
| Oak/gum/cypress | 19,376 | 0.1 | – | 12,434 | – | 6,942 | – |
| Fir/spruce/mountain hemlock | 8,144 | 0.0 | – | 8,144 | – | – | – |
| Total | 18,894,529 | 100 | 9,056,910 | 1,561,695 | 1,778,653 | 3,366,526 | 3,130,747 |

## Box 2: Forest Carbon in the Assessment Area

Forests play a valuable role as carbon sinks. The accumulated terrestrial carbon pool within forest soils, belowground biomass, dead wood, aboveground live biomass, and litter represents an enormous store of carbon (Birdsey et al. 2006). Terrestrial carbon stocks in the region have generally been increasing for the past few decades, and the potential for managing forests to maximize and maintain this carbon is gaining attention (Malmsheimer et al. 2011). Carbon sequestration and storage in forest ecosystems depend on the health and function of those ecosystems in addition to human management, episodic disturbances, and forest stressors.

Forest lands within the assessment area are estimated to hold approximately 1.3 billion metric tons of carbon, or roughly 69.1 metric tons per acre (USFS 2013). Depending on the forest-type group, carbon density ranges from 42.7 metric tons per acre (other eastern softwoods group) to 98.6 metric tons per acre (oak/gum/cypress group) (Fig. 5). The spruce/fir and maple/beech/birch groups store greater amounts of carbon per acre than the oak/hickory and oak/pine groups. However, because the vast majority of forest land is classified as oak/hickory and maple/beech/birch, most of the total carbon in the assessment area is found in these two types (67 percent in oak/hickory and 22 percent in maple/beech/birch).

Carbon density also varies by ownership. The highest density of carbon is on federal lands administered by the USFS, the National Park Service, the U.S. Fish and Wildlife Service (USFWS), and the Department of Defense, ranging from 76.5 to 87.7 metric tons per acre. Private lands store only 67.7 metric tons per acre. However, most of the forest land in the assessment is private land. Therefore, 1 billion metric tons of carbon is stored on private land, versus 209 million metric tons stored on public lands.

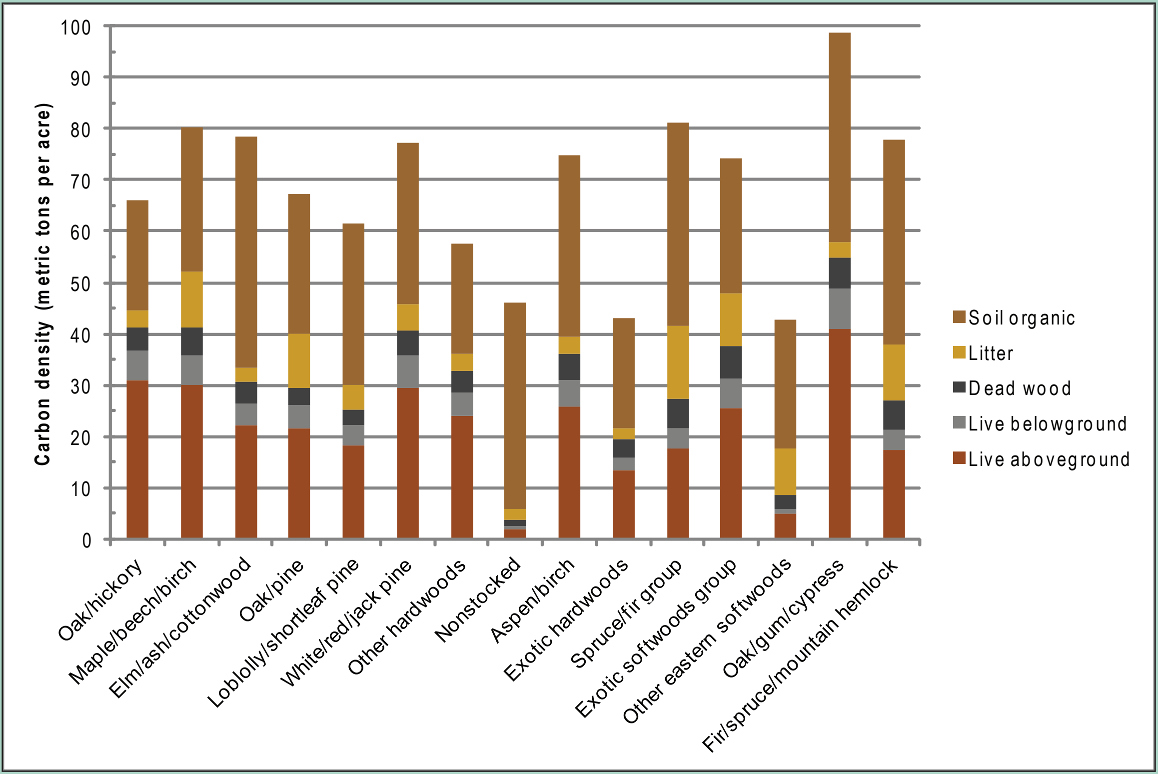

Figure 5.—Forest carbon density by forest-type group. Forest-type groups are arranged from left to right by area of forest land (USFS 2013).

# DRIVERS OF CHANGE IN FOREST ECOSYSTEMS

The forest ecosystems of the assessment area have undergone significant changes over the past several thousand years. These changes were largely driven by periodic climate change and anthropogenic pressures on the natural resource base, which in turn have had major implications for fire occurrence and behavior, invasive species establishment, soil stability and structure, hydrology, and other drivers of species composition and structure.

## Past Ecosystem Change

Paleoecological records from pollen and macrofossils have been collected from lakes and bogs throughout the eastern United States as a means to determine long-term vegetation dynamics (Davis 1983). During the last glacial maximum 18,000 to 20,000 years before present (YBP), only a portion of the assessment area (Section 221F in Ohio) was covered in ice. In the rest of the assessment area, a belt of tundra extended from Pennsylvania southward along the mountains. Forest species formed novel assemblages of conifers such as spruce and pine, and deciduous species were conspicuously absent (Davis 1983). After the last glaciers began to retreat from the northern latitudes, at the start of the Holocene epoch approximately 11,700 YBP, tree species started to respond to the warming climate and the melting glaciers. Many tree species were able to migrate northward at a rate of 700 to 1,000 feet per year, but expansion over the Appalachian Mountains was generally slower (around 300 feet per year) (Davis 1983). Spruce and fir moved northward at different rates, depending on the suitability of climate, seed dispersal, and establishment success (Davis 1983). The large-scale replacement of eastern white pine and other northern species by deciduous or mixed deciduous forest occurred between 10,000 and 12,000 YBP (Jacobson et al. 1987). Elms and maples arrived from the west around 10,000 to 12,000 YBP. Oaks arrived 10,000 YBP and dominated the landscape until 500 YBP. Some species arrived relatively recently in the assessment area, largely due to the migration barrier presented by the Appalachian Mountains. Hickories arrived 10,000 YBP in Ohio, but expanded slowly over the Appalachian Mountains, reaching Maryland only 5,000 YBP. Chestnut arrived in Tennessee 10,000 YBP, and reached Maine after a slow northeast migration only 2,000 YBP. Eastern white pine and eastern hemlock expanded from ancient forest refugia near the Atlantic coast and arrived 10,000 YBP (Davis 1983).

Repeated periods of warming and cooling over the last 15,000 years have resulted in multiple waves of species expanding from the south and from climatic refuges along the Atlantic coast (Shuman et al. 2002). These waves of species migrations resulted in very different species assemblages from those typical today, partially because not all species were able to migrate at the same rate. The last major shift in climate occurred approximately 3,000 YBP. This wetter and cooler climate is similar to our present climate, which favors tree growth and reforestation.

At the same time, the effects of Native Americans on the vegetation of the region became evident. Charcoal scars throughout the region have confirmed a link between oak dominance and fire (Abrams 1992, Nowacki and Abrams 2008). Native Americans are thought to be responsible for the numerous low-intensity fires that promoted oak regeneration (Abrams 1992). Native American cultures centered on maize agriculture were in place by 1,000 YBP. The development of small-scale agriculture and other activities also resulted in extensive trail and trade networks and subsistence-based manipulation of the vegetation. By the early 17th century, the use of fire by Native Americans began to diminish as native populations crashed from disease and as European settlers laid claim to land. Witness trees, as recorded in surveyors' notes, are often the only indication of what composed presettlement forests and their disturbance regimes (Black and Abrams 2001). When grouped by fire relations, witness trees can be converted to show spatial differences in presettlement fire regimes (Thomas-Van Gundy and Nowacki 2013). Witness tree data show that white oak was dominant over large areas of the Central Appalachians (Table 5) (Abrams 2003). Exceptions occurred in Ohio's glaciated plateau, where white oak was codominant in maple-beech forests, and in the many landforms of the Appalachian Mountains. Analysis of witness trees within the Monongahela National Forest correlates white oak with low elevation and high moisture, whereas higher elevations supported sugar maple, American beech, birch, red spruce, eastern hemlock, and black cherry, among others (Thomas-Van Gundy and Strager 2012). Industrialization and settlement during the 18th and 19th centuries also created heavy demands on forests within the Central Appalachians region. The logging boom of 1880 to 1930 is often considered the most important driver of forest ecosystems in the assessment area, although the forests of Ohio had already declined from 95 percent of land cover to 40 percent by 1880, largely due to agriculture (Birch and Wharton 1982, Widmann et al. 2007). Large-scale clearcutting was conducted for the purposes of wood harvesting and agricultural land clearing. The effects of repeated logging that removed most old-growth forests, and the subsequent wildfires, are still being observed today. Secondary forests are largely even-aged with poor structure and reduced species diversity. Other impacts include the loss of soil that will take thousands of years to replace, degraded stream channels, and old railroad grades and logging roads that impair watershed hydrology and create edge effects. In the early 1900s, frequent and intense fires favored oaks, hickories, and yellow pines at the expense of hemlock, red spruce, white pine, and mesophytic hardwoods.

**Table 5.—Witness tree observations from various locations in the Central Appalachians**

| Region, location | Presettlement forest composition | Reference |
|---|---|---|
| Southwestern Pennsylvania | White oak (40%), black oak (9%), hickory (9%), dogwood (8%) | (Abrams and Downs 1990) |
| Eastern West Virginia Ridges | White oak (35%), chestnut (15%), chestnut oak (13%), black oak (12%) | (Abrams and McCay 1996) |
| Eastern West Virginia Valleys | White oak (23%), maple (22%), pine (15%), basswood (10%) | (Abrams and McCay 1996) |
| Southern West Virginia | White oak (24%), chestnut (12%), hickory (9%), chestnut oak (6%) | (Abrams et al. 1995) |
| Monongahela National Forest | White oak (19%), sugar maple (10%), American beech (8%) | (Thomas Van-Gundy and Strager 2012) |
| Southeastern Ohio | White oak (40%), hickory (14%), black oak (12%), American beech (8%) | (Dyer 2001) |
| Northeastern Ohio Fine till | American beech (36%), sugar maple (17%), white oak (14%) | (Whitney 1994) |
| Northeastern Ohio Coarse till | White oak (37%), hickory (13%), black oak (6%) | (Whitney 1994) |

## Primary Agents of Change

Agents of change within the assessment area include both natural and anthropogenic pressures. Fire suppression, wind events, severe weather, pests and diseases, invasive species, large-scale surface mining, acid deposition, fragmentation, and land use change are the primary agents of change in the Central Appalachians region. Each of the forest ecosystems addressed in this assessment faces a particular suite of threats and stressors (Table 6). We define threats and stressors as agents that tend to disrupt the natural functioning of forest ecosystems or impair their health and productivity. This information is collected from published literature as well as local forest managers. The impacts of particular threats and stressors are very dependent on local conditions and are not consistent across an area as large and diverse as the Central Appalachians.

These particular threats should be considered in addition to landscape-level threats such as acid deposition, forest fragmentation, the legacy of past management practices, and altered disturbance regimes. It is often difficult to examine the effects of just one of these landscape-level threats in isolation, because they have all interacted across the assessment area over the past century. Fragmentation caused by mining, agricultural and urban development, forest management, and other factors has tended to reduce the ratio of interior to edge conditions in forests (Drohan et al. 2012a, Irwin and Bockstael 2007). The disruption of natural disturbance regimes has included fire suppression in upland systems as well as hydrologic disruption in riparian and lowland forests. Natural regeneration and succession of forest ecosystems is strongly tied to disturbance regimes, so in many cases alteration of disturbance regimes has resulted in regeneration failure for those disturbance-adapted species and reduced landscape diversity (Abrams and Nowacki 1992, Nowacki and Abrams 2008, Patterson 2006). Conversely, other species may benefit from the altered disturbance regime, particularly fire-sensitive, shade-tolerant trees.

**Table 6.—Major disturbances and threats to forest ecosystems in the Central Appalachians**

| Forest Ecosystem | References |
|---|---|
| **All forest ecosystems (Central Appalachians)** | |
| **Atmospheric deposition** of nitrates, sulfates, ozone, and other anthropogenic emissions negatively affects forest productivity and resilience. | (Potter et al. 2010) |
| **Deer herbivory** is considered a keystone driver through impacts on plant regeneration, structure, and species diversity, especially where deer density is high. | (Collins and Carson 2003, MDNR 2010, ODNR 2010b) |
| **Drought** can lead to increased fire hazard, decreased plant growth, regeneration failure, and increased susceptibility to insects and diseases. | (ODNR 2010b) |
| **Energy development** for wind energy and shale-gas installations alter ecosystem structure through vegetation clearing, soil disturbance, increased erosion potential, fragmentation, and direct impacts on forest wildlife species. | (Drohan et al. 2012b, National Research Council 2007) |
| **Fragmentation** from industrial and urban development has resulted in dispersal barriers that impede migration of species and exchange of genetic material, reduced forest patch size, and increased forest edge. | (Irwin and Bockstael 2007, Potter et al. 2010, Riitters 2011) |
| **Geographic dispersal barriers** slow the dispersal and migration of species in multiple directions across the Appalachian Mountains. | (Davis 1983) |
| **Insect pests and diseases** increase the risk of individual tree mortality and species extinction or extirpation. | (DeSantis et al. 2013, Lovett et al. 2006, MDNR 2010, ODNR 2010b, Potter et al. 2010) |

(continued on next page)

**Table 6 (continued).**

| Forest Ecosystem | References |
|---|---|
| **Appalachian (Hemlock)/Northern Hardwood Forest** | |
| **Acid deposition** negatively affects forest productivity and resilience. | (ODNR 2010b, Potter et al. 2010) |
| **Deer herbivory** results in reduced growth and mortality of seedlings and saplings of target browse species. | (Collins and Carson 2003, MDNR 2010) |
| **Insect pests and diseases** such as emerald ash borer, hemlock woolly adelgid, hypoxylon canker, and beech bark disease can cause reduced growth and mortality of target species. | (Anderson 1995, Burns and Honkala 1990, DeSantis et al. 2013, Hessl and Pederson 2013, MDNR 2010) |
| **Invasive plants** such as garlic mustard, ailanthus, Japanese stiltgrass, basket grass, and paper mulberry reduce natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013) |
| **Dry Calcareous Forest, Woodland, and Glade** | |
| **Insect pests and diseases** such as red oak borer, gypsy moth, sudden oak death, oak decline, and armillaria root disease can cause reduced growth and mortality of target species. | (MDNR 2010, ODNR 2010b) |
| **Invasive plants** such as ailanthus, Asiatic bittersweet, garlic mustard, multiflora rose, Japanese honeysuckle, bush honeysuckle, autumn olive, spotted knapweed, viper's bugloss, Japanese stiltgrass, and Canada bluegrass can reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Hutchinson and Vankat 1998, Kurtz 2013) |
| **Suppression of natural fire regimes** has contributed to woody encroachment of eastern redcedar and mountain laurel; overabundance of these shrubs can reduce diversity and affect species regeneration. | (Abrams 1992, Nowacki and Abrams 2008, Smith and Johnson 2004) |
| **Dry Oak and Oak/Pine Forest and Woodland** | |
| **Insect pests and diseases** such as gypsy moth, sirex woodwasp, southern pine beetle, oak decline, and armillaria root disease can cause reduced growth and mortality of target species. | (MDNR 2010, ODNR 2010b) |
| **Invasive plants** such as ailanthus, Japanese stiltgrass, multiflora rose, Japanese honeysuckle, bush honeysuckle, autumn olive, Japanese barberry, sericea lespideza, yellow sweetclover, and crown vetch reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013) |
| **Past management activities** which created microsite conditions conducive to pine regeneration are difficult to reconstruct without intense fire, resulting in a gradual conversion from pine to oak species. | (Vose et al. 1993) |
| **Suppression of natural fire regimes** has reduced structural and species diversity, allowed mesic hardwood encroachment on many sites, and limited suitable conditions for natural regeneration. | (Abrams 2003, Nowacki and Abrams 2008, Patterson 2006, Sharitz et al. 1992) |

(continued on next page)

**Table 6 (continued).**

| Forest Ecosystem | References |
|---|---|
| **Dry/Mesic Oak Forest** | |
| **Insect pests and diseases** such as ambrosia beetle, red oak borer, gypsy moth, oak decline, armillaria root disease, hypoxylon canker, and phytophtora root rot can cause reduced growth and mortality of target species. | (Lovett et al. 2006, ODNR 2010b, Raffa et al. 2008) |
| **Invasive plants** such as ailanthus, Japanese stiltgrass, and garlic mustard reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013, MDNR 2010) |
| **Suppression of natural fire regimes** has reduced structural and species diversity, allowed mesic hardwood encroachment on many sites, and limited suitable conditions for natural regeneration. | (Abrams 2003, Nowacki and Abrams 2008, Patterson 2006, Sharitz et al. 1992) |
| **Large Stream Floodplain and Riparian Forest** | |
| **Energy development** for wind energy and shale-gas installations alter ecosystem structure through vegetation clearing, soil disturbance, increased erosion potential, pollution, fragmentation, mine land abandonment, and direct impacts on forest wildlife species. | (Drohan et al. 2012b, National Research Council 2007) |
| **Erosion** from improperly designed or poorly maintained roads, trails, or log landings can increase the amount of siltation and sedimentation transported and deposited by streams. | (Pennsylvania Department of Environmental Protection 2012) |
| **Industrial and urban development** has resulted in hydrologic infrastructure that affects the flood regime, such as impoundments, channelization, dams and reservoirs, and drainage and clearing for agriculture. | (Irwin and Bockstael 2007, Potter et al. 2010, Riitters 2011) |
| **Insect pests and diseases** such as emerald ash borer, thousand cankers disease, and elm yellows can cause reduced growth and mortality of target species. | (DeSantis et al. 2013, Grafton 2013, Kurtz 2013) |
| **Invasive plants** are transported by water and establish more rapidly here than in other systems. Species such as Japanese stiltgrass, Japanese hops, and bush honeysuckle can reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013) |
| **Mixed Mesophytic and Cove Forest** | |
| **Forest arson** and debris burning are the major causes of wildfire. | (MDNR 2010, ODNR 2010b) |
| **Insect pests and diseases** such as emerald ash borer, hemlock woolly adelgid, and beech bark disease can cause reduced growth and mortality of target species. | (Hessl and Pederson 2013, ODNR 2010b) |
| **Invasive plants** such as Japanese stiltgrass, garlic mustard, ailanthus, and bush honeysuckle can reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013) |
| **Mountaintop removal mining and valley fill** changes topography, soil water capacity, and runoff; and buries headwater streams where mining waste is dumped. | (U.S. EPA 2005, 2009) |

(continued on next page)

**Table 6 (continued).**

| Forest Ecosystem | References |
|---|---|
| **North-Central Interior Beech/Maple Forest** | |
| **Energy development** for wind energy and shale-gas installations alter ecosystem structure through vegetation clearing, soil disturbance, increased erosion potential, fragmentation, and direct impacts on forest wildlife species. | (Drohan et al. 2012b, National Research Council 2007) |
| **Fragmentation and urban development** has resulted in dispersal barriers that impede migration of species and exchange of genetic material, reduced forest patch size, and increased forest edge. | (Irwin and Bockstael 2007, Potter et al. 2010, Riitters 2011) |
| **Invasive plants** such as princess tree, silk tree, garlic mustard, creeping charlie, Japanese stiltgrass, ailanthus, and glossy buckthorn reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013) |
| **Insect pests and diseases** such as hemlock woolly adelgid, gypsy moth, emerald ash borer, sirex woodwasp, anthracnose disease, sudden oak death, and beech bark disease can cause reduced growth and mortality of target species. | (DeSantis et al. 2013, Hessl and Pederson 2013, ODNR 2010b) |
| **Small Stream Riparian Forest** | |
| **Energy development** for wind energy and shale-gas installations alter ecosystem structure through vegetation clearing, soil disturbance, increased erosion potential, pollution, fragmentation, mine land abandonment, and direct impacts on forest wildlife species. | (Drohan et al. 2012b, National Research Council 2007) |
| **Erosion** from improperly designed or poorly maintained roads, trails, or log landings can increase the amount of siltation and sedimentation transported and deposited by streams. | (Pennsylvania Department of Environmental Protection 2012) |
| **Industrial and urban development** has resulted in hydrologic infrastructure that affects the flood regime, such as impoundments, channelization, dams and reservoirs, and drainage and clearing for agriculture. | (Irwin and Bockstael 2007, Potter et al. 2010, Riitters 2011) |
| **Invasive plants** are transported by water and establish more rapidly here than in other systems. Species such as Japanese stiltgrass, Japanese hops, and bush honeysuckle can reduce suitable conditions for natural regeneration, facilitate other exotic species, and alter understory plant communities. | (Grafton 2013, Kurtz 2013) |
| **Insect pests and diseases** such as emerald ash borer, hemlock woolly adelgid, thousand cankers disease, and elm yellows cause reduced growth or mortality of target species. | (DeSantis et al. 2013, Grafton 2013, Kurtz 2013) |
| **Spruce/Fir Forest** | |
| **Acid deposition** at high-elevation sites adversely affects the growth and physiology of red spruce. Acid deposition has also been linked to increased predisposition to frost damage in red spruce. | (Friedland et al. 1984, McLaughlin et al. 1990, Schuler and Collins 2002) |
| **Anthropogenic impacts** from surface mining and wind energy development, roads, recreation, and residential development have resulted in fragmentation, altered hydrology, and forest conversion. | (Schuler and Collins 2002) |
| **Deer browse** results in reduced growth and mortality of seedlings and saplings of target browse species (e.g., eastern hemlock). | (Michael 1992, Schuler and Collins 2002) |
| **Frost damage** is a major cause of foliar loss in red spruce. | (Friedland et al. 1984) |
| **Insect pests and diseases** such as hemlock and balsam woolly adelgids, emerald ash borer, and beech bark disease can cause reduced growth and mortality of target species. | (DeSantis et al. 2013, Hessl and Pederson 2013, Schuler and Collins 2002) |

## Fragmentation and Land-use Change

Residential and urban development has led to the fragmentation of forests across the assessment area, resulting in a patchwork of public and private parcels of natural, agricultural, and developed lands. As mentioned earlier, 40 percent of the assessment area is now agricultural or developed land (USFS 2013). Northern Ohio and western Maryland have a particularly large proportion of these developed and agricultural lands, and the percentage of interior forest is lowest in the area (0 to 27 percent) (USFS 2011). The most affected lands are those on the fringes of major towns and cities, and in rural areas where second homes contribute to sprawling development (Irwin and Bockstael 2007, USFS 2011). Forest lands across the assessment area are often heavily dissected by roads, private property, trails, and utility lines. In Ohio, only 25 percent of the forest land is more than 0.25 mile from a road (Widmann et al. 2009). Parcelization is also a concern as the number of forest land owners is increasing and the size of parcels is decreasing (Widmann et al. 2009).

Fragmentation of natural landscapes creates isolated plant and animal populations that are unable to migrate easily and exchange genetic information, leading to reduction in biological and genetic diversity (Riitters 2011). It also causes increased incidence of edges along forest boundaries (Sisk et al. 1997). Fragmentation has also resulted in the degradation of watersheds, loss of wildlife habitat, increased disturbances, and the spread of invasive species (Widmann et al. 2007).

## Natural Disturbances

Natural disturbance has historically been a regular influence on forest ecosystems in the assessment area. Forest systems have distinct disturbance regimes, characterized in part by the soils, landforms, and vegetation (McNab et al. 2007). Small-scale canopy disturbances are often caused by drought, wind, ice, snow, flooding, landslides, insect outbreaks, intermediate-intensity fires, and pathogens (NatureServe 2011). Larger scale canopy disturbances, potentially affecting entire stands and swaths of forest across the landscape, include tornadoes, hurricanes, high-intensity fires, periodic flooding along major river floodplains, and catastrophic insect and pathogen outbreaks. Annual spring floods along rivers and streams are also typical disturbance events, but hydrology has been modified by channelization, drainage tiles, dams, roads, and other anthropogenic activities that change soil or runoff characteristics (NatureServe 2011). Beaver historically affected floodplains along small streams by building dams that sometimes killed relatively large stands of trees and created temporary ponds and wetlands; beaver remain a small disturbance agent in the contemporary landscape.

## Insect Pests and Diseases

Insect and disease outbreaks have long influenced the structure of forest ecosystems in the Central Appalachians. Before European settlement and the introduction of nonnative species, outbreaks were caused by native insect species, including the spring hemlock looper and forest tent caterpillar. Recent outbreaks of another native species, the southern pine beetle, have occurred in the New Jersey Pine Barrens, and increasing populations in southeast Ohio warrant monitoring of this pest (NRCS 2014a).

International trade and the inadvertent movement of nonnative invasive species from countries around the world have amplified the amount of exposure to, and impacts on, tree species of the Central Appalachians region. Gypsy moth is a serious pest and has caused huge losses of basal area in valuable red and white oak (MDNR 2010, ODNR 2010b). Beech bark disease has resulted in mortality of beech trees across millions of acres in the eastern United States, and has yet to invade the majority of the beech range (Morin et al. 2007). The hemlock woolly adelgid has threatened hundreds of thousands of eastern hemlocks with needle loss, followed by branch dieback, and eventually death (Jonas et al. 2012). The emerald ash borer has caused mortality in all ash species, including white ash, black ash, and green ash, resulting in the loss of more than 50 million trees between 2002 and 2009 (Kovacs et al. 2010). The Asian longhorned beetle is not confirmed in the assessment area, but its arrival from adjacent areas would result in damage and mortality to many species including maples, buckeyes, birches, willows, and elms (Townsend Peterson and Scachetti-Pereira 2004). Diseases, such as chestnut blight fungus, have virtually eliminated American chestnut as a canopy tree although chestnut stump sprouts and saplings persist in the understory (Merkle et al. 2007). One or more species of fungus in the genus *Hypoxylon* can injure or kill trees weakened by other factors, such as drought, logging, and root disease (Anderson 1995).

## Nonnative and Invasive Plants

Nonnative plant species are a risk to forest ecosystems when they become invasive. These species affect forest ecosystems through direct competition for resources, alteration of fire or hydrologic conditions, disruption of natural succession and pollination, and other cascading influences (Frelich et al. 2012, Tu et al. 2001). Invasive plant species can be introduced into native ecosystems by the transportation of seed on vehicles or equipment, on the soles of shoes, in manure from domestic or wild animals, or by wind and water. The FIA program has monitored 25 invasive species in the eastern United States since 2007 (Fig. 6). In West Virginia, it is estimated that 28 percent of plant species occurring in the wild are nonnative invasive species (Kurtz 2013). Kudzu, glossy buckthorn, bush honeysuckle, autumn olive, crown vetch, Japanese knotweed, Japanese stiltgrass, garlic mustard, ailanthus, mile-a-minute, and multiflora rose are among the area's most problematic invasives (Grafton 2013).

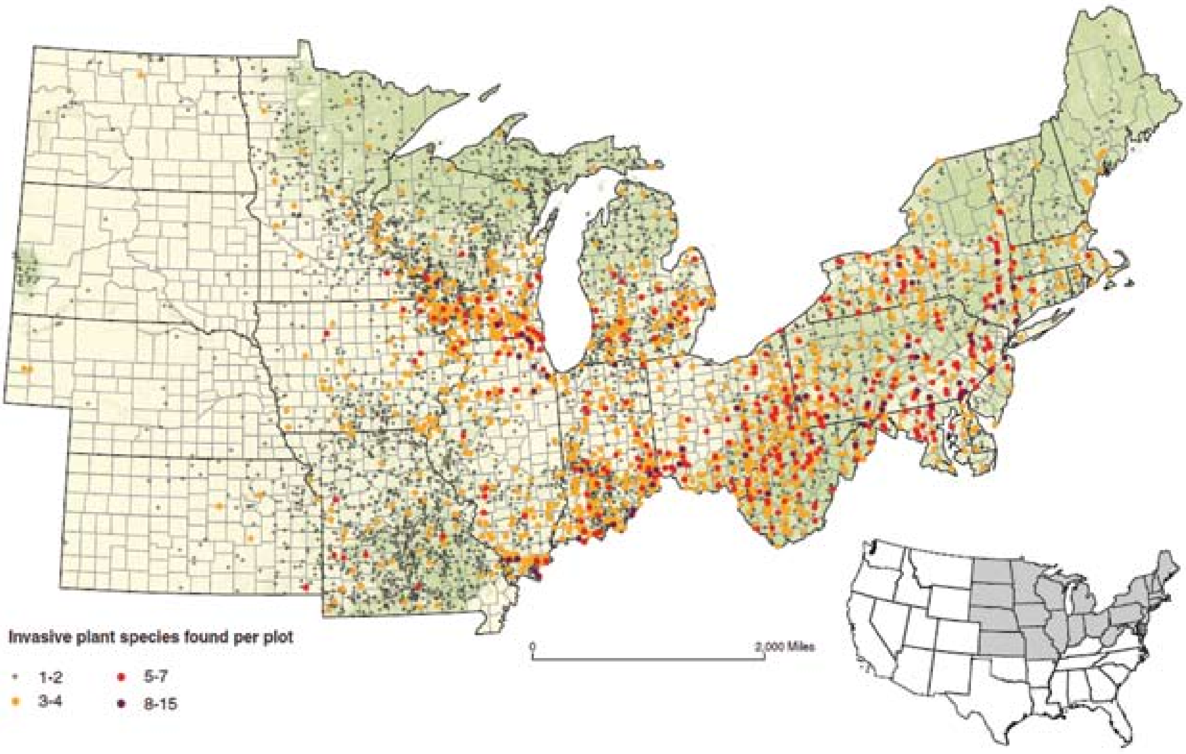

Figure 6.—Number of invasive plant species observed per FIA plot (2005 to 2010) (Kurtz 2013).

## Shifts in Fire Regime

Fire regimes have shifted in the assessment area over the past several hundred years, and these shifts influence the composition of forest ecosystems. Both natural and human-caused fire has been a component of the eastern United States for thousands of years, although the return interval, intensity, and extent are largely dependent on landscape position in the Central Appalachians region (Abrams 1992, Nowacki and Abrams 2008, Thomas-Van Gundy and Nowacki 2013). Studies in the eastern United States and Canada that have dated fire scars in oak forests have shown that fire-return intervals either increased or decreased immediately after European settlement, depending on the stand and location. A 400-year reconstruction of fire history in western Maryland used fire scars as evidence that pre-European fires were as important as post-European fires, and that fire suppression in the 20th century has coincided with the increase of shade-tolerant species, to the detriment of oaks, hickories, and other fire-tolerant species (Shumway et al. 2001). The historic role of fire in the development and maintenance of oak forests has been well-established in the literature (Abrams 1992, Brose and Van Lear 1999). By the 1950s, fire exclusion began to favor red maple, sugar maple, American beech, and black cherry (Brose and Van Lear 1999, Nowacki and Abrams 2008, Schuler and Gillespie 2000, Wright and Bailey 1982). Oaks continue to be replaced by other hardwood species, especially red maple (Brose et al. 2008).

## Mineral, Gas, and Wind Energy Development

Coal mining, natural gas fracturing, and wind power development are today's most influential natural resource extraction activities in the Central Appalachians. Coal mining is the dominant driver of land-use change in West Virginia, primarily changing forested conditions to nonforest (Liu et al. 2006). The mountaintop removal form of surface mining is a process that removes tons of bedrock from the sides and tops of mountains to reach the underlying coal seams. The dramatic alteration of the landform is permanent, and waste disposal into valleys has resulted in the burial of headwater streams. Although the Surface Mining Control & Reclamation Act provides federal regulations on coal mining and reclamation operations, mined and reclaimed areas generally have lower infiltration capacity and higher runoff than pre-mine conditions (Townsend et al. 2009). Grading of the topsoil and subsoil, followed by seeding with grasses and herbs, has generally resulted in nearly impervious reclamation lands with compacted soils and herbaceous cover, rather than native forest (Bussler et al. 1984, Chong and Cowsert 1997, Holl 2002, Negley and Eshleman 2006, Simmons et al. 2008). Alterations to the water table, transition to overland flow as the dominant runoff process, and increases in peak streamflow also are common consequences of mine land reclamation (Negley and Eshleman 2006).

Natural gas wells first appeared in the mid-1800s, and new wells continue to be drilled even as old wells are capped. In West Virginia and Ohio, there are more than 87,400 active gas-producing wells, with 487 horizontally drilled Marcellus wells (Kasey 2012, Resources for the Future 2012, WVDEP 2013a). Maryland had only seven gas wells operating in 2010, and although the Marcellus shale formation extends into western Maryland, horizontal drilling permits have been denied, pending research reports on the safety of hydraulic fracturing (O'Malley 2011). Electricity produced from natural gas creates approximately half the carbon dioxide emissions of electricity produced from coal; however, hydraulic fracturing requires extensive road and pipeline networks and millions of gallons of water. It is estimated that approximately 30 acres of land are disturbed for each shale gas drilling pad (Drohan et al. 2012b). Many well pads are located on soils with high to very high runoff potential, making actions to minimize long-term ecosystem degradation critical (Drohan et al. 2012a).

Wind turbines in the Allegheny Mountains, West Virginia. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

Although wind energy has the potential to reduce greenhouse gas emissions and other adverse emissions, wind turbine placement has had notable ecological impacts, such as land surface disturbance (1 to 7 acres per turbine), road construction, vegetation clearing, soil removal and compaction, and fragmentation of forests (National Research Council [NRC] 2007). These disturbances can have subsequent impacts on forest composition and structure, as well as forest species sensitive to edge effects. Collision with wind turbines can cause significant mortality of birds and bats. Turbine design, site characteristics, location, and temporal patterns of use can all influence the rates of bird and bat mortality, but changes in how the turbines are operated can reduce mortality (NRC 2007).

## FOREST-DEPENDENT WILDLIFE

The Central Appalachians region is one of the most ecologically diverse regions of the eastern United States (The Nature Conservancy 2003). The variations in topography, geology, and temperature and precipitation regimes in the region have resulted in the development of an exceptional variety of habitats supporting an abundance of wildlife, including more than 540 species identified as species of conservation concern in West Virginia alone (West Virginia Division of Natural Resources [WVDNR] 2014).

One of the most prevalent and well-known wildlife species is the white-tailed deer. It was almost eliminated from the region in the early 1900s as a result of deforestation and unregulated hunting, but now exists at higher densities than in the past several hundred years. Since the extirpation of the eastern cougar and eastern timber wolf from the region, deer have few natural predators to control population numbers, although black bear, bobcat, and coyotes do prey on fawns opportunistically. White-tailed deer, which can double in population size annually under optimum conditions, have exceeded their environmental carrying capacity in some areas (Côté 2004, Waller and Alverson 1997).

At high densities, deer can have a keystone effect on the forest ecosystem. As deer browse plant species preferentially, they change the relative abundance and diversity of native species and promote the establishment of invasive species (Abrams and Johnson 2012, Collins and Carson 2003, Horsley et al. 2003, Knight et al. 2009). High deer densities can alter the availability of food to other wildlife species such as wild turkey and eastern gray squirrels that also rely on hard mast crops.

Although deer occur throughout a variety of forest types in the assessment area, the distributions of some wildlife species are limited to specific

White-tailed deer, which can have a significant impact on vegetation near the forest floor. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

environmental conditions for all or a portion of their life cycle. Vernal pool obligate species, such as the spotted salamander, tiger salamander, and red-spotted newt breed only in isolated wetlands that are dry for part of the year. Because these ephemeral wetlands can occur where other water resources are scarce, they also provide important habitat for migratory and resident birds, large and small mammals (e.g., bats), and other species. Forestry practices also often result in destruction of these habitats because they are difficult to distinguish from the surrounding forest when pools have dried up in the summer.

Ephemeral pool. Seasonally wet areas like this one are important for amphibian reproduction. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

The spruce/fir forest ecosystem of the Allegheny Mountains section provides other unique habitats supporting endemic and obligate species. Many sensitive wildlife species residing there are competitive only in the microclimates provided by high-elevation and complex topography. The Cheat Mountain salamander is listed as a federally threatened species and the West Virginia northern flying squirrel was removed from the endangered species list in 2013, but remains a USFS Regional Forester's Sensitive Species and a State Species of Greatest Conservation Need in West Virginia (WVDNR 2014). The dense shading and moist microclimate associated with spruce and spruce/northern hardwood forests, along with highly organic and often acidic and rocky soils beneath the conifers, provide a habitat where the Cheat Mountain salamander may have a competitive advantage over other salamanders, such as the red-backed salamander, which is dominant at lower elevations. The northern flying squirrel also has an intricate relationship with these habitats. Like the Cheat Mountain salamander, the northern flying squirrel competes with a similar species, the southern flying squirrel, which is dominant at lower elevations. Many boreal bird species are characteristic of these high-elevation habitats as well, ranging from predatory birds such as the northern goshawk and saw-whet owl to Neotropical migrants such as the blackburnian warbler and red crossbill, all of which reach the southeastern extent of their breeding ranges in the Central Appalachians.

Deciduous forests in the region also provide critical breeding bird habitat. Four of the birds of highest conservation priority in the Appalachian Mountains region are hardwood interior forest species: the cerulean warbler, Kentucky warbler, wood thrush, and worm-eating warbler (Appalachian Mountains Joint Venture Board 2008). Within the assessment area, these species require mature deciduous or mixed forest habitat for breeding, and each is associated with particular herbaceous and understory structure. These Neotropical migrants are vulnerable to a variety of threats, including tropical deforestation on wintering grounds and forest habitat loss, fragmentation, and modification of breeding grounds. Another bird common in mature oak and oak-pine forests in the region is the wild turkey, an important game species (USFWS 2010).

Bats are also associated with forested habitats and are primary predators of nocturnal insects, including many forest and agricultural pests. Populations of many bat species in the eastern United States are in a state of rapid decline as a result of white-nose syndrome, first detected in New York in 2007. This disease is caused by the fungus *Geomyces destructans*, which has spread through hibernacula throughout eastern North America. Bat mortality can reach 100 percent at infected sites. As of 2012, approximately 6 million bats had died from the disease in the United States and Canada. The syndrome was confirmed in West Virginia in the winter of 2008-2009 and in Maryland and Ohio in the following two winters. It has already had a major impact on many bat species, including the endangered Indiana bat, northern bat, little brown bat, small-footed bat, and tri-colored bat. The last four "forest bats" are on the USFS Regional Forester's Sensitive Species list as well as state sensitive species listings, and may be soon proposed for federal listing.

Riparian habitats can be critical for many other wildlife species, providing breeding and foraging habitat for a wide variety of waterfowl, amphibians, reptiles, and mammals, as well as diverse invertebrate fauna. The beaver, another species that was nearly extirpated at the start of the 20th century, requires riparian systems for habitat and plays a keystone role in creating and maintaining open water wetland habitats. The brook trout is the only trout species native to the assessment area and much of the eastern United States, and is often used as an indicator of the health of a watershed. Primary threats to brook trout include poor land management, high water temperatures, urbanization, acid deposition and runoff, sedimentation, surface and ground water withdrawals and impoundments, and introduction of nonnative fish species. As a result of these and other factors, brook trout populations have been greatly reduced in Ohio and West Virginia, and only three intact subwatersheds remain in the western panhandle of Maryland (Trout Unlimited 2006).

## CURRENT LAND MANAGEMENT TRENDS

### Forest Ownership

There are numerous types of forest landowners within the assessment area (Table 7, Fig. 7). About 14 percent of forest land in the region is publicly owned. National forests and state land compose the largest percentages of public forest land, followed by land owned by county and municipal governments, the National Park Service, and the U.S. Department of Defense. The Monongahela National Forest administers approximately 920,000 acres in West Virginia, and the Wayne National Forest administers approximately 250,000 acres in Ohio. Most of the forests in the assessment area, however, are privately owned. This category reflects a diversity of landowner types, including industrial and corporate organizations, conservation organizations, families, and individuals. As a result, private ownership patterns are complex and change over time.

### Trends in Forest Use and Management

Most private forest land is held by hundreds of thousands of nonindustrial family forest owners

**Table 7.—Ownership categories of forest land in the assessment area (USFS 2013)**

| Ownership | Forest land (acres) | % |
|---|---|---|
| Private | 16,194,332 | 85.7 |
| National forest | 1,267,057 | 6.7 |
| State | 946,630 | 5.0 |
| County and municipal | 251,036 | 1.3 |
| National Park Service | 85,911 | 0.5 |
| Department of Defense | 80,562 | 0.4 |
| Other federal | 34,622 | 0.2 |
| Other local government | 22,553 | 0.1 |
| U.S. Fish and Wildlife Service | 11,826 | 0.1 |
| Total | 18,894,530 | 100 |

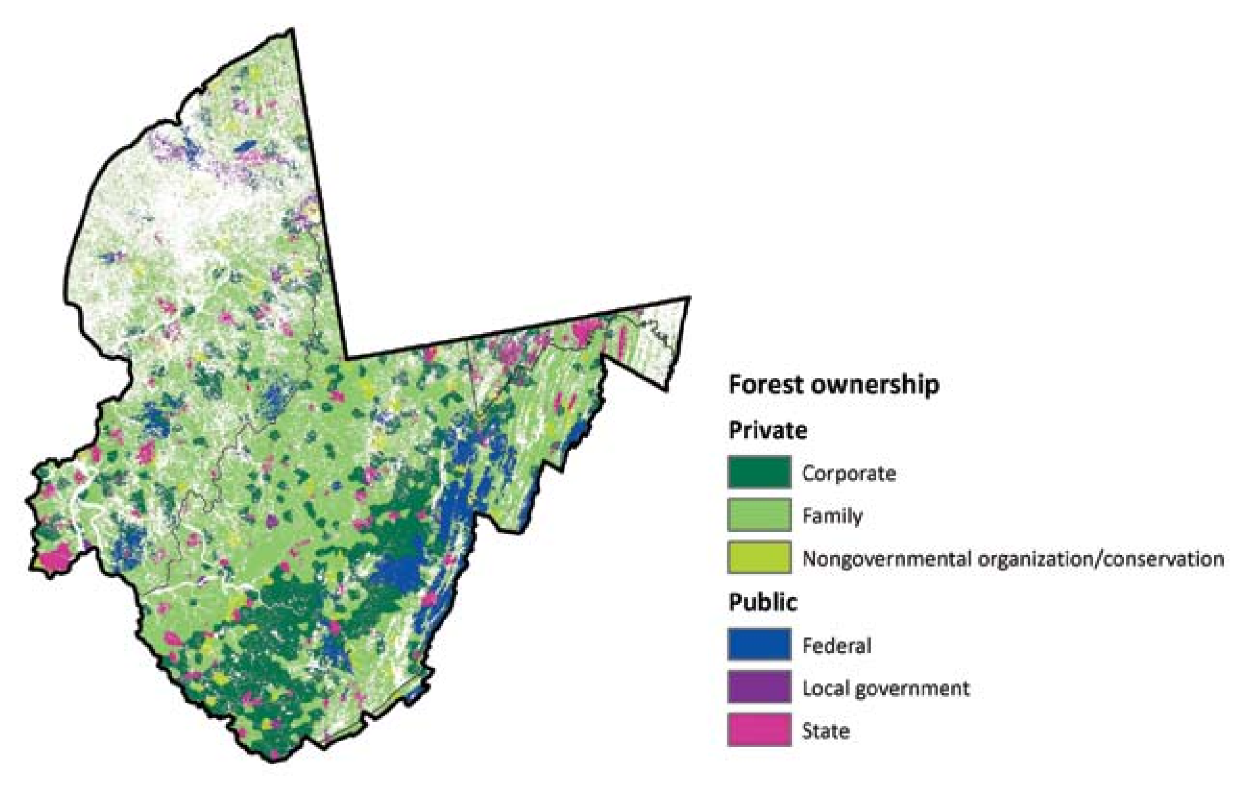

Figure 7.—Public and private forest ownership within the assessment area (Hewes et al. 2014).

(Butler 2008). The primary reasons for forest ownership are privacy, scenery, part of home or cabin, nature protection, to pass land on to heirs, and for access to hunting and fishing (Butler 2008). A survey of 5-year management plans identified a variety of landowner goals and management styles: minimal or no activity, harvesting firewood, harvesting pulp and sawlogs, transferring to heirs, and buying more forest land. Family owners can enroll their lands in conservation easements or forest certification programs such as the American Tree Farm System (ATFS), which require forests to have written management plans (Box 3). About 1.5 million acres in Ohio, West Virginia, and Maryland are currently certified by the ATFS (ATFS 2014). Engaged family forest owners often look to extension agents, Conservation Districts, and private consultants to provide technical assistance and other resources for managing forests.

Industrial forest landowners manage forest lands for timber products, and have a vested interest in long-term forest management. Millions of acres of corporate land have been transferred in the last decade to REITs and TIMOs, which are considered private nonindustrial forest landowners, largely due to unfavorable taxation on industry-owned forests (Froese et al. 2007, Zhang et al. 2012). REITs own and operate income-producing real estate and timberland holdings, sometimes made public through trading of shares on a stock exchange, and thus are able to take advantage of more favorable tax policies. TIMOs act as investment managers for institutional clients who own the timberlands as investments or partnership shares (Fernholz et al. 2007). The goal in both cases is to maximize the growth of the timberland asset over the short term. Thus, the purchase of timberland by REITs and TIMOs raises concerns about parcelization, development, and high-yield management practices (Fernholz et al. 2007). TIMOs in particular have managed forested lands similar to high-intensity industrial forests, with a high percentage in pine plantations (Fernholz et al. 2007).

Public (federal, state, and county) agencies and tribal organizations own extensive tracts of forest in the assessment area. These lands are often managed to provide many environmental benefits, often including wildlife habitat, water protection, soil conservation, nature preservation, timber production, recreation, cultural resources, and a variety of other uses (MDNR 2010; ODNR 2010b; USFS 2006a, 2006b).

## Box 3: Programs for Private Landowners

All three states offer incentives to private forest landowners, with the intent of maintaining larger parcels of privately owned forest and promoting sustainable production of forest products. About 85 percent of the forested land in the area is privately owned, however, and most of these lands lack a management plan (USFS 2008).

### Ohio

More than 65,000 acres of private forest lands in Ohio are enrolled in the Ohio Forest Tax Law program under the “new law” rules implemented in 1993 with the overarching goal to protect land from urban sprawl. This program requires at least 10 acres and a commitment to manage for soil and water conservation and productive forest land. Together with protected lands, about 870,000 acres, or roughly 10 percent of Ohio’s forests, have commitments to soil and water conservation (ODNR 2010b). The Current Agricultural Use Value program is designed to promote timber production, and property assessment values are reduced to $100 per acre. To qualify, a landowner must devote land exclusively to agricultural use, which includes the growth of timber for a noncommercial purpose. This program does not require a management plan (ODNR 2014).

### Maryland

Maryland also administers programs to help ease property taxes and maintain healthy forests. The Forest Conservation Management Agreement (FCMA) is a conservation easement program that lowers assessed values to $125 per acre on a minimum of 5 acres and a minimum expiration date of 15 years (MDNR 2014). As of January 2014, 1,300 landowners had 84,000 acres enrolled. In the Western Region, which overlaps the Maryland portion of the assessment area, 234 landowners had 17,670 acres enrolled (Tim Culbreth, MDNR, pers. commun.). The Woodland Assessment Program is a county program; similar to FCMA, there are no enrollment fees or timeframe, but property assessment values are reduced to $187.50 per acre of forest. The Maryland Income Tax Modification program allows woodland owners to deduct double the cost for reforestation and timber stand improvement practices on 3 to 1,000 acres from the federal adjusted gross income on the Maryland tax return.

### West Virginia

In West Virginia, the Managed Timberland Program provides tax incentives for forest landowners who practice sustainable forestry on their nonindustrial, privately owned forestland comprising 10 acres or more (West Virginia Division of Forestry 2012). Participation in this program has been growing steadily since 1997, and there are now nearly 2.4 million acres enrolled. Many participating landowners have also participated in the USFS Forest Stewardship Program in order to receive assistance with writing a forest management plan at a reduced cost (Dye 2013).

## Forest Certification

Forest certification is a process designed to ensure that forest products originate from forests that are sustainably managed. Forest lands are certified through several systems, including the Forest Stewardship Council (FSC), the Sustainable Forestry Initiative (SFI), and the ATFS (Table 8). The Ohio Department of Natural Resources has dual certification for sustainable forest management of its state forests through FSC and SFI, with a total of 202,927 certified acres. Nearly all of Maryland's 211,000 acres of state forests are dual certified under FSC and SFI.

## Timber Harvest and Forest Products

As mentioned above, the forestry sector is a notable economic contributor in the assessment area. Within the Central Appalachians region, forest removals (not including mortality) averaged 277 million cubic feet in 2011 (USFS 2013). Over half the total harvested roundwood was used as pulpwood and around 30 percent was used as saw logs, with the remainder being diverted to a variety of uses or left behind as logging slash. Pulpwood production peaked in 1994 and has been gradually declining over recent years. More specific harvest data is available at the state level (Table 9). Across the assessment area, hardwoods account for most commercial species, including tulip tree, red and white oaks, soft and hard maples, and black cherry (Piva and Cook 2011, Walters et al. 2008, Wiedenbeck and Sabula 2008). In West Virginia, 97 percent of industrial roundwood processed in 2007 consisted of hardwood species, 37 percent of which was tulip tree (Piva and Cook 2011).

The FIA data also provide more information about the amount of wood removed from forests in the assessment area through timber harvest or conversion of forest to nonforest, with the vast

**Table 8.—Forest land enrolled in certification programs (acres)**[a]

| | Forest land enrolled in certification program (acres) | | | |
|---|---|---|---|---|
| State | Forest Stewardship Council Council (FSC) | Sustainable Forestry Initiative (SFI) | American Tree Farm System (ATFS) | Dual-certified (FSC and SFI) |
| Maryland | – | – | 139,021 | 211,000 |
| Ohio | 203,957 | 202,927 | 293,585 | 202,927 |
| West Virginia | 39,039 | 257,044 | 1,013,352 | – |

[a] Data compiled from multiple sources (ATFS 2014, Forest2Market 2013, SFI 2013).

**Table 9.—Statewide average annual roundwood removals in million cubic feet (Piva and Cook 2011, Walters et al. 2008, Wiedenbeck and Sabula 2008)**

| | Average annual roundwood removals (milllion cubic feet) | | |
|---|---|---|---|
| | Ohio (2003 to 2006) | Maryland (2008) | West Virginia (2007) |
| Total industrial roundwood | 91.2 | 29.1 | 189 |
| Domestic logs | 67.7 | 16 | 104 |
| Pulpwood | 23.5 | 12.5 | 66.7 |

majority of removals in this region being due to timber harvest. The amount of wood harvested annually in the Central Appalachians region is less than the amount that is grown each year, suggesting that the harvest of timber products is biologically sustainable (Lister and Perdue 2013, Widmann and Morin 2012, Widmann et al. 2007). The net annual growth-to-removal ratio is based upon FIA data and provides a primary measure of sustainability. This ratio compares net growth (i.e., gross growth minus mortality) to removals from forest management for forested lands; values greater than 1.0 indicate that net annual growth is greater than annual removals and that the removal rate is sustainable. Across all ownership classes in the assessment area, the growth-to-removal ratio was 2.3 for the most recent inventory period (2008 through 2012), meaning that growth was more than double removals (Table 10). Among ownership classes in the assessment area, national forests and national parks have the highest growth-to-removal ratio, indicating low levels of harvest compared to other owners (Table 10).

## CHAPTER SUMMARY

The climate, geology, and soils of the Central Appalachians region of Ohio, West Virginia, and Maryland support a mosaic of forest ecosystems. These communities supply important benefits to the people of the area, including forest products and recreation opportunities. Past changes in climate, fire regime, and land use have shaped the landscape into its current condition. Shifts in fire regime, habitat fragmentation, species invasions, insect pests and diseases, and other alterations to the landscape threaten the integrity and diversity of the ecosystems and the benefits they provide. Management on public lands in recent decades has focused on reducing these stressors and improving ecosystem function. About 85 percent of the forested land in the area is privately owned, however, and the majority of these lands lack a management plan. New opportunities and incentives have arisen in recent years to help private and public land managers to restore and conserve the ecosystems of the Central Appalachians for future generations.

**Table 10.—Growth, mortality, and removals of growing stock on forest land in the assessment area (USFS 2013)**

| Ownership | Annual net growth (cubic feet) | Annual removals (cubic feet) | Annual net growth:removals |
|---|---|---|---|
| National Forest | 42,954,113 | 324,147 | 132.5 |
| National Park Service | 5,706,942 | 66,516 | 85.8 |
| U.S. Fish and Wildlife Service | 508,390 | – | – |
| Department of Defense | 1,967,529 | – | – |
| Other federal | 757,053 | – | – |
| State | 28,140,927 | 10,821,876 | 2.6 |
| County and municipal | 10,964,142 | 202,251 | 54.2 |
| Other local government | 1,403,549 | 258,295 | 5.4 |
| Private | 768,866,740 | 310,059,634 | 2.5 |
| Other[a] | 2,234,386 | 52,090,765 | 0.0 |
| Total | 863,503,771 | 373,823,484 | 2.3 |

[a]Represents estimated net growth and removals for lands that were diverted from forest and nonforest.

# CHAPTER 2: CLIMATE CHANGE SCIENCE AND MODELING

This chapter provides a brief background on climate change science, climate simulation models, and models that project the impacts of changes in climate on tree species and ecosystems. Throughout the chapter, boxes indicate resources to find more information on each topic. The resources listed are up-to-date, nontechnical reports based on the best available science. A more detailed scientific review of climate change science, trends, and modeling can be found in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007), and the third National Climate Assessment (Melillo et al. 2014).

## CLIMATE CHANGE

Climate is not the same thing as weather. Weather is a set of the meteorological conditions for a given point in time in one particular place (such as the temperature at 3:00 p.m. on June 22 in Athens, OH). Climate, in contrast, is the long-term average of meteorological conditions and patterns for a geographic area. This climate average is calculated from individual measurements taken at multiple locations across a geographic area, and at different points through time. The IPCC (2007: 30) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer." A key finding of the IPCC in its Fourth Assessment Report (2007) was that "warming of the climate system is unequivocal." This was the first assessment report in which the IPCC considered the evidence strong enough to make such a statement. Current observations of higher global surface, air, and ocean temperatures and thousands of long-term (more than 20 years) data sets from all continents and oceans contributed to this conclusion. These data sets showed significant changes in snow, ice, and frozen ground; hydrology; coastal processes; and terrestrial, marine, and biological systems. The IPCC's Fifth Assessment Report contains the most recent and comprehensive evidence of global changes synthesized to date (see Box 4 for a link to the draft). Selected global and national assessments are listed in Box 4.

### The Warming Trend

The Earth is warming, and the rate of warming is increasing (IPCC 2007). Measurements from weather stations across the globe indicate that the global mean temperature has risen steadily over the past 50 years, and that the year 2011 was 0.9 °F (0.5 °C) warmer than the 1951 to 1980 mean (IPCC 2007) (Fig. 8). The first 13 years of the 21st century rank among the warmest 14 years in the 134-year period of record of global temperature (National Oceanic and Atmospheric Administration [NOAA] 2014b). Temperatures in the United States have risen by 2 °F (1.1 °C) in the last 50 years (Karl et al. 2009). The 2012 continental U.S. average annual temperature of 55.3 °F was 3.1 °F above the 20th-century average, and was the warmest year in the 1895 to 2013 period of record for the nation (NOAA 2014b).

## Box 4: Global and National Assessments

### Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC; http://www.ipcc.ch/) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socioeconomic impacts. Its Fifth Assessment Report consists of the Climate Change 2014 Synthesis Report and reports by Working Groups I, II, and III. Drafts of these reports are available for download at the Web address below. Please note that Web addresses are current as of the publication date of this assessment but are subject to change.

**Climate Change 2014: Synthesis Report and Working Group contributions to the Fifth Assessment Report**

www.ipcc.ch/report/ar5/

**Climate Change 2007: Synthesis Report**

www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html

### U.S. Global Change Research Program

The U.S. Global Change Research Program (USGCRP; http://www.globalchange.gov/) is a federal program that coordinates and integrates global change research across 13 government agencies to ensure that it effectively and efficiently serves the nation and the world. Mandated by Congress in the Global Change Research Act of 1990, the USGCRP has since made the world's largest scientific investment in the areas of climate science and global change research. It has released several national synthesis reports on climate change in the United States, which are available for download at the Web addresses below.

**Synthesis and Assessment Products**

http://library.globalchange.gov/products/assessments/

**National Climate Assessment**

http://nca2014.globalchange.gov/

**Effects of Climatic Variability and Change on Forest Ecosystems: a Comprehensive Science Synthesis for the U.S.**

www.treesearch.fs.fed.us/pubs/42610

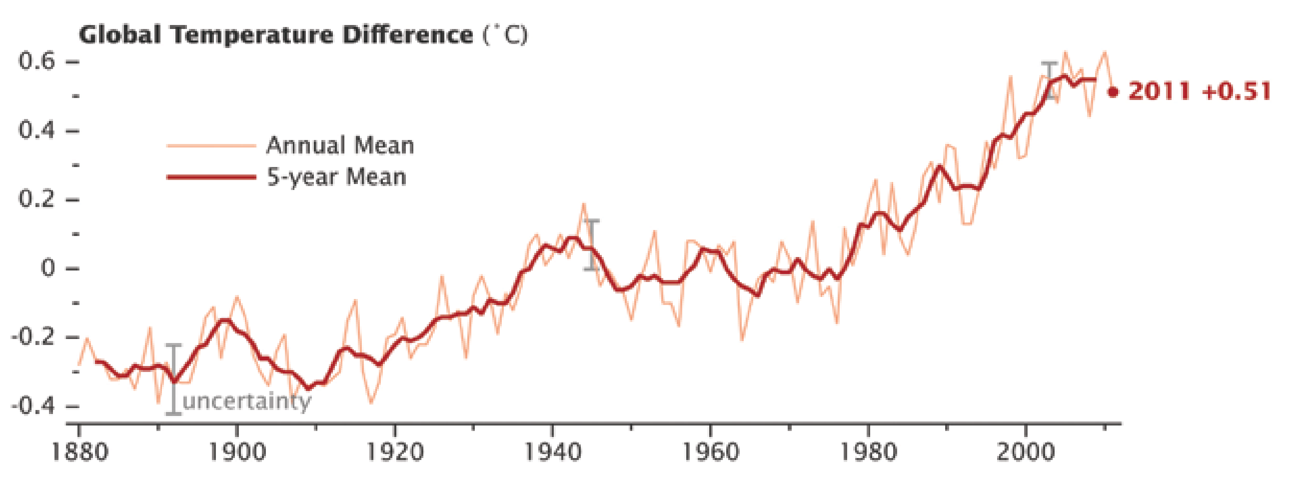

Figure 8.—Trends in global temperature compared to the 1951 to 1980 mean. Data source: NASA Goddard Institute for Space Studies. Image courtesy of NASA Earth Observatory, Robert Simmon; www.giss.nasa.gov/research/news/20120119/.

Average annual global temperature increases of the last 50 years are just one aspect of a more complex and wide-ranging set of climatic changes. For example, the frequency of cold days, cold nights, and frosts has decreased over many regions of the world while the frequency of hot days and nights has increased (IPCC 2007). The frequency of heat waves and heavy precipitation events has increased over this period, with new records for both heat and precipitation in portions of the United States in July 2011 and March 2012 (NOAA 2012). Global rises in sea level, decreasing extent of snow and ice, and shrinking of mountain glaciers have all been observed over the past 50 years, and are consistent with a warming climate (IPCC 2007).

Average temperature increases of a few degrees may seem small, but even small increases can result in substantial changes in the severity of storms, the nature and timing of precipitation, droughts and heat waves, ocean temperature and volume, and snow and ice—all of which affect humans and ecosystems. Temperature increases above 3.6 °F (2 °C) are likely to cause major societal and environmental disruptions through the rest of the century and beyond (Richardson et al. 2009). The synthesis report of the International Scientific Congress on Climate Change concluded that "recent observations show that societies and ecosystems are highly vulnerable to even modest levels of climate change, with poor nations and communities, ecosystem services and biodiversity particularly at risk" (Richardson et al. 2009: 12).

Based on available evidence, 97 percent of the climate science community attributes this increase in temperature and associated changes in precipitation and other weather events to human activities (Anderegg et al. 2010, Cook et al. 2013, Doran and Zimmerman 2009, Stott et al. 2010). Scientists have been able to attribute these changes to human causes by using climate model simulations of the past, both with and without human-induced changes in the atmosphere, and then comparing those simulations to observational data. Overall, these studies have shown a clear human "fingerprint" on recent changes in temperature, precipitation, and other climate variables due to changes in greenhouse gases and particulate matter in the air (Stott et al. 2010). Chapter 3 provides specific information about recent climate trends for the assessment area.

## The Greenhouse Effect

The greenhouse effect is the process by which certain gases in the atmosphere absorb and re-emit energy that would otherwise be lost into space (Fig. 9). The greenhouse effect is necessary for human survival: without it, Earth would have an average temperature of about 0 °F (-18 °C) and be covered in ice, rather than a comfortable 59 °F (15 °C). Several naturally occurring greenhouse gases in the atmosphere, including carbon dioxide ($CO_2$), methane, nitrous oxide, and water vapor, contribute to the greenhouse effect. Water vapor is the most abundant greenhouse gas; its residence time in the atmosphere, however, is on the order of days as it responds to changes in temperature and other factors. Carbon dioxide, methane, nitrous oxide, and other greenhouse gases reside in the atmosphere for decades to centuries. Thus, these other long-lived gases are of primary concern with respect to long-term warming.

## Human Influences on Greenhouse Gases

Humans have increased the concentrations of carbon dioxide, methane, nitrous oxide, and halocarbons in the atmosphere since the beginning of the industrial era (Fig. 10). More carbon dioxide has been released by humans into the atmosphere than any other greenhouse gas. Carbon dioxide levels increased at a rate of 1.4 parts per million (ppm) per year from 1960 to 2005 (IPCC 2007), and reached an average of 395 ppm in January 2013 (Tans and Keeling 2013). In recent decades, fossil fuel burning has accounted for an estimated 83 to 94 percent

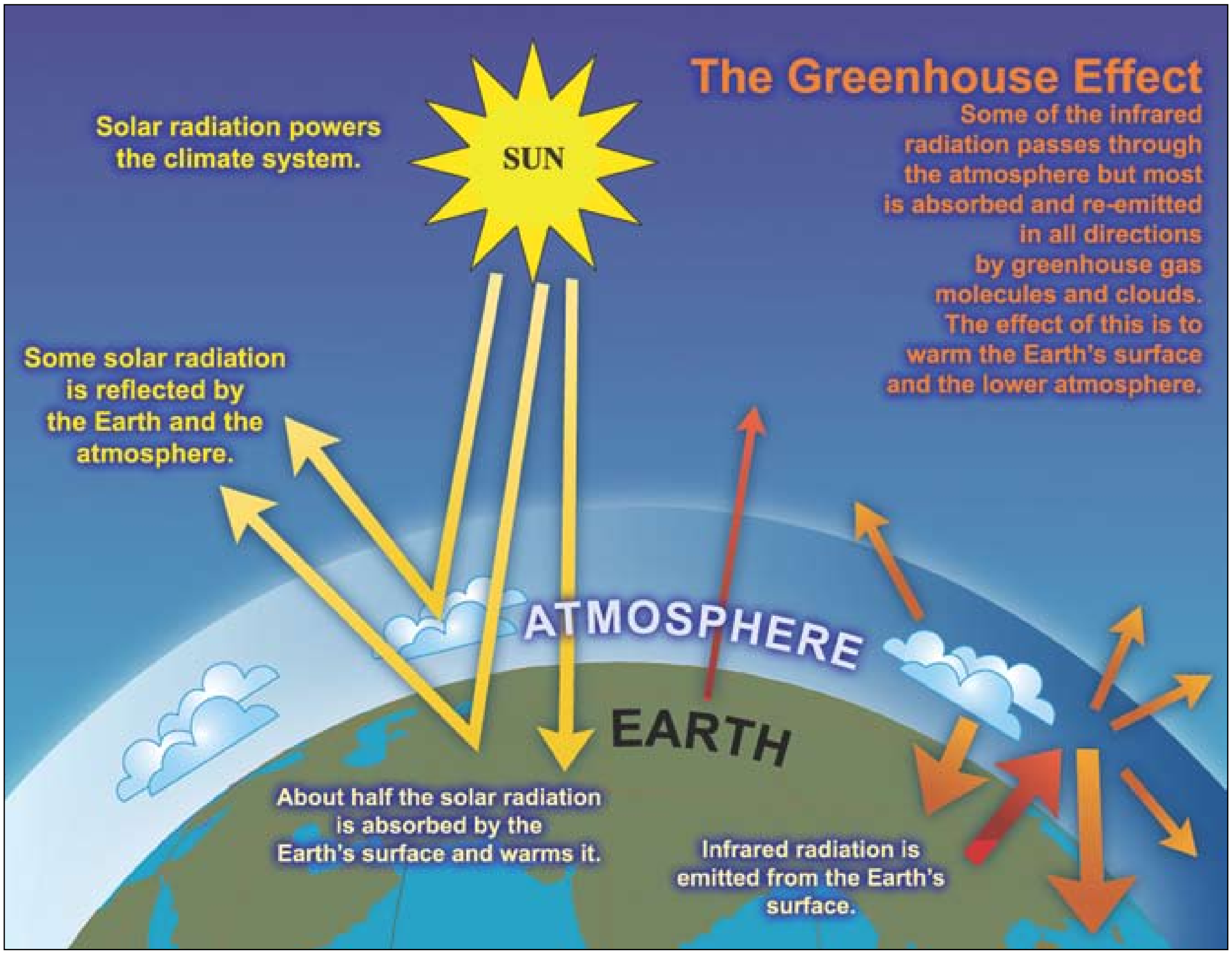

Figure 9.—Idealized model of the natural greenhouse effect. Figure courtesy of IPCC (2007).

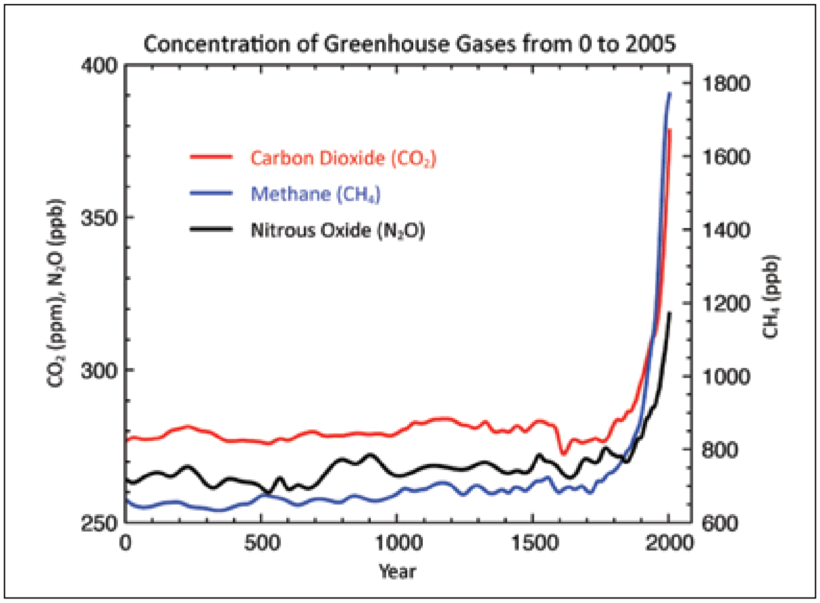

Figure 10.—Concentrations of greenhouse gases showing increases in concentrations since 1750 attributable to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air. Figure courtesy of IPCC (2007).

of the human-induced increase in carbon dioxide. The remaining 6 to 17 percent of human-induced emissions comes primarily from deforestation of land for conversion to agriculture, which releases carbon dioxide when forests burn or decompose (van der Werf et al. 2009). However, increases in fossil fuel emissions over the past decade mean that the contribution from land-use changes has become a smaller proportion of the total (Le Quéré et al. 2009).

Methane is responsible for roughly 14 percent of greenhouse gas emissions in terms of $CO_2$-equivalent ($CO_2$-eq) (IPCC 2007). Concentrations of this gas have also been increasing as a result of human activities, including agricultural production of livestock and increases in rice production. Livestock production contributes to methane emissions primarily from fermentation in the guts of cattle and other ruminants. Rice production requires wet conditions that are also ideal for microbial methane production. Other sources of methane include biomass burning, microbial-induced methane emissions from landfills, fossil fuel combustion, and leakage of natural gas during extraction and distribution.

Nitrous oxide accounts for about 8 percent of global greenhouse gas emissions in terms of $CO_2$-eq (IPCC 2007). The primary human source of nitrous oxide is agriculture. The use of fertilizer causes emissions from soil as microbes break down nitrogen-containing products. This is especially dramatic in areas where tropical forests are converted to agricultural lands. Other human-caused sources of nitrous oxide include nylon production and combustion of fossil fuels.

Humans have also reduced ozone, which protects us from ultraviolet radiation, in the atmosphere through the use of chlorofluorocarbons (CFCs) once used widely in refrigeration, air conditioning, and other uses. Restrictions against the use of CFCs under the Montreal Protocol led to a decline in CFC emissions, and reductions in ozone have subsequently slowed. After CFCs were banned, another class of halocarbons, hydrofluorocarbons (HFCs, also known as F-gases), largely replaced CFCs in refrigeration and air conditioning. HFCs do not deplete stratospheric ozone, but many are powerful greenhouse gases. Currently HFCs account for about 1 percent of greenhouse gas emissions in terms of $CO_2$-eq (IPCC 2007).

## CLIMATE MODELS

Scientists use models, which are simplified representations of reality, to simulate future climates. Models can be theoretical, mathematical, conceptual, or physical. General circulation models (GCMs) combine complex mathematical formulas representing physical processes in the ocean, atmosphere, and land surface within large computer simulations. In this assessment, GCMs are used to project future climate and as inputs to impact models.

### General Circulation Models

General circulation models simulate physical processes in the earth, oceans, and atmosphere through time using mathematical equations in three-dimensional space. They can work in time steps as small as minutes or hours in simulations covering decades to centuries. Because of their high level of complexity, GCMs require intensive computing power, and must be run on supercomputers.

Although climate models use highly sophisticated computers, limits on computing power mean that projections are limited to relatively coarse spatial scales. Instead of simulating climate for every single point on Earth, modelers divide the land surface, ocean, and atmosphere into a three-dimensional grid (Fig. 11). Each cell within the grid is treated as an individual unit, and is able to interact with adjacent cells. Although each model is slightly different, the size of each cell in the grid is usually between 2 and 3° latitude and longitude, or for the middle latitudes, about the size of West Virginia. These horizontal grids are stacked in interconnected vertical layers that simulate ocean depth or atmospheric thickness at increments usually ranging from 650 to 3,280 feet.

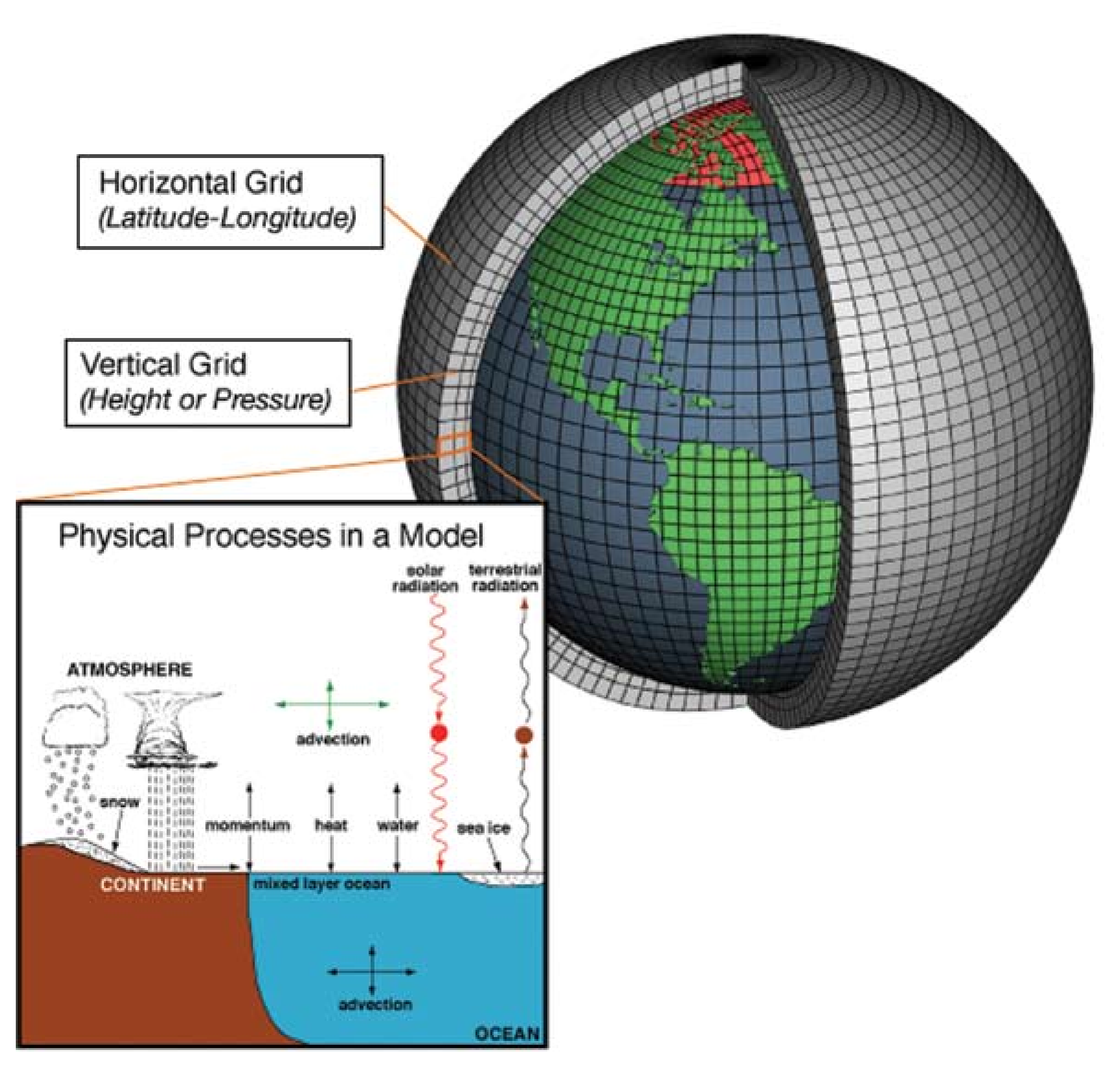

Figure 11.—Schematic describing climate models, which are systems of differential equations based on the basic laws of physics, fluid motion, and chemistry. The planet is divided into a three-dimensional grid that is used to apply basic equations; atmospheric models calculate winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points. Figure courtesy of NOAA (2008).

Several research groups from the United States and abroad have developed GCMs that have been used in climate projections for the IPCC reports and elsewhere (Box 5). These models have been developed by internationally renowned climate research centers such as NOAA's Geophysical Fluid Dynamics Laboratory (GFDL CM2) (Delworth et al. 2006), the United Kingdom's Hadley Centre (HadCM3) (Pope et al. 2000), and the National Center for Atmospheric Research (PCM) (Washington et al. 2000). These models use slightly different grid sizes and ways of quantitatively representing physical processes. They also differ in sensitivity to changes in greenhouse gas concentrations, which means that some models will tend to project higher increases in temperature than others under the same greenhouse gas concentrations (Winkler et al. 2012).

Like all models, GCMs have strengths and weaknesses (Box 6). In general, they are useful and reliable tools because they are based on well-understood physical processes and have been judged in part by their ability to accurately simulate past climate. Simulations with GCMs can be run for past climate, and output from these simulations generally correspond well with proxy-based estimates of ancient climates and actual historical measurements of recent climates. Projections by GCMs are not perfect, however. Sources of error in model output include incomplete scientific understanding of some climate processes and the fact that some influential climate processes occur at spatial scales that are too small to be modeled with current computing power. Technological advances in the computing industry along with scientific advances in our understanding of Earth's physical processes will lead to continued improvements in GCM projections.

## Emissions Scenarios

General circulation models require significant amounts of information to project future climates. Some of this information, like future greenhouse gas concentrations, is not known and must be estimated. Although human populations, economies, and technological developments will certainly affect future greenhouse gas concentrations, these developments cannot be completely foreseen. One common approach for dealing with uncertainty about future greenhouse gas concentrations is to develop storylines (narratives) about how the future may unfold and calculate the potential greenhouse gas concentrations for each storyline. The IPCC's set of standard emissions scenarios is a widely accepted set of such storylines (IPCC 2007). In GCMs, the use of different emissions scenarios results in different climate projections.

### Box 5: More Resources on Climate Models and Emissions Scenarios

**U.S. Forest Service**

**Climate Projections FAQ**
www.treesearch.fs.fed.us/pubs/40614

**U.S. Global Change Research Program**

**Climate Models: an Assessment of Strengths and Limitations**
library.globalchange.gov/sap-3-1-climate-models-an-assessment-of-strengths-and-limitations

**Intergovernmental Panel on Climate Change**

**Chapter 8: Climate Models and Their Evaluation**
www.ipcc.ch/publications_and_data/ar4/wg1/en/ch8.html

**Special Report on Emissions Scenarios: Summary for Policymakers**
http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

## Box 6: Model Limitations and Uncertainty

> *"All models are wrong, some are useful."*
> *–George Box (Box and Draper 1987)*

Models are conceptual representations of reality, and any model output must be evaluated for its accuracy to simulate a biological or physical response or process. The overall intention is to provide the best information possible for land managers given the uncertainty and limitations inherent in models.

Model results are not considered standalone components of this vulnerability assessment because there are many assumptions made about the processes simulated by GCMs and impact models, uncertainty in future greenhouse gas concentrations, and limitations on the grid scale and numbers of inputs that a model can reliably handle. Precipitation projections usually have much more variability among models than temperature. Regions with complex topography contain much more diversity in microclimates than many models can capture. Many nonclimate stressors, such as insect pests or pathogens, can overshadow the impact of climate on a species or community, especially in the short term. Therefore, model results used in this assessment were evaluated by local experts to identify regional caveats and limitations of each model, and are considered with additional knowledge and experience in the forest ecosystems being assessed.

We integrated fundamentally different types of impact models into our assessment of forest vulnerability to climate change. These models operate at different spatial scales and provide different kinds of information. The DISTRIB model projects the amount of available suitable habitat for a species. The LINKAGES model projects species establishment and growth. The LANDIS PRO model projects changes in basal area and abundance. There are similarities between some inputs into these models—downscaled climate models and scenarios, simulation time periods, and many of the same species—but because of the fundamental differences in their architecture, their results are not directly comparable. Their value lies in their ability to provide insights into how various interrelated forest components may respond to climate change under a range of possible future climates.

Models can be useful, but they are inherently incomplete. For that reason, an integrated approach using multiple models and expert judgment is needed. The basic inputs, outputs, and architecture of each model are summarized in this chapter with clear descriptions of the limitations and caveats of each model. Limitations of these models with specific applicability to the Central Appalachians forest ecosystems are discussed in more detail in Chapter 5.

Emissions scenarios quantify the effects of alternative demographic, technological, or environmental developments on atmospheric greenhouse gas concentrations. None of the current scenarios includes any changes in national or international policies, such as the Kyoto Protocol, directed specifically at climate change. However, some of the scenarios that include a reduction in greenhouse gases through other means suggest what we could expect if these policies were implemented. Six different emissions scenarios are commonly used in model projections for reports such as the IPCC Fourth Assessment Report (Fig. 12).

The A1FI scenario is the most fossil-fuel intensive, and thus projects the highest future greenhouse gas concentrations; GCM simulations using the A1FI scenario project the highest future warming. On the other end of the spectrum, the B1 scenario represents a future where alternative energies decrease our reliance on fossil fuels and greenhouse gas concentrations increase the least. GCM simulations using the B1 scenario project the lowest increase in global temperature. Although these scenarios were designed to describe a range of future emissions over the coming decades, it is important to note that the future will likely be different from any of the

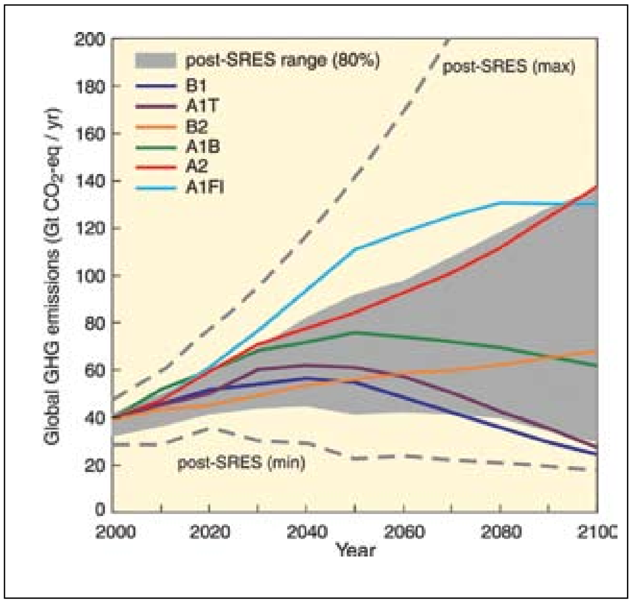

Figure 12.—Projected global greenhouse gas (GHG) emissions (in gigatons [Gt] of $CO_2$-eq per year) assuming no change in climate policies under six scenarios (B1, A1T, B2, A1B, A2, and A1FI) originally published in the Special Report on Emissions Scenarios (SRES) (IPCC 2000), and the 80th-percentile range (gray shaded area) of recent scenarios published since SRES. Dashed lines show the full range of post-SRES scenarios. Figure courtesy of IPCC (2007).

developed scenarios. It is highly unlikely that future greenhouse gas emissions will be less than described by the B1 scenario even if national or international policies were implemented immediately. In fact, current emissions more closely track the greenhouse gas emissions of the A1FI scenario, and global emissions since the year 2000 have even exceeded those values in some years (Raupach et al. 2007).

## Downscaling

As mentioned previously, GCMs simulate climate conditions only for relatively large areas on a relatively coarse scale. To better examine the future climate of areas within the Central Appalachians region, a smaller grid scale is needed. One method of improving the resolution uses statistical downscaling, a technique by which statistical relationships between GCM model outputs and on-the-ground measurements are derived for the past (Hayhoe et al. 2007, Stoner et al. 2013). First, a statistical relationship is developed between GCM output for a past “training period,” and observed climate variables of interest (e.g., temperature and precipitation). The historical relationship between GCM output and monthly or daily climate variables at the regional scale can then be tested by using an independent historical “evaluation period” to confirm the relationship is robust. Finally, the historical relationship between GCM output and observed climate variables is used to downscale both historical and future GCM simulations to the same scale as the initial observations. The statistical relationships are then used to adjust large-scale GCM simulations of the future to much smaller spatial scales. The grid resolution for downscaled climate projections is typically around 6.2 miles (i.e., a cell represents 38.4 square miles).

Statistical downscaling has several advantages and disadvantages (Daniels et al. 2012). It is a relatively simple and inexpensive way to produce smaller-scale projections using GCMs. One limitation is that downscaling assumes that past relationships between large-scale weather systems and local climate will remain consistent under future change. Evaluation of this assumption was performed by applying the asynchronous regional regression model (ARRM) to a high-resolution (15.5 miles) GCM data set under the new RCP 8.5 scenario, and comparing the high-resolution output directly to the projections using SRES scenarios (Hayhoe et al. 2013). The RCP 8.5 scenario is one of the newest suite of scenarios developed by the IPCC, and is comparable to the SRES A1FI scenario used in this assessment. Hayhoe and others (2013) found that the assumption holds true for small projections of change, but larger projections of change may result in small biases. Maximum daily temperatures showed bias within the assessment area only for hot days, whereas minimum daily temperatures showed more widespread bias, indicating potential overestimation of increases in warm nights.

Precipitation projections appear to have widespread bias within the assessment area only on the wettest days. Another limitation is that downscaling depends on local climatological data. If there are too few weather stations in the area of interest, it will be difficult to obtain a good downscaled estimate of future climate for that area. Finally, local influences on climate that occur at finer scales (such as land cover type or topography) cannot be addressed by statistical downscaling, adding to uncertainty when downscaling climate projections.

Another approach, dynamical downscaling, uses a regional climate model (RCM) embedded within a GCM (Daniels et al. 2012). Like GCMs, RCMs simulate physical processes through mathematical representations on a grid. However, RCMs operate on a finer resolution than GCMs, typically ranging from 15.5 to 31 miles, but can be finer than 6.2 miles. Thus, they can more realistically simulate the effects of topography, land cover, lakes, and regional circulation patterns that operate on smaller scales. However, dynamical downscaling requires even more computational power than statistical downscaling. This means that dynamically downscaled data are usually available for only one or two GCMs or scenarios, and for limited geographic areas. Because dynamically downscaled data are currently limited for the assessment area, we use statistically downscaled data in this report.

## Downscaled GCMs Used in this Assessment

In this assessment, we report statistically downscaled climate projections for two model-emissions scenario combinations: GFDL A1FI and PCM B1 (unless otherwise noted). Both models and both scenarios were included in the IPCC Fourth Assessment Report (IPCC 2007). The latest version of the National Climate Assessment (NCA) (Melillo et al. 2014) also draws on statistically downscaled data based on IPCC models and scenarios but uses the A2 scenario as an upper bound, which projects lower emissions compared to A1FI. The IPCC Assessment includes several other models, which are represented as a multi-model average in its reports. The NCA takes a similar approach in using a multi-model average. For this assessment, we instead selected two models that simulated climate in the eastern United States with low error and that bracketed a range of temperature and precipitation futures (Hayhoe 2010a). This approach gives readers a better understanding of the level of agreement among models and provides a range of alternative scenarios that can be used by managers in planning and decisionmaking. Working with a range of plausible futures helps managers avoid placing false confidence in a single scenario given uncertainty in projecting future climate.

The GFDL model developed by NOAA is considered moderately sensitive to changes in greenhouse gas concentrations (Delworth et al. 2006). In other words, any change in greenhouse gas concentration would lead to a change in temperature that is higher in some models and lower than others. The A1FI scenario is the highest greenhouse gas emissions scenario used in the 2007 IPCC assessment, and is most similar to current trends in global greenhouse gas emissions. Therefore the GFDL A1FI scenario represents a higher-end projection for future temperature increases.

The PCM, in contrast, is considered to have low sensitivity to greenhouse gas concentrations. The B1 scenario is the lowest greenhouse gas emissions scenario used in the 2007 IPCC assessment, and is much lower than the most likely trajectory for greenhouse gas emissions for the coming decades. Therefore, the PCM B1 combination represents a lower-end projection of future climate change.

Together, the GFDL A1FI and PCM B1 scenarios span a large range of possible future climate scenarios. Although both projections are possible, the GFDL A1FI scenario represents a more realistic

A woods road in the Scioto Trail State Park, Ohio. Photo by the Ohio Department of Natural Resources, used with permission.

projection of future greenhouse gas emissions and temperature increases (Raupach et al. 2007). No likelihood has been attached to any of the emissions scenarios, however, and it is possible that actual emissions and temperature increases could be lower or higher than these projections (IPCC 2007).

This assessment uses a statistically downscaled climate data set (Hayhoe 2010a). Daily mean, minimum, and maximum temperature and total daily precipitation were downscaled to an approximately 7.5-mile resolution grid across the United States. This data set uses a modified statistical ARRM to downscale daily GCM output and historical climate data (Stoner et al. 2013).

Asynchronous quantile regression used historical gridded meteorological data from 1960 through 1999 at 1/8-degree resolution (6.2 to 9.3 miles, depending on the latitude) (Maurer et al. 2002). In addition to the gridded data set, weather station data from the Global Historical Climatology Network were used to train the downscaling model. Weather stations were required to have at least two decades of continuous daily observations in order to robustly sample from the range of natural climate variability and to avoid overfitting model results (Hayhoe 2010b).

This data set was chosen for several reasons. First, it covered the entire United States, and thus allowed a consistent data set to be used in this and other regional vulnerability assessments being conducted simultaneously. Second, it included downscaled projections for the A1FI emissions scenario, which is the scenario that most closely matches current trends in global greenhouse gas emissions (Raupach et al. 2007). Third, the availability of data at daily time steps was advantageous because it was needed for some impact models used in this report. Fourth, the quantile regression method is more accurate at reproducing extreme values at daily time steps than simpler statistical downscaling methods (Hayhoe 2010b). Finally, the 7.5-mile grid scale resolution was fine enough to be useful for informing land management decisions. A disadvantage is that some cells within the assessment area represent highly complex landforms with steep elevation gradients from valleys to ridges, but cannot account for the local microclimates or changes in microclimates on a smaller scale.

Summarized projected climate data are shown in Chapter 4. To show projected changes in temperature and precipitation, we calculated the average daily mean, minimum, and maximum temperatures for each month for three 30-year time periods (2010 through 2039, 2040 through 2069, 2070 through 2099). The monthly averages were used to calculate seasonal and annual values. Mean sums of average daily precipitation were also calculated for each season and annually for the same time periods. We then subtracted these values from the corresponding baseline climate average (1971 through 2000) to determine the departure from current climate conditions. Historical climate data used for the departure analysis was taken from ClimateWizard (Girvetz et al. 2009). Chapter 3 includes more information about the observed climate data from ClimateWizard.

The downscaled future climate projections were also used in each of the forest impact models described below. This consistency in future climate data allows for more effective comparison across different model results. These models generally require monthly precipitation and temperature values as inputs. They also operate on grid scales that may be larger or smaller than the grid scale of the downscaled data set, and grid scales were adjusted accordingly.

## IMPACT MODELS

Downscaled climate projections from GCMs provide important information about future climate, but they tell us nothing about how climate change might affect soil moisture, hydrology, forest composition, productivity, or interactions between these factors. Other models, commonly called impact models, are needed to project impacts on physical and biological processes (Fig. 13). Impact models use downscaled GCM projections as inputs, as well as information about tree species, life history traits of individual

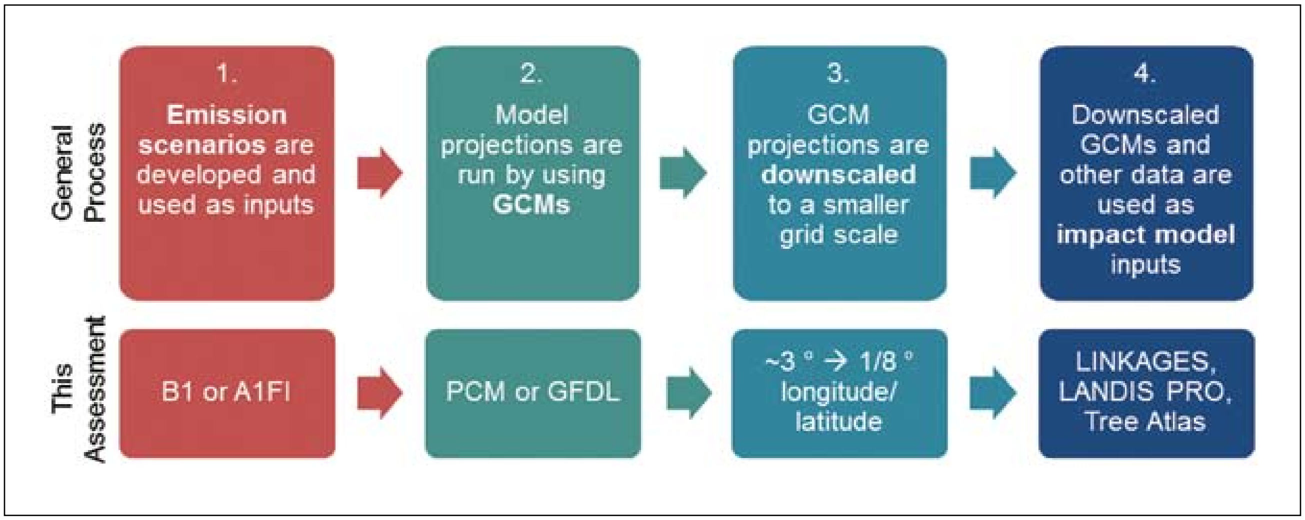

Figure 13.—Steps in the development of climate impact models using projections from general circulation models (GCMs) and specific steps taken in this assessment.

species, and soil types. Several different models are used to simulate impacts on species and forest ecosystems. These models generally fall in one of two main categories: species distribution models (SDMs) and process models. In this assessment, we used one species distribution model, the Climate Change Tree Atlas (Landscape Change Research Group 2014), and two process models, LINKAGES (version 2.2; Wullschleger et al. 2003) and LANDIS PRO (Wang et al. 2013). These models operate at different spatial scales and provide different kinds of information. We chose them because they have been used to assess climate change impacts on ecosystems in our geographic area of interest, and have stood up to rigorous peer review in scientific literature.

## MODELS FOR ASSESSING FOREST CHANGE

Species distribution models establish a statistical relationship between the current distribution of a tree species and key attributes of its habitat. This relationship is used to predict how the range of the species will shift as climate change affects those attributes. Species distribution models, such as the Tree Atlas, are much less computationally expensive than process models, so they can typically provide projections for the suitable habitat of many species over a larger area. There are some caveats that users should be aware of when using them, however (Wiens et al. 2009). These models use a species' realized niche instead of its fundamental niche. The realized niche is the actual habitat a species occupies given predation, disease, and competition with other species. A species' fundamental niche, in contrast, is the habitat it could potentially occupy in the absence of competitors, diseases, or herbivores. Given that a species' fundamental niche may be greater than its realized niche, SDMs may underestimate current niche size and future suitable habitat. In addition, species distributions in the future might be constrained by competition, disease, and predation in ways that do not currently occur. If so, SDMs could overestimate the amount of suitable habitat in the future. Furthermore, fragmentation or other physical barriers to migration may create obstacles for species otherwise poised to occupy new habitat. Therefore, a given species might not actually be able to enter the assessment area in the future, even if an SDM like the Tree Atlas projects it will gain suitable habitat. Additionally, the Tree Atlas does not suggest that existing trees will die if suitable habitat moves out of an area. Rather, this is an indication that they will be living farther outside their ideal range and will be exposed to more climate-related stress.

In contrast to SDMs, process models, such as LANDIS PRO and LINKAGES, simulate ecosystem and tree species dynamics based on mathematical representations of physical and biological processes. Process models can simulate future change in tree species dispersal, succession, biomass, and nutrient dynamics over space and time. Because these models simulate spatial and temporal dynamics of a variety of complex processes and operate at a finer pixel size, they typically require more computational power than SDMs. Therefore, fewer species can be modeled compared to SDMs. Process models also have several assumptions and uncertainties that should be taken into consideration when applying results to management decisions. Process models rely on empirical and theoretical relationships that are specified by the modeler. Any uncertainties in these relationships can be compounded over time and space, leading to potential biases.

Although useful for projecting future changes, both process models and SDMs share some important limitations. They assume that species will not adapt evolutionarily to changes in climate. This assumption may be true for species with long generation times (such as trees), but some short-lived species may be able to adapt even while climate is rapidly changing. Both types of models may also magnify the uncertainty inherent in their input data. Data on the current distribution of trees, site characteristics, and downscaled GCM projections are estimates that add to uncertainty. No single model can include all possible variables, and there are "unknown unknowns"; thus there are important inputs that will be excluded from individual models. In this assessment, competition from understory vegetation, herbivory, and pest outbreaks are a few of the processes excluded from the impact models. Given these limitations, it is important for all model results to pass through a filter of local expertise to ensure that results match with reality on the ground. Chapter 6 and Appendix 5 explain the expert elicitation process for determining the vulnerability of forest ecosystems based on local expertise and model synthesis.

Steep slopes, prone to soil erosion and slippage. Photo by Patricia Butler, Northern Institute of Applied Climate Science (NIACS) and Michigan Tech, used with permission.

## Climate Change Tree Atlas

The Climate Change Tree Atlas incorporates a diverse set of information about potential shifts in the distribution of tree species habitat in the eastern United States over the next century (Landscape Change Research Group 2014). The species distribution model DISTRIB measures relative abundance, referred to as importance value, for 134 eastern tree species. The model then projects future importance values and suitable habitat for individual tree species by using downscaled GCM data readjusted to a 12.4-mile grid of the eastern United States (east of the 100th meridian) (Landscape Change Research Group 2014).

The DISTRIB model uses inputs of tree abundance, climate, and the environment to simulate species habitat. Tree abundance is estimated from the U.S. Forest Service's Forest Inventory and Analysis (FIA) data plots (Miles et al. 2006). Current and future climates are simulated from the most recent downscaled climate data created by Hayhoe and colleagues (Hayhoe 2010a) for two GCMs (GFDL and PCM) and two emissions scenarios (A1FI and B1) (see Chapter 4 for maps of downscaled climate data for the assessment area). Inputs characterizing land use, fragmentation, climate, elevation, soil class, and soil properties were obtained from various agencies and data clearinghouses to provide the 38 predictor variables (Table 11) (Iverson et al. 2008b, Riitters et al. 2002). The reliability of individual habitat models is evaluated through the calculation of a model reliability score, which is based on statistically quantified measures of fitness (methods are fully described in Matthews et al. [2011a]).

Each tree species is further evaluated for additional factors not accounted for in the statistical models (Matthews et al. 2011b). These modifying factors (Appendix 4) are supplementary information on life history characteristics such as dispersal ability or

**Table 11.—Parameters used to predict current and future tree species habitat (Iverson et al. 2008b)**

**Land use and fragmentation (%)**

- Cropland
- Nonforest land
- Forest land
- Water
- Fragmentation index (Riitters et al. 2002)

**Climate (°C, mm)**

- Mean annual temperature
- Mean January temperature
- Mean July temperature
- Mean May through September temperature
- Annual precipitation
- Mean May through September precipitation
- Mean difference between July and January temperature

**Elevation (m)**

- Elevation coefficient of variation
- Minimum elevation
- Maximum elevation
- Average elevation
- Range of elevation

**Soil class (%)**

- Alfisol
- Aridisol
- Entisol
- Histosol
- Inceptisol
- Mollisol
- Spodosol
- Ultisol
- Vertisol

**Soil property**

- Soil bulk density (g/cm$^3$)
- Potential soil productivity (m$^3$/ha timber)
- Percent clay (<0.002 mm size)
- Soil erodibility factor
- Soil permeability rate (cm/h)
- Percent soil passing sieve no. 10 (coarse)
- Soil pH
- Depth to bedrock (cm)
- Percent soil passing sieve no. 200 (fine)
- Soil slope (%) of a soil component
- Organic matter content (% by weight)
- Total available water capacity (cm)

fire tolerance as well as information on sensitivity to disturbances such as pests and diseases that have had negative effects on the species. This supplementary information allows us to identify when an individual species may do better or worse than model projections suggest.

There are important strengths and limitations of the Tree Atlas that should be considered when interpreting results. Importantly, DISTRIB projects where the habitat suitability may potentially change for a particular species, but does not project where the species may actually occur by a certain time. The actual rate of migration into the new suitable habitat will be influenced by large time lags, dispersal and establishment limitations, and availability of refugia.

The FIA data plots are nonbiased and extensive across the assessment area, but are spatially sparse at a 12.4-mile resolution. Species that are currently rare on the landscape are often undersampled in the FIA data, and consequently have lower model reliability. Likewise, species that are currently abundant on the landscape usually have higher model reliability. The methods assume the species are in equilibrium with the environment, and do not account for species that rapidly change distributions (e.g., invasive species). The models do not account for biological or disturbance factors (e.g., competition or fire) that affect species' abundance. Thus, the modifying factors are provided as a supplement to the model output to help address these deficiencies.

For this assessment, DISTRIB uses the GFDL A1FI and PCM B1 climate scenarios. The results provided in Chapter 5 are now available from the online Climate Change Tree Atlas (www.nrs.fs.fed.us/atlas) under "Regional Assessments."

## LINKAGES

The LINKAGES model (version 2.2; Wullschleger et al. 2003) is a forest succession and ecosystem dynamics process model modified from an earlier version of LINKAGES (Pastor and Post 1985). The LINKAGES model integrates establishment and growth of individual tree species over 30 years on a plot from bare ground, incorporating ecosystem functions such as soil-water balance, litter decomposition, nitrogen cycling, soil hydrology, and evapotranspiration. Inputs to the model include climate variables (e.g., daily temperature, precipitation, wind speed, and solar radiation), soil characteristics (e.g., soil moisture capacity and percent rock, sand, and clay for multiple soil layers), and biological traits for each tree species (e.g., growth rate and tolerance to cold and shade). A full list of model inputs is presented in Table 12. Outputs to the model include tree species composition, number of stems, biomass, leaf litter, available nitrogen, humus, and organic matter, as well as hydrologic dynamics such as runoff. Unlike the LANDIS PRO model (below), LINKAGES is not spatially dynamic, and does not simulate tree dispersal or any other spatial interaction among grid cells. Simulations are done at yearly time steps on multiple 0.2-acre circular plots, which correspond to the average gap size when a tree dies and falls over. Typically, the model is run for a specified number of plots in an area of interest, and results are averaged to determine relative species biomass and composition across the landscape over time.

For this assessment, LINKAGES simulates changes in tree species establishment probability over the next century for 23 common tree species within the

**Table 12.—Parameters used in the LINKAGES model**

**Location**
- Latitude, longitude

**Climate (daily)**
- Total daily precipitation
- Daily minimum temperature
- Daily maximum temperature
- Daily total solar radiation
- Mean monthly wind speed

**Soil**
- Field capacity for 12 soil layers
- Wilting point for 12 soil layers
- Hydrological coefficients for 12 soil layers (based on percent sand and clay)
- Organic matter (Mg/ha)
- Nitrogen (Mg/ha)
- Percent rock for 12 soil layers

**Tree species**[a]
- Total annual degree day maximum and minimum (Moscow Forestry Sciences Laboratory 2014)
- Height and diameter growth equation coefficients (Miles et al. 2006)
- Typical maximum mortality age (Loehle 1988)
- Frost tolerance (Moscow Forestry Sciences Laboratory 2014)
- Shade tolerance
- Drought tolerance
- Nitrogen equation coefficients (Natural Resources Conservation Service 2014b, Post and Pastor 1996)
- Sprout stump number and minimum and maximum diameter
- Mineral or organic seed bed
- Maximum seeding rate
- Crown area coefficients
- Root:shoot ratio by species
- Leaf litter quality class
- Foliage retention time
- Leaf weight per unit crown area

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[a] From Post and Pastor (1996) unless noted otherwise.

Central Appalachians region. The model projects changes in forest composition by using downscaled daily mean temperature and precipitation under GFDL A1FI and PCM B1, and compares these projections with those under a current climate scenario (i.e., the climate during 1990 through 2009) at a future time period. One hundred and fifty-six 0.2-acre virtual plots were parameterized in LINKAGES; this number represents 1 plot for each of 6 landforms in 26 ecological subsections.

There are important strengths and limitations of LINKAGES that should be considered when interpreting results. Section-level estimates were derived from the weighted average of landforms in a subsection and the weighted average of subsections in a section. Most of the 156 plots were located at the geographic center of a subsection, which provided climate variables that represented average conditions for that subsection. However, plot locations were modified for subsections with large elevation gradients, such as the Northern High Allegheny Mountain subsection within the Allegheny Mountains section (elevation 1,676 to 4,766 feet). For these subsections, the geographic center was often located at either the highest elevation or the lowest elevation, which skewed the temperature values to appear colder (at high elevation) or warmer (at low elevation) than the average of the subsection. Therefore, plots were located at a representative point at a mid-elevation. This approach better reflects the average climate conditions for a subsection, but nevertheless fails to fully address the elevation gradient and associated climate conditions for tree species within mountainous sections. Therefore some species that occur only at the upper or lower end of an elevation gradient may appear to have lower growth potential than expected, because the results represent the average of the entire subsection.

## LANDIS PRO

The LANDIS PRO model (Wang et al. 2014) is a spatially dynamic process model that simulates species-, stand-, and landscape-level processes. It is derived from the LANDIS model (Mladenoff 2004), but has been modified extensively from its original version. The LANDIS PRO model can simulate very large landscapes (millions of acres) at relatively fine spatial and temporal resolutions (typically 200 to 300 feet and 1- to 10-year time steps). One new feature of the model compared to previous versions is that inputs and outputs of tree species data include tree density and volume and are compatible with FIA data. Thus, the model can be directly initialized, calibrated, and validated with FIA data. This compatibility ensures the starting simulation conditions reflect what is best known on the ground and allows the modelers to quantify the uncertainties embedded in the initial data.

Species-level processes include seedling germination and establishment, growth, vegetative reproduction, and tree mortality. Species-level processes are simulated from known life history characteristics and empirical equations. Stand-level processes include competition and succession. Landscape-level processes include fire, wind, insect outbreaks, disease, invasive species, harvesting, silviculture, and fuels treatments. The LANDIS PRO model stratifies the landscape into land types based on topography, climate, soil, and other environmental characteristics. Within a land type, species establishment and resource availability are assumed to be similar. Combined with anthropogenic and natural disturbances, these land type-specific processes are capable of simulating landscape heterogeneity, time, and space.

Basic inputs to the LANDIS PRO model include maps of species composition, land types, stands, management areas, and disturbance areas. In addition, species characteristics such as longevity, maturity, shade tolerance, average seed production, and maximum diameter at breast height are given as inputs into the model. A software program, Landscape Builder, is used to generate the species composition map (Dijak 2013). Landscape Builder uses the FIA unit map, national forest type map, national size class map, the National Land Cover Dataset (U.S. Geological Survey 2011), and landform maps to assign the number of trees by age cohort and species to each grid cell. Landform maps specify the slope, aspect, and landscape position to replicate the complex topography of the assessment area (Fig. 14). Initialized landscapes are compared to FIA data at both the landscape and land type scale. Species models are calibrated by adjusting the model input parameters until simulation results match FIA data. In this assessment, the initial landscape was simulated from 1978 through 2003 data, and the number of trees and basal area by species was compared to 2003 FIA data. Results of the model predictions are validated by comparing simulations from 1978 through 2008 to the FIA data of 2008. The Landscape Builder model was also validated to verify that the theories and assumptions in LANDIS PRO are valid. The calibrated and validated model was further validated by comparing long-term simulations (150 years) to Gingrich stocking charts and Reineke density diagrams to verify that stand development processes and relationships were adequately simulated (Wang et al. 2013).

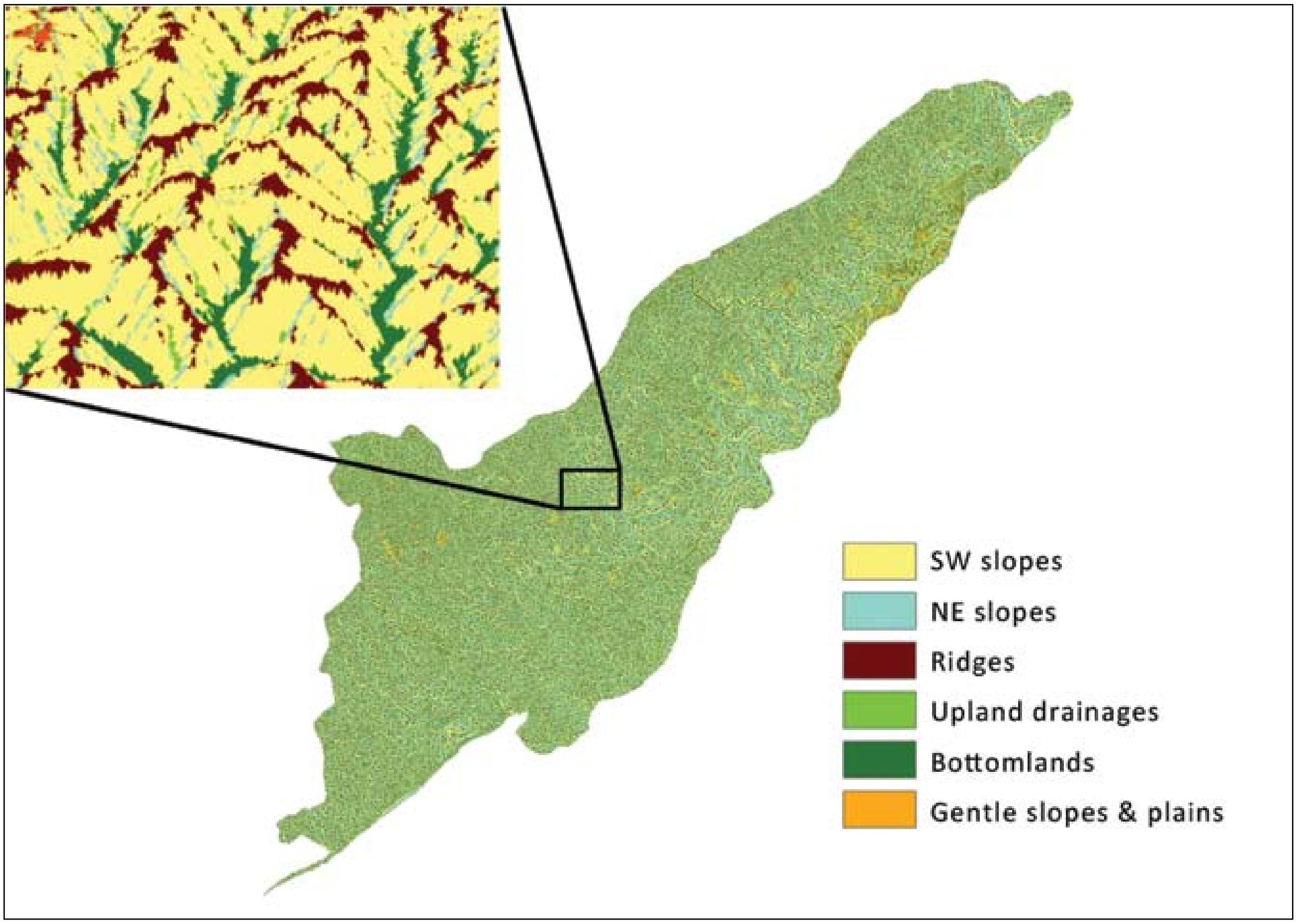


Figure 14.—Example landform map (e.g., subsection 890) used in landscape initialization in the LANDIS PRO model (Dijak 2013).

Basic outputs in LANDIS PRO for a species or species cohort include biomass, age, and carbon. Disturbance and harvest history can also be simulated across space and time. The spatially dynamic nature of the model and its fine spatial resolution are unique advantages of LANDIS PRO compared to LINKAGES (described above) and statistically based models such as DISTRIB. Disadvantages of LANDIS PRO are that it is too computationally intensive to be run for a large number of species (in contrast to DISTRIB) and does not account for ecosystem processes such as nitrogen cycling or decomposition (in contrast to LINKAGES).

For this assessment, LANDIS PRO simulates changes in basal area and trees per acre on 866-foot grid cells over the next century for 16 dominant tree species across the Central Appalachians region. The model projects changes in forest composition by using downscaled daily mean temperature and precipitation from the GFDL A1FI and PCM B1 climate scenarios, and compares these projections with those under a current climate scenario.

There are important strengths and limitations of LANDIS PRO that should be considered when interpreting results. This model assumes that historical successional dynamics are held constant into the future. It is also assumed that the resource availability by land type was able to capture the effects of landscape heterogeneity at the 866-foot resolution. Species that are currently rare on the landscape are often undersampled in the FIA data, and consequently have lower model reliability. Species that are currently abundant on the landscape have higher model reliability.

## CHAPTER SUMMARY

Temperatures have been increasing in recent decades at global and national scales, and the overwhelming majority of climate scientists attribute this change to increases in greenhouse gases from human activities. Even if dramatic changes are made to help curtail greenhouse gas emissions, these greenhouse gases will persist in our atmosphere for decades to come. Scientists can model how these increases in greenhouse gases may affect global temperature and precipitation patterns by using GCMs. These large-scale climate models can be downscaled and incorporated into other types of models that project changes in forest composition and ecosystem processes. Although there are inherent uncertainties in what the future holds, all of these types of models can help us frame a range of possible futures. This information can then be used in combination with the local expertise of researchers and managers to provide important insights about the potential effects of climate change on forest ecosystems.

# CHAPTER 3: OBSERVED CLIMATE CHANGE

As discussed in Chapter 1, climate is one of the principal factors that has determined the composition and extent of forest ecosystems in the Central Appalachians over the past several thousand years. This chapter describes the climate trends in the assessment area that have been observed over the past century, including documented patterns of climate-related processes and extreme weather events. It also presents evidence that ecosystems in the Central Appalachians are already exhibiting signals that they are responding to shifts in temperature and precipitation.

## CURRENT CLIMATE

The existing climates within the Central Appalachians are strongly influenced by atmospheric weather, latitude, topography, and changes in elevation (Chapter 1). Lake-effect precipitation is a factor in the north and west, whereas dramatic changes in elevation are responsible for orographic effects on rain and snow in the mountainous regions. This heterogeneity of climates across the region can be seen at finer scales, but is often lost in broad-scale averages.

Temperature and precipitation at weather stations in the Central Appalachians region have been recorded for more than 100 years. The average temperature and precipitation across the assessment area was examined by using the ClimateWizard Custom Analysis tool (ClimateWizard 2013, Girvetz et al. 2009). Data for the tool are derived from PRISM (Parameter-elevation Regressions on Independent Slopes Model) (Gibson et al. 2002), which models historical measured point data onto a continuous 2.5-mile grid over the entire United States. Temperature and precipitation data were used to derive annual, seasonal, and monthly values for the 30-year average (also referred to as the "climate normal") for 1971 through 2000 (Table 13, Figs. 15 and 16) and for each section (Appendix 2).

**Table 13.—Annual and seasonal mean, minimum, and maximum temperature and total precipitation for 1971 through 2000 (ClimateWizard 2013)**

| Season | Mean temperature (°F) | Minimum temperature (°F) | Maximum temperature (°F) | Mean precipitation (inches) |
|---|---|---|---|---|
| Annual | 51.1 | 40.0 | 62.3 | 43.1 |
| Winter (Dec-Feb) | 31.2 | 21.7 | 40.7 | 9.2 |
| Spring (Mar-May) | 50.2 | 38.0 | 62.4 | 11.5 |
| Summer (Jun-Aug) | 70.1 | 58.5 | 81.6 | 12.7 |
| Fall (Sep-Nov) | 53.0 | 41.6 | 64.4 | 9.7 |

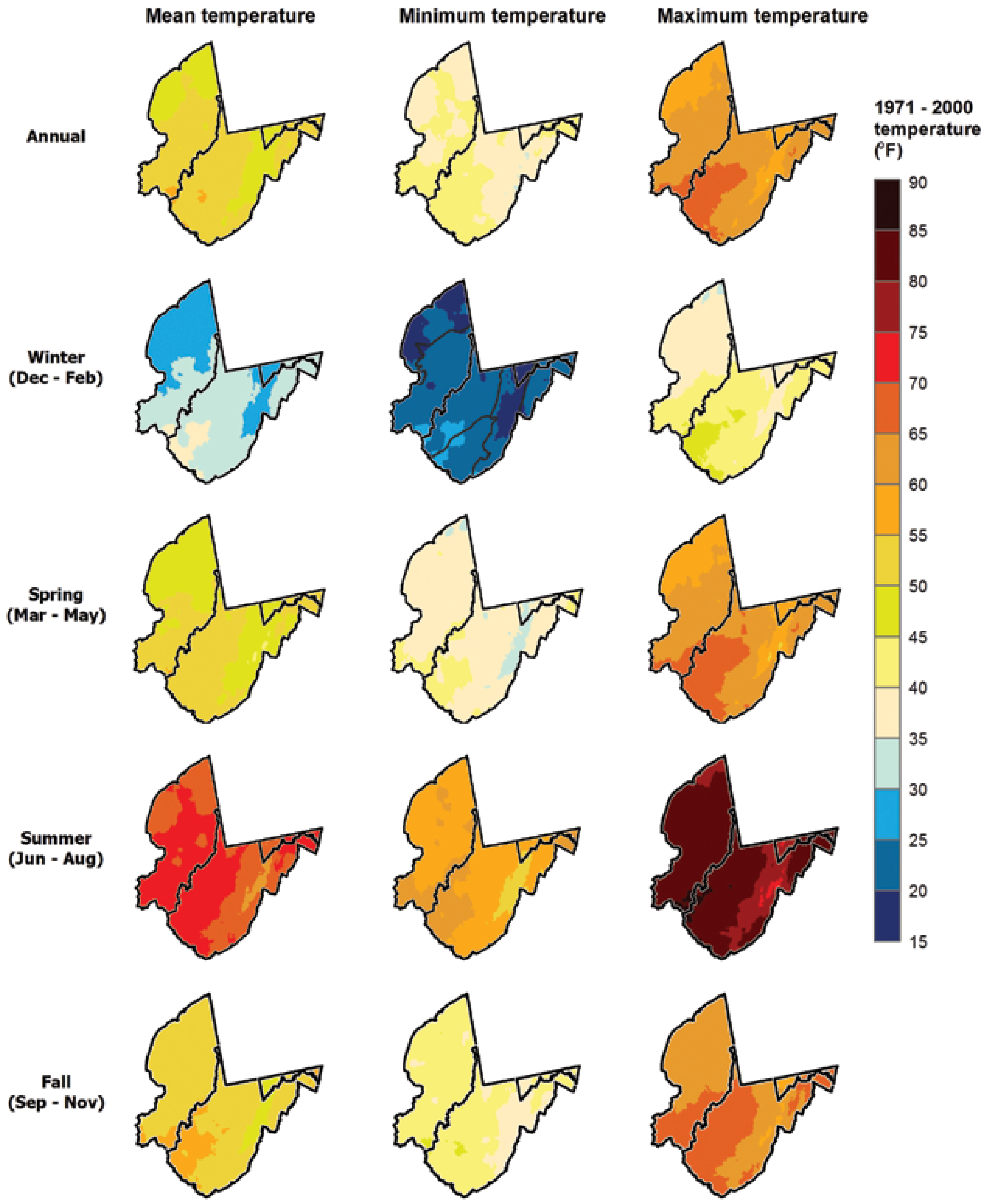


Figure 15.—Thirty-year annual and seasonal averages of mean, minimum, and maximum temperatures across the assessment area from 1971 through 2000. Data source: ClimateWizard (2013).

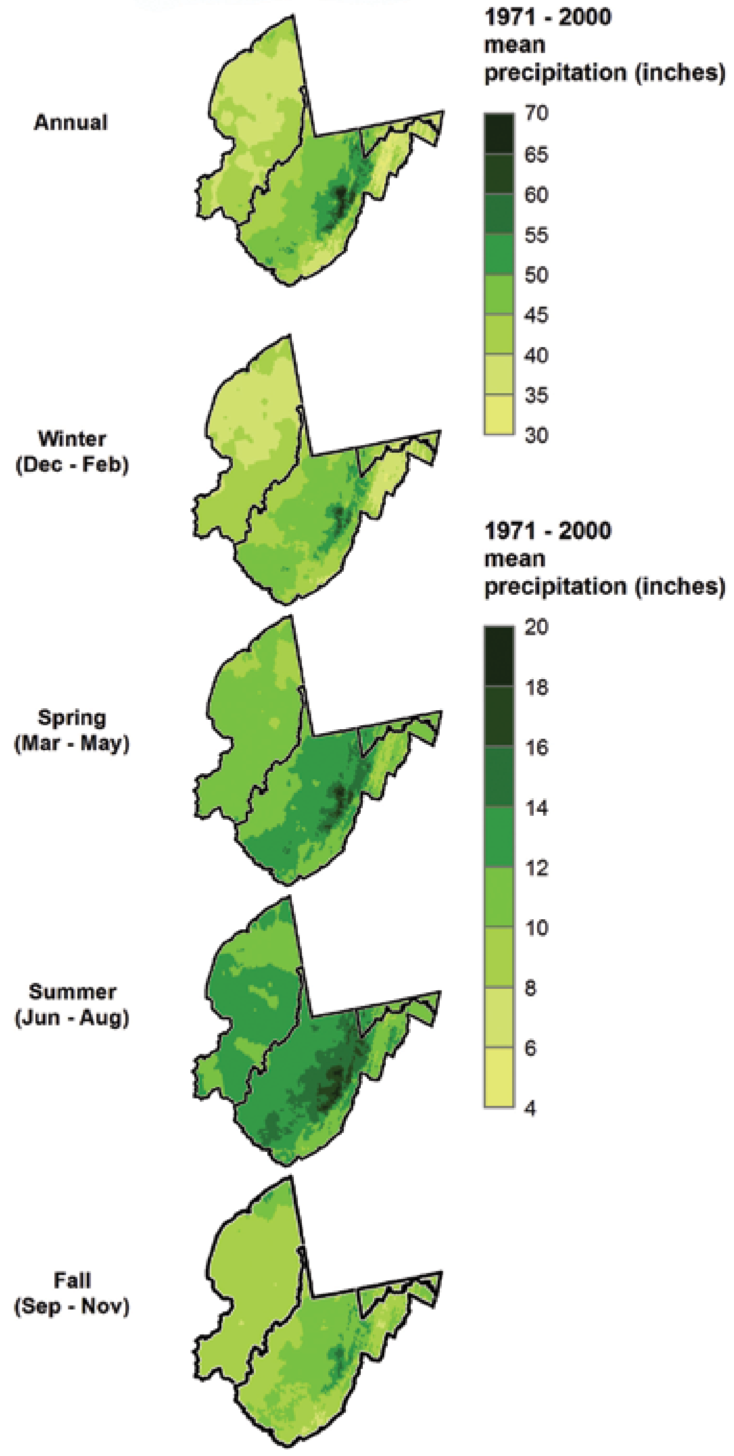


Figure 16.—Thirty-year averages of mean annual and seasonal precipitation across the assessment area from 1971 through 2000. Data source: ClimateWizard (2013).

## HISTORICAL TRENDS IN TEMPERATURE AND PRECIPITATION

The Central Appalachians region has experienced changes in temperature and precipitation over the past 111 years, and the rate of change appears to be increasing. Long-term trends from 1901 through 2011 were examined by using the ClimateWizard Custom Analysis tool to gain a better understanding of how climate has been changing (Appendix 2). Trends in annual, seasonal, and monthly temperature (mean, minimum, and maximum) and total precipitation were examined both for the entire assessment area, and separately for each ecological section within the assessment area (Tables 14 and 15). Long-term trends show that some aspects of the climate have been changing. Accompanying tables and figures present the change over the 111-year period estimated from the slope of the linear trend. In the following text we highlight increasing or decreasing trends for which we have moderate to high confidence that they did not occur by chance. For more information regarding confidence in trends and the PRISM data, refer to Appendix 2. Observed changes in other ecological indicators are often described on a statewide basis because finer resolution data were not available, unless otherwise indicated.

### Temperature

Between 1901 and 2011, annual mean temperatures fluctuated from year to year by several degrees. The coolest year on record was 1917, and the warmest year on record was 1921 (Fig 17). Many of the highest temperatures on record were between 1921 and the mid-1950s, and there was a cool period in the 1960s and 1970s. Temperatures appear to be increasing in the past few decades, but they are not as high as were experienced in the mid-20th century.

Although annual mean temperatures increased both globally and across the United States over the same time period, the increase in the assessment area was very small (0.5 °F) (Fig. 17). Seasonal mean temperatures did not change overall (Table 14), but there were several trends when monthly mean temperatures were examined (Fig. 18). April mean temperatures increased by 2.4 °F. August mean temperatures increased by 1.2 °F, and November mean temperatures increased by 2.3 °F. Although the direction of change appears negative for the maximum temperatures in all seasons except spring, trends in maximum temperatures were small enough that they may have occurred by chance. Maximum temperatures increased the most in April (3.2 °F), and decreased the most in September (-2.1 °F), October (-2 °F), and July (-1.2 °F). Annual minimum temperature increased by 1.1 °F. Minimum temperatures also increased in summer (1.6 °F) and fall (1.4 °F) (Fig. 18). Minimum temperatures increased the most in April (1.6 °F), June (1.4 °F), July (1.3 °F), August (2.1 °F), and November (2.8 °F). April and November are notable because both minimum and maximum temperatures increased in those months.

**Table 14.—Change in annual and seasonal mean temperatures and precipitation from 1901 to 2011 in the assessment area**

| Season | Mean temperature (°F) | Minimum temperature (°F)[a] | Maximum temperature (°F) | Precipitation (inches) |
|---|---|---|---|---|
| Annual | 0.5 | **1.1** | -0.1 | 1.7 |
| Winter (Dec-Feb) | 0.3 | 0.8 | -0.1 | -1.0 |
| Spring (Mar-May) | 0.8 | 0.6 | 0.9 | 0.7 |
| Summer (Jun-Aug) | 0.6 | **1.6** | -0.4 | -0.3 |
| Fall (Sep-Nov) | 0.3 | **1.4** | -0.7 | **2.3** |

[a] Values in boldface indicate less than 10-percent probability that the trend could have occurred by chance alone.

**Table 15.—Change in annual and seasonal mean temperatures and precipitation from 1901 to 2011 by ecological section within the assessment area (ClimateWizard 2013)**

| Section | Season | Mean temperature (°F)[a] | Minimum temperature (°F) | Maximum temperature (°F) | Precipitation (inches) |
|---|---|---|---|---|---|
| 221E | Annual | 0.3 | 0.7 | -0.1 | 1.3 |
| | Winter | -0.1 | 0.4 | -0.5 | -1.2 |
| | Spring | 0.4 | 0.1 | 0.8 | 0.4 |
| | Summer | 0.4 | **1.2** | -0.4 | -0.1 |
| | Fall | 0.3 | 1.0 | -0.5 | **2.3** |
| 221F | Annual | 0.5 | **1.0** | 0.1 | **4.2** |
| | Winter | 0.9 | 1.3 | 0.4 | 0.1 |
| | Spring | **1.1** | **0.9** | **1.3** | 0.8 |
| | Summer | 0.2 | **1.1** | -0.7 | 1.0 |
| | Fall | -0.1 | 0.7 | -0.8 | **2.4** |
| M221A | Annual | **1.4** | **2.1** | 0.7 | 2.0 |
| | Winter | 1.7 | **2.2** | 1.1 | -0.4 |
| | Spring | **1.8** | **1.6** | **1.9** | 1.7 |
| | Summer | **1.6** | **2.6** | 0.6 | **-2.2** |
| | Fall | 0.6 | **2.1** | -0.9 | **2.8** |
| M221B | Annual | **0.8** | **1.9** | -0.3 | 0.0 |
| | Winter | 0.4 | 0.8 | 0.0 | -1.8 |
| | Spring | **1.1** | **1.6** | 0.6 | 0.9 |
| | Summer | **1.0** | **2.6** | -0.7 | -1.3 |
| | Fall | 0.6 | **2.4** | **-1.2** | **2.2** |
| M221C | Annual | 0.3 | **1.1** | -0.5 | 0.8 |
| | Winter | -0.4 | -0.1 | -0.6 | **-1.6** |
| | Spring | 0.3 | 0.4 | 0.1 | 0.7 |
| | Summer | **0.7** | **1.8** | -0.5 | -0.4 |
| | Fall | 0.6 | 2.1 | -0.9 | **2.1** |

[a] Values in boldface indicate less than 10-percent probability that the trend could have occurred by chance alone.

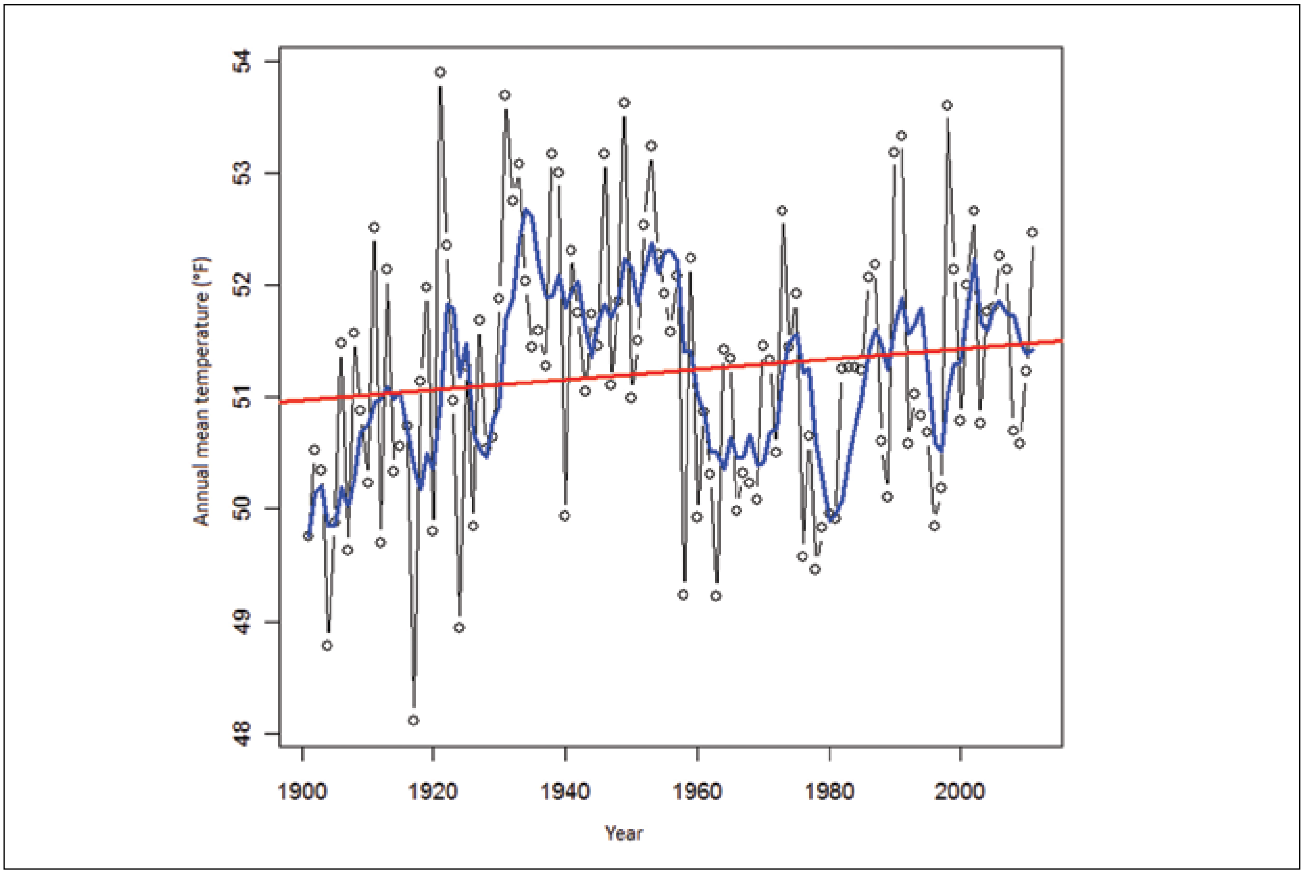


Figure 17.—Annual mean temperature across the assessment area from 1901 through 2011. The blue line represents the rolling 5-year mean. The red regression line shows the trend across the entire time period (0.005 °F per year; p = 0.28). Data source: ClimateWizard (2013).

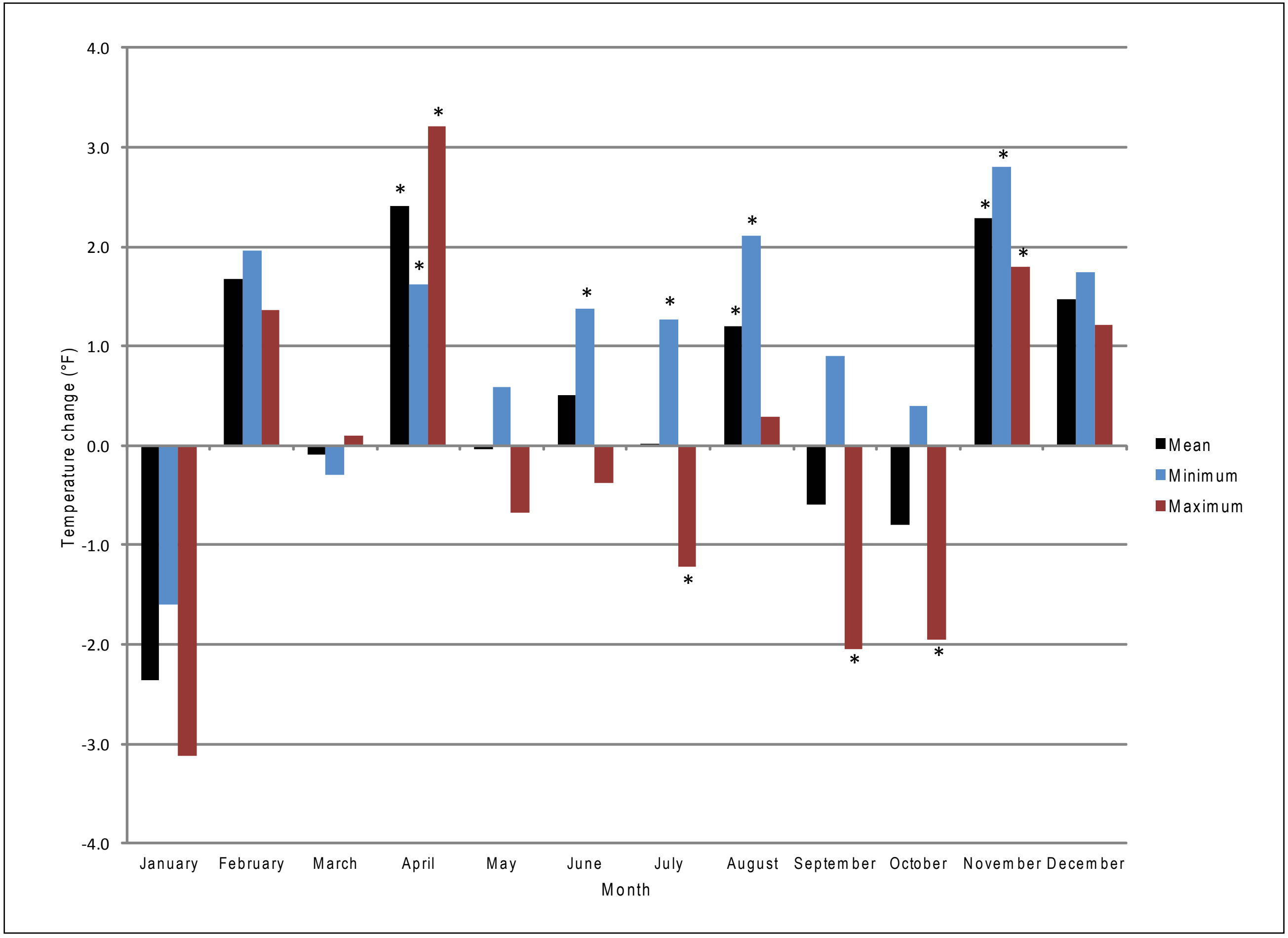


Figure 18.—Change in monthly mean, minimum, and maximum temperatures across the assessment area from 1901 through 2011. Asterisks indicate there is less than 10-percent probability that the trend could have occurred by chance alone. Data source: ClimateWizard (2013).

Temperature trends also differed geographically across the assessment area, with some areas warming or cooling more than others (Table 14). In general, the easternmost sections (M221A and M221B) have changed more than other sections (see Chapter 1 for a map showing ecological sections). Annual mean temperatures increased by 1.4 °F in M221A and by 0.8 °F in M221B. There were no trends in mean winter and fall temperatures in any section of the assessment area. Mean spring temperatures increased in 221F, M221A, and M221B. Mean summer temperatures increased in M221A, M221B, and M221C. Minimum temperatures increased the most in M221A and M221B. In M221A, minimum temperatures increased annually and in all seasons. In M221B, minimum temperatures increased annually and in all seasons except winter. In both M221A and M221B, minimum temperatures increased the least in spring (1.6 °F) and the most in summer (2.6 °F). Maximum temperatures increased in two sections, both in spring (221F and M221A). Maximum temperature cooled significantly only in fall and only in Section M221B.

Spatially interpolated trends in temperature are available through 2011 and are presented in Fig. 19. Stippling on the maps indicates trends which have moderate to high probability that they did not occur by chance. Spatial analysis showed that increases in annual temperatures ranged from 1 to 4 °F over large portions of the assessment area, whereas decreases were observed in only a few isolated locations, indicated by the stippling. The greatest increases are observed in minimum temperatures, with increases of up to 6 °F consistently appearing in Sections M221A and M221B and increases of up to 3 °F appearing in widespread areas throughout the assessment area. The greatest decreases are observed in maximum temperatures, with widespread areas cooling by as much as 5 °F. These observed decreases in summer maximums may be evidence of a regional “warming hole” (see section on “Regional Patterns Contributing to Local Trends”).

## Precipitation

From 1901 through 2011, mean annual precipitation within the assessment area fluctuated by as much as 20 inches from year to year (ClimateWizard 2013) (Fig. 20). The driest year on record for the assessment area as a whole was 1929. Precipitation was lower than the long-term average during distinct periods over the last century, including a few years during the “Dust Bowl” era of the 1930s, a dry spell from 1960 through 1969, and 1987. The four wettest years on record occurred during the past 20 years. The time series of annual precipitation for the assessment area displays high variability from year to year and the surge in precipitation at the beginning of the 21st century may be driving an upward trend, although there are not enough data years from the 21st century to determine whether the trend is real or due to chance (Box 7).

Because of the large interannual variability of precipitation averaged across the assessment area, any positive or negative trend observed in mean annual or seasonal precipitation in the assessment area was small enough that it could have occurred by chance, except for fall (Table 14). Fall precipitation increased by 2.3 inches from 1901 to 2011.

Several trends were observed in monthly mean precipitation (Fig. 22). When averaged across the entire assessment area, precipitation increased in May (0.9 inches), September (0.9 inches), and November (1.2 inches).

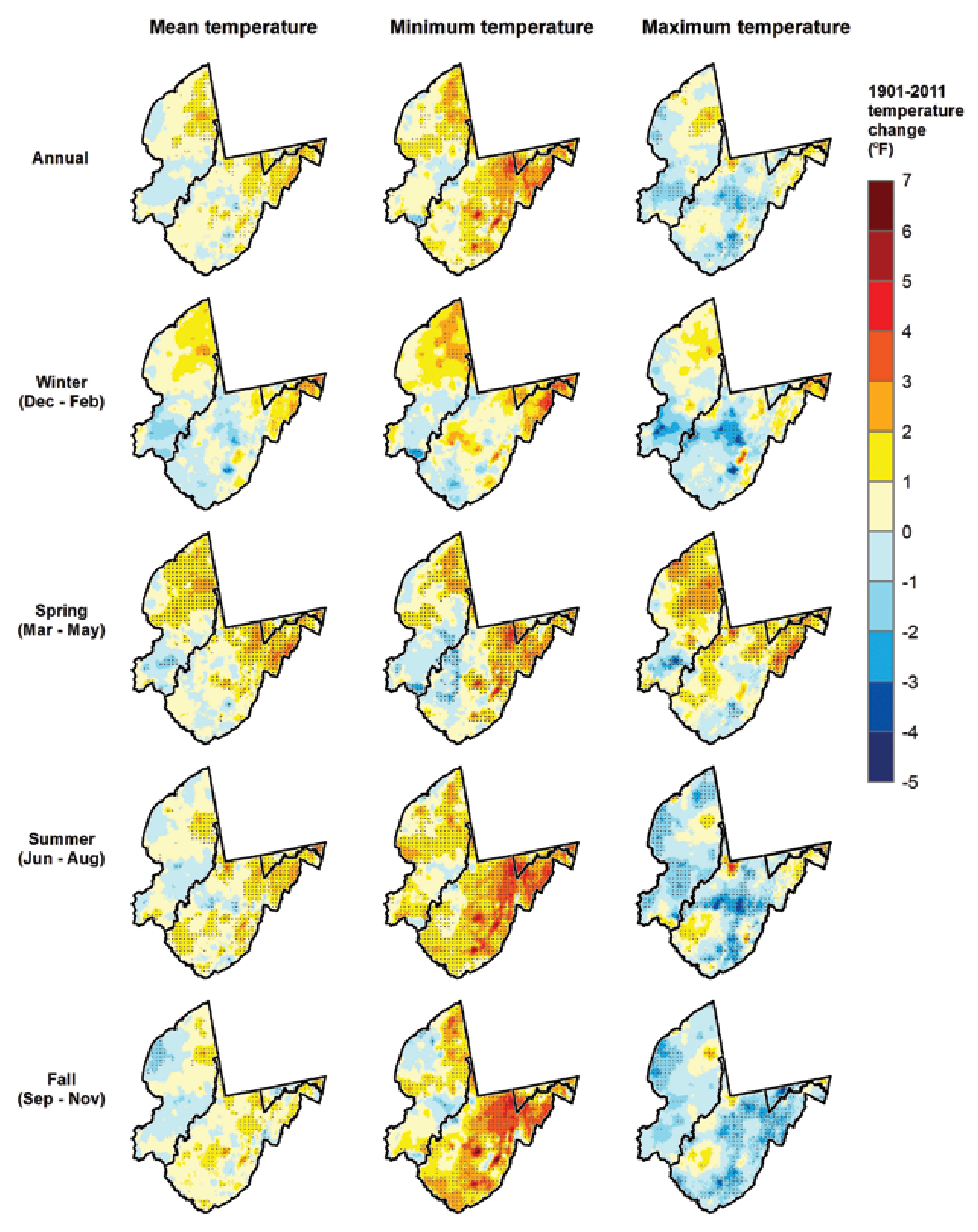


Figure 19.—Annual and seasonal change in mean, minimum, and maximum temperatures across the assessment area from 1901 through 2011. Stippling indicates there is less than 10-percent probability that the trend could have occurred by chance alone. Data source: ClimateWizard (2013).

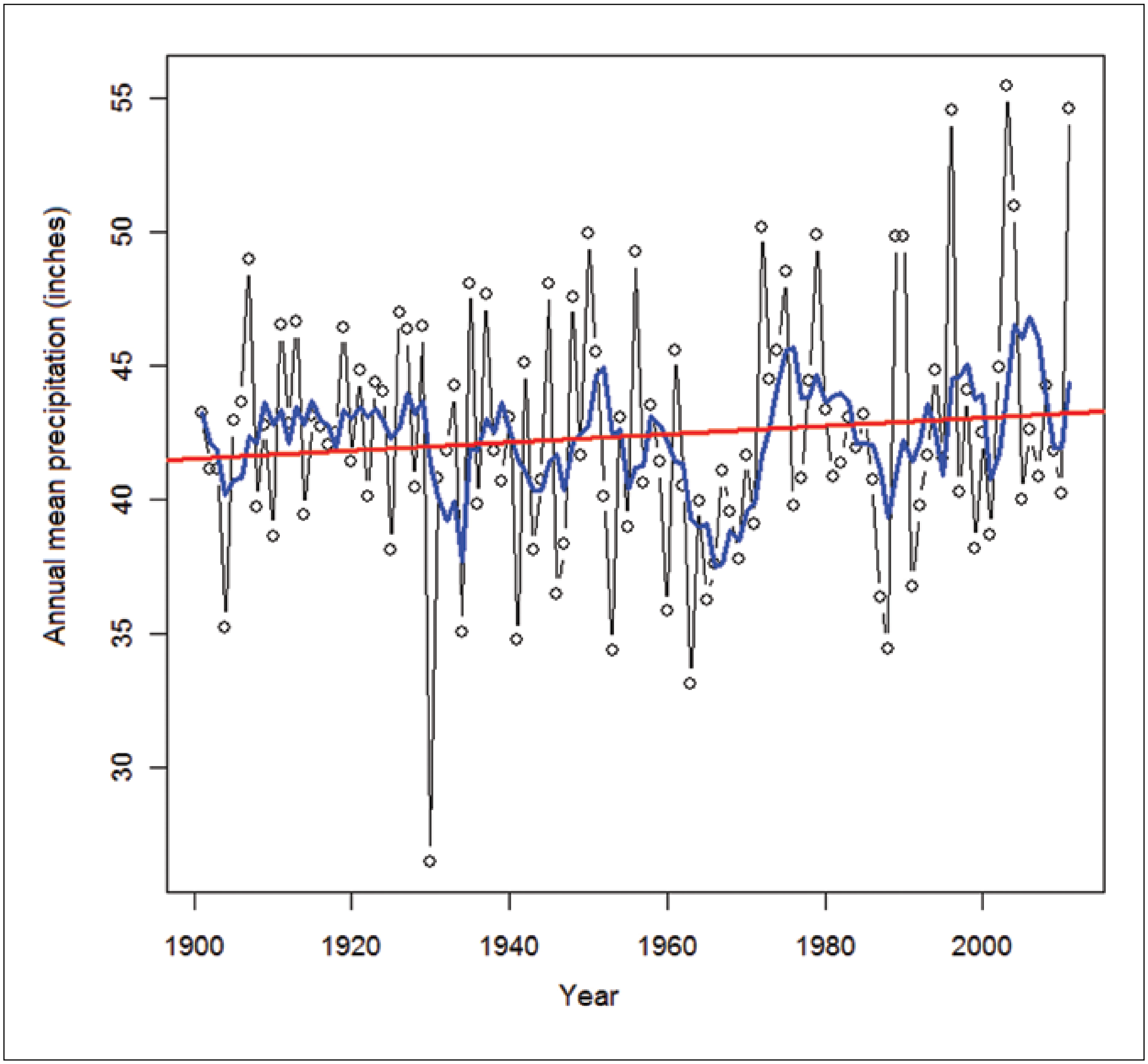


Figure 20.—Annual mean precipitation across the assessment area from 1901 through 2011 (ClimateWizard 2013). The blue line represents the rolling 5-year mean. The red regression line shows the trend across the entire period (0.015 inches per year; p = 0.26). Data source: ClimateWizard (2013).

## Box 7: Climate Changes over the 21st Century

In this chapter, we present changes in climate over the entire historical record for which spatially interpolated data trends are available for the assessment area. Looking across the entire record is helpful in detecting long-term changes, but it can also obscure short-term trends. In fact, the long-term trend is made up of shorter periods of warming and cooling, depending on the time period analyzed.

The period from 2001 to 2012 was the warmest on record for the world, North America, and the United States (Blunden and Arndt 2012, World Meteorological Organization 2011). Statewide averages for the early 21st century can be explored within the entire climate record (1895 to 2012) through the National Climatic Data Center's Climate at a Glance maps (National Oceanic and Atmospheric Administration [NOAA] 2014b). Temperatures across Ohio were above the long-term average for 7 years during this period, and below average for 4 years (NOAA 2014d). Ohio experienced its record warmest temperatures since the 1920s in 1998 and again in 2012 (NOAA 2014d) (Fig. 21). Maryland experienced its second warmest year in 2012 (its warmest year was in 1998). Since 2000, only 1 year was below the long-term average in Maryland, and the rest were above average. West Virginia experienced its record low for average annual temperature in 1917, followed by its record high in 1921. West Virginia displays an enormous amount of variation from year to year, with the third warmest temperature in 2012.

Precipitation has also changed dramatically during 2001 through 2012. Ohio experienced its wettest year since 1895 in 2011. Since 2000, 7 years have been above average or much above average, whereas only 4 years were slightly below average (NOAA 2014d). Maryland and West Virginia also follow this pattern; both experienced their wettest year in 2003, and both have had more above-average years than below average.

And what about the "warming hole" patterns of low summer temperatures and high spring and summer precipitation? Across the assessment area, summer temperatures during the 21st century were much higher than the long-term average for the area, with record warming in Maryland (NOAA 2014d). Although it is too early to determine a trend, the recent warming temperatures suggest a possible reversal of the "warming hole." Summer precipitation trends have not changed markedly in the assessment area over the 21st century, but spring precipitation has been higher than average (NOAA 2014d). Overall, the climate information from the 21st century seems to be consistent with the trends over the past century in some ways but not others. The area is getting generally wetter, and the 1930s continues to be the warmest decade on record.

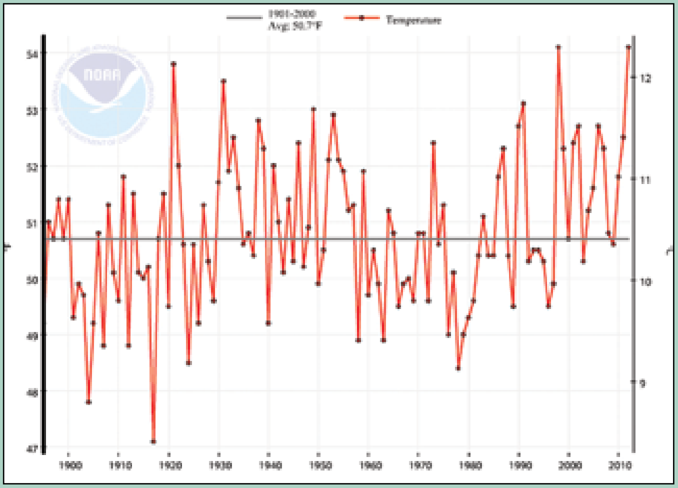


Figure 21.—Annual mean temperatures for Ohio from 1895 through 2011. Image courtesy of NOAA (2014d).

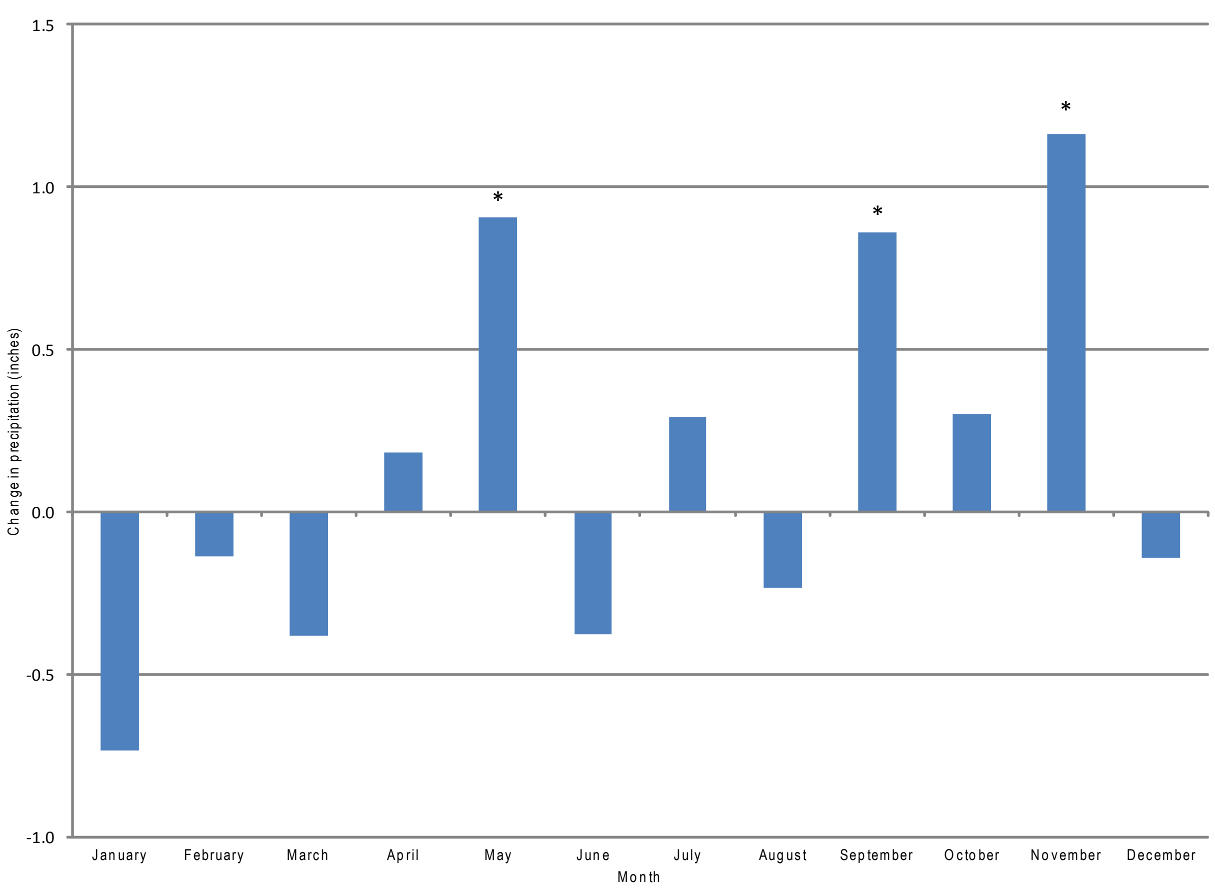


Figure 22.—Change in monthly mean precipitation within the assessment area from 1901 through 2011. Asterisks indicate there is less than 10-percent probability that the trend could have occurred by chance alone. Data source: ClimateWizard (2013).

When we examined changes at the ecological section level, trends emerged in some areas (Table 14). In general, the greatest increase in precipitation was observed in Ohio (Section 221F), where an increase of 2.4 inches was observed in fall, contributing to a total increase of 4.2 inches in annual precipitation. Precipitation increased in fall in every section, with the greatest increase in M221A (2.8 inches). In the easternmost section (M221A), summer precipitation decreased by 2.2 inches from 1901 to 2011. In southern West Virginia (M221C), winter precipitation decreased by 1.6 inches.

Spatially interpolated trends in precipitation are available through 2011 and are presented in Figure 23. Spatial analysis showed that increases in annual precipitation ranged from 1 to 4 inches over large portions of the assessment area, whereas decreases were observed in only a few isolated locations. Precipitation has increased the most during fall, and has decreased the most during winter. Precipitation has increased over large areas in spring, but has decreased during the summer in the easternmost sections.

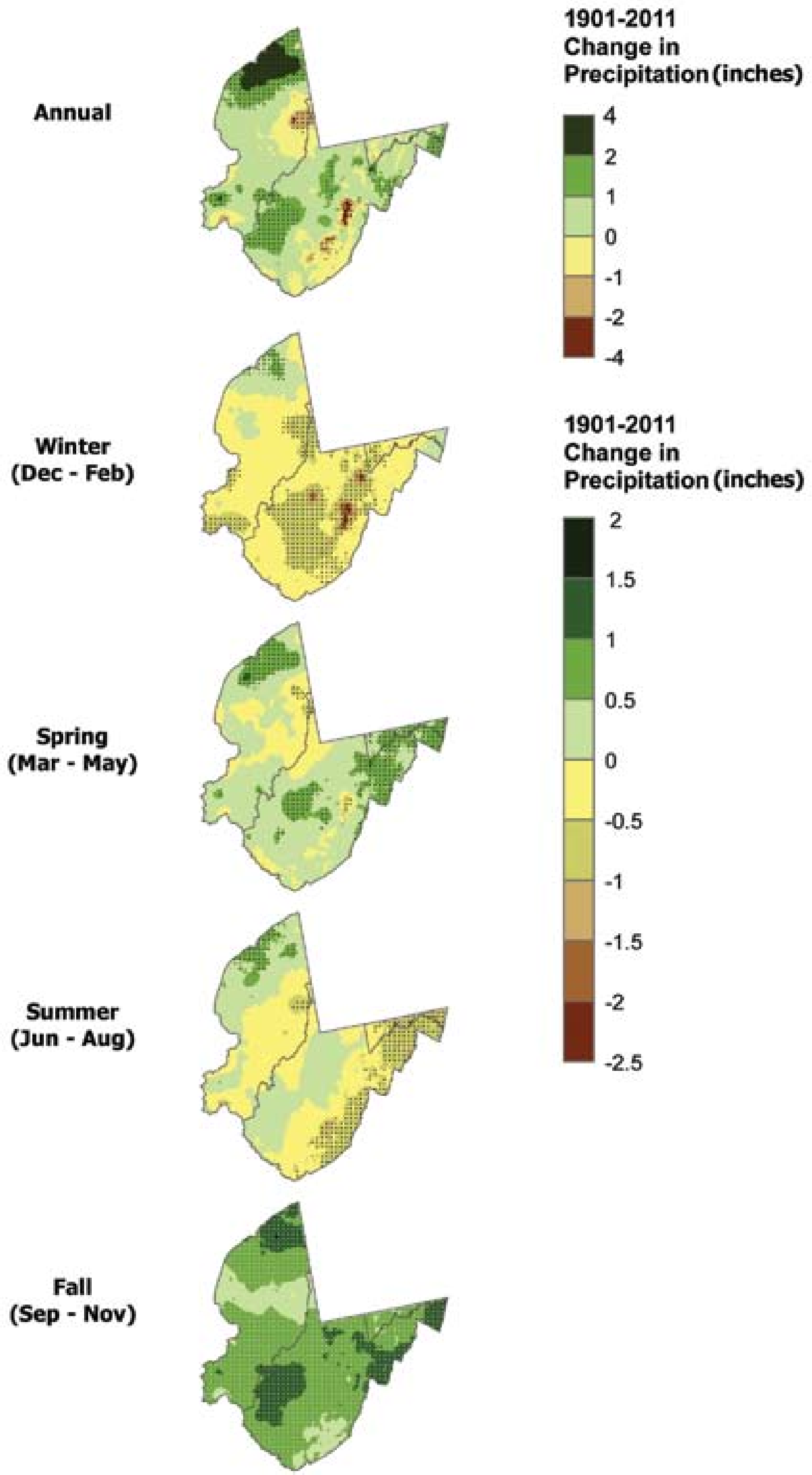


Figure 23.—Annual and seasonal changes in mean precipitation from 1901 through 2011 in the assessment area. Stippling indicates there is less than 10-percent probability that the trend has occurred by chance. Data source: ClimateWizard (2013).

### Regional Patterns Contributing to Local Trends

Some studies have observed a decrease in temperature, especially summer highs, in the southeastern and central United States since the 1950s, a phenomenon that has been referred to as a “warming hole” (Kunkel et al. 2013b, Meehl et al. 2012, Pan et al. 2004, Portmann et al. 2009). A recent study examined mean temperatures across the United States from 1950 through 1999 and found that decadal variations in sea-surface temperature were the most important contributor to the observed warming hole (Meehl et al. 2012). These findings are consistent with other studies that found that decreases in summer high temperature are correlated with increases in sea-surface temperatures (Kunkel et al. 2006), precipitation (Pan et al. 2004, Portmann et al. 2009), aerosols (Leibensperger et al. 2012), and increased soil moisture availability (Pan et al. 2004). Further research is needed to understand the “warming hole” and its implications for the region as global air and sea surface temperatures continue to rise. An analysis of recent climate trends in the United States suggests that the warming hole may have already disappeared as the mean annual temperature has increased significantly in all states since 1970 (Tebaldi et al. 2012).

Observed temperature and precipitation trends in the assessment area are consistent with the “warming hole” pattern in the regional climate. When averaged across the assessment area, maximum temperatures decreased and precipitation increased in July (Fig. 18) (ClimateWizard 2013).

## HISTORICAL TRENDS IN EXTREMES

Although it can be very instructive to examine long-term trends in mean temperature and precipitation, in many circumstances extreme events can have a greater impact on forest ecosystems and the human communities that depend on them. Weather or climate extremes are defined as individual weather events or long-term patterns that are unusual in their occurrence or have destructive potential (Bader et al. 2008). These events can trigger catastrophic disturbances in forest ecosystems, along with significant socioeconomic disasters. In addition, the distribution of individual species or forest types is often controlled by particular climatic extremes. Scientists agree that climate change has increased the probability of several kinds of extreme weather events, although it is difficult to directly attribute one particular event to climate change (Coumou and Rahmstorf 2012). As mean summer and winter temperatures have increased at a national scale, the chance of experiencing unusually warm or cool seasons has become higher over the last 30 years (Hansen et al. 2012). Extreme events are difficult to analyze with standard statistical methods, so long-term studies of weather and climate trends are necessary.

### Extreme Temperatures

Extreme temperatures can influence forest ecosystems in a variety of ways: some tree species are limited by hot growing-season temperatures, and others are limited by cold winter temperatures. Extreme temperatures may also be associated with disturbance events like drought, wildfire, ice storms, and flooding. Warmer mean temperatures are often correlated with higher extreme temperatures (Kling et al. 2003, Kunkel et al. 2008). Long-term records indicate that the number of hot days (exceeding the 95th percentile of warm temperatures) has increased across most of the contiguous United States since the 1960s, a time series which excludes the hot, droughty years of the 1930s and 1950s (DeGaetano and Allen 2002; Kunkel et al. 2013b, 2013c; Perera et al. 2012; Peterson et al. 2008). The number of extreme cold days (not exceeding the 5th percentile of cold maximum and minimum temperatures) has decreased across the United States since the 1960s (DeGaetano and Allen 2002). Winter maximum and minimum temperatures across the country have increased by an average 3.5 °F over the second half of the 20th century (Peterson et al. 2008). These trends correspond to global patterns of increasing occurrence of extreme hot weather and decreasing occurrence of extreme cool weather (Hansen et al. 2012). The frequency of extreme temperatures within the assessment area is a function of latitude and elevation, with northerly and high-elevation areas likely to experience fewer hot days over 90 °F and more cold days below 0 °F than southern and low-elevation areas (Polsky et al. 2000).

## Intense Precipitation

Precipitation has increased over the United States by an average of 5 percent during the second half of the 20th century (Karl et al. 2009, NOAA 2014b). The assessment area is located in one of the wetter regions of the country, and some areas of the assessment area have been experiencing increases in precipitation (e.g., the Ohio portion). Similar studies corroborate precipitation increases up to 25 percent in the same area (Karl et al. 2009). From 1948 through 2011, the amount of precipitation falling during a state's largest annual storm increased by 15 percent in Ohio, 14 percent in Maryland, and 6 percent in West Virginia (Madsen and Willcox 2012). The timing of precipitation events has shifted, however, and intense precipitation events have become more frequent while light rain events have not changed (Groisman et al. 2012, Kunkel et al. 2008). Throughout the Midwest during the last 40 years (including Ohio and West Virginia), there was a 50-percent increase in the frequency of days with more than 4 inches of rainfall and a 40-percent increase in the frequency of days with more than 6 inches of rainfall (Groisman et al. 2004, 2005, 2012). A study of the eastern United States found that heavy precipitation events are occurring more frequently in Ohio and West Virginia; heavy precipitation events that used to occur every 12 months are now occurring every 8.9 months (Madsen and Willcox 2012). A study of the Ohio River Basin (which includes all of the assessment area) also observed an increase in heavy rainfall from 1908 to 2007; the greatest increase was found for 1-year events (25 percent), with smaller increases for events having longer average recurrence intervals (3 percent) (Bonnin et al. 2011). A study of trends in return intervals from 1950 to 2007 also found that threshold precipitation events are occurring more frequently across the Midwest and Northeast, suggesting that extreme rainfall events are becoming more frequent, even where there have been no observed increases in total precipitation (DeGaetano and Allen 2002).

## Severe Thunderstorms, Tornadoes, and Hurricanes

Storm movement across the Central Appalachians region is generally from west to east, but strong storms from the eastern seaboard can also influence weather within the assessment area. The higher Allegheny Mountains buffer the West Virginia and Ohio portions of the assessment area, but Maryland can be heavily influenced by these east coast storms. Strong thunderstorms occur most frequently from May to August within the assessment area, and there is a general increase in frequency and expansion northward and eastward as the season progresses (Robinson et al. 2013). Thunderstorm frequency is higher west of the Appalachian Mountains than in the rest of the assessment area in April and May. Based on long-term data from 1896 to 1995, the assessment area averaged 35 to 45 thunderstorm days per year (Changnon 2003). A study of severe thunderstorm observations over the eastern United States identified an increase in thunderstorm frequency over the last 60 years, but it is difficult to determine whether those increases are biased by increased accuracy in storm reporting (Robinson et al. 2013).

Tornadoes also affect the assessment area, although less frequently than thunderstorms. Most of these tornadoes occur within Ohio (17 tornadoes per year on average), with occasional occurrences in West Virginia (2) and Maryland (7) (National Weather Service 2012). Although the number of tornadoes observed in a year appears to be increasing, the slightly positive trend is biased due to increased technology and reporting success, such as the introduction of Doppler radar technology in the 1990s (NOAA 2013a). The increase in tornado occurrence is observed in only the weakest tornadoes, and there is no evidence of increasing frequency of stronger tornadoes (Kunkel et al. 2013a). Hail is often produced during tornado weather and is more prevalent in the mountainous panhandle of Maryland due to orographic lifting (as moist air is forced into high elevations) and cooler ground temperatures, which allow for less melt on descent (Mogil and Seaman 2009).

Hurricanes tracking up the Atlantic seaboard also affect the assessment area. From 1985 to 2009, four major hurricanes and more than a dozen tropical storms tracked up the eastern seaboard. As a result, much of the assessment area has been subjected to intense rain, hail, wind, and flooding, although the Allegheny Mountains buffer the Ohio portion from much of the impact (Kunkel et al. 2013c). Not every hurricane formed in the Atlantic makes landfall or affects the assessment area, but there is some evidence that the strength and frequency of hurricanes have been increasing since 1970, and that this increase is associated with warming sea surface temperatures (Holland and Webster 2007, Kunkel et al. 2008). Based on the average number of hurricanes from 1981 to 2010, the 2011 hurricane season was above average, and was the 12th above-average season since 1995 (Blunden and Arndt 2012). There is no evidence of change in the frequency of hurricanes that make landfall (Holland and Webster 2007, Kunkel et al. 2008). Hurricane Isabel made landfall in 2003, followed by Irene in 2008, and Sandy in 2013. Trends in severe weather frequency are difficult to attribute to changes in climate only; recent advances in technology, population density, and social media have contributed to increases in storm and tornado reporting (Robinson et al. 2013). Losses from catastrophic storms, defined as a storm producing more than $1 million in damages, have been used to explore trends in storm frequency and severity across the central and northeastern United States (Changnon 2011a, 2011b).

## Windstorms

In warm months of the year, the assessment area occasionally experiences very powerful straight-line windstorms, otherwise known as derechos. These events can result in substantial wind-throw disturbances in forest ecosystems. A recent example was the April 2011 storm that passed through Ohio and the northeastern border of West Virginia on its southwest-to-northeast track through the central United States. This single storm produced wind gusts of 58 to 74 miles per hour, hail, and tornadoes (NOAA 2013c). A much larger storm caused 22 deaths and widespread damage across the eastern United States, including the assessment area, on June 29, 2012 (NOAA 2013b). The average annual frequency of derechos within the assessment area decreases from Ohio (11) to Maryland (9) (Coniglio and Stensrud 2004). There is not enough evidence currently available to examine trends in derecho frequency and distribution due to limited data in the first half of the 20th century (Peterson 2000).

# PHYSICAL PROCESSES

Climate and weather patterns also drive many physical processes important for forest ecosystems. Climate-driven factors such as snowpack and soil frost can regulate annual phenology, nutrient cycling, and other ecosystem dynamics. Changes to climate-driven physical processes can result in impacts and stress on forest ecosystems that might not be anticipated from mean climate values alone. This section presents a few key trends that have been observed in the Central Appalachians and throughout the broader region.

## Flooding and Streamflow

Although floods also depend on soil saturation, soil temperature, and drainage capabilities, floods are primarily attributed to spring snowmelt, heavy rainfall, tropical storms, and hurricanes. Floods can develop slowly as the water table rises, or quickly if large amounts of rainfall rapidly exceed moisture thresholds. Although snowpack in the Central Appalachians is generally short-lived, melting can contribute substantial volume to winter and spring peak flow and flooding (Eisenbies et al. 2007, Kochenderfer et al. 2007). Areas with steep and narrow terrain are more prone to flash flooding of the smaller rivers, streams, and tributaries (Eisenbies et al. 2007). Long-term data on flooding are difficult to interpret because of the variety of measures used to describe floods. Many floods originate from small, unmonitored watersheds, and thus go unreported (Wiley and Atkins 2010). Major regional floods can be observed through stream gauge measurements and are reported for the three states within the assessment area. Sixteen major floods have been recorded in West Virginia since 1844 (Wiley and Atkins 2010). In Maryland, 57 floods were recorded from 1860 to 2004, with at least 13 of them attributed to hurricanes (Joyce and Scott

A small stream meandering through hemlock forest. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

2005). In Ohio, 38 major floods were recorded from 1861 to 1990, 315 minor flood events from 2000 to 2007, and a major flood in 2011 (Ohio Emergency Management Agency 2011, Robertson et al. 2011). Damage from floods has been increasing in the Midwest in recent decades (Villarini et al. 2011). A nationwide study of streamflow between 1944 and 1993 demonstrated that baseflow and median (average) streamflow have increased at many streams in the Midwest and Mid-Atlantic (Lins and Slack 1999). More recent studies have confirmed increased annual and low streamflow from 1961 to 1990, at least partially due to increased storm frequency (Groisman et al. 2004). At the same time, maximum flow (including floods) did not change (Lins and Slack 1999).

Several factors complicate the explanation of trends in flood frequency. Changes in flooding frequency are driven not only by increased precipitation but also by changes in land cover and land use (Groisman et al. 2004, Jones et al. 2012, Wang and Cai 2010). In particular, human-caused land-use change over the past century has had a considerable influence on flooding frequency (Villarini et al. 2011). After these factors have been taken into account, however, studied watersheds in the Midwest still exhibited increased discharge over the past several decades, which may be attributed to climate change (Tomer and Schilling 2009).

## Snow and Winter Storms

Cold and snowy winters are characteristic of the Central Appalachians region, which lies between two major storm tracks of the eastern United States (Hartley 1999). The assessment area experiences more snowstorms than nearby southern states, but fewer than nearby northern and eastern states (Changnon and Changnon 2007). Snowfall in the Central Appalachians is influenced by many factors including winter temperature, lake-effect weather, and elevation. Although precipitation has been increasing, the proportion that falls as snow has been decreasing (Kunkel et al. 2009a, 2009b). The ratio of snow to precipitation is strongly correlated with mean daily temperature across the United States (Feng and Hu 2007). As daily temperature increased from 1949 to 2005, the proportion of precipitation falling as snow decreased over non-lake effect areas of Ohio and most of West Virginia (Feng and Hu 2007). Decreasing trends in seasonal snowfall were also observed in the central and southern Appalachians from 1963 to 1993 (Hartley 1999). Regional trends indicate that although snowfall is quite variable from year to year, the most recent 30 years have had fewer heavy snowfalls, but more-intense snowfalls when they do occur (Feng and Hu 2007). Snowfall has increased over the same period in the lake-effect area of Ohio, and in the Northern Ridge and Valley section of West Virginia and Maryland (Feng and Hu 2007). Long-term records from across the Great Lakes indicate that lake-effect snow increased gradually during the 20th century, likely due to the warming of these water bodies and the decreasing trend in lake-ice cover.

Across the Midwest and Northeast, long-term records have shown that ice on inland lakes is breaking up earlier in the spring and forming later in the fall (Benson et al. 2012). Annual ice cover on Lake Erie has declined by half from 1973 to 2010 (Wang et al. 2012).The combined effect of these trends is a longer ice-free period for lakes across the region and the assessment area, including Lake Erie, which influences climate and weather in the assessment area.

## Drought

Droughts are among the greatest stressors on forest ecosystems, and can often lead to secondary effects of insect and disease outbreaks on stressed trees and increased fire risk (Maherali et al. 2006). Because droughts often affect large regions, data are available at regional and statewide scales, but not at finer scales. There is no evidence for increased drought severity, frequency, or extent on

Fall colors on the Hocking State Forest, Ohio. Photo by the Ohio Department of Natural Resources, used with permission.

average across the assessment area. The Palmer Drought Severity Index (PDSI) is a soil moisture index which measures meteorological drought by calculating the cumulative departure (from the long-term mean) in moisture supply and demand (Dai et al. 2004). The Palmer Hydrological Drought Index (PHDI) measures hydrological drought based on precipitation and evaporation. Both indicators can be important in understanding the effects on groundwater supply. In North America and the United States, there has been a trend toward wetter conditions since 1950, and there is no detectable trend for increased drought based on the PDSI (Dai et al. 2004, Karl et al. 1996). Another study of hydrologic trends in the United States over the last century (1915 through 2003) also observed reduced duration and severity of droughts across the Central Appalachians region as a result of increased precipitation (Andreadis and Lettenmaier 2006). Statewide data (NOAA 2014d) were also explored to examine changes in the yearly and seasonal Palmer drought indices. A positive (wetter) trend from 1895 to 2013 was observed in West Virginia and Ohio annually and for each season according to both indices. In Maryland, the PDSI shows no increasing or decreasing trend in annual or spring droughts, but shows that fall and winter have been getting wetter and summer has been getting drier (NOAA 2014d). The PHDI shows that winter and spring have been getting wetter, whereas annual, summer, and fall conditions have been getting slightly drier in Maryland (NOAA 2014d).

## Growing Season Length

Growing season length is often estimated as the period between the last spring freeze and first autumn freeze (climatological growing season), but can also be estimated through the study of plant phenology (biological growing season) (Linderholm 2006). A large body of research indicates that the growing season has lengthened by 10 to 20 days at global, hemispheric, and national scales, primarily due to an earlier onset of spring (Christidis et al. 2007, Easterling 2002, Linderholm 2006, Parmesan 2007, Parmesan and Yohe 2003, Root et al. 2003, Schwartz et al. 2006b, Zhang et al. 2007). There is evidence, however, of both positive and negative regional trends being dissolved into these broad-scale averages. Several studies suggest that the growing season is lengthening within the assessment area, but primarily due to a later onset of fall. In fact, a recent study exploring past trends in spring onset dates in the Southeast, including the assessment area, showed that spring has been occurring later by 4 to 8 days since the 1950s (Schwartz et al. 2013). This phenomenon has been linked to the warming hole, and specifically, to processes that promote cooling during the winter (Meehl et al. 2012). Another study of the Southeast and New England also found an anomalous trend toward delayed onset of spring in nearby Virginia (Fitzjarrald et al. 2001).

The onset of fall is also highly influenced by local temperature changes rather than global mean temperatures (Badeck et al. 2004). Remote sensing of vegetation patterns is one method commonly used to estimate the start, end, and length of the growing season. Studies using remote sensing have found no significant trend in the start of season, but did find that the end of season occurred later, and the total growing season lengthened by approximately 9 days from 1981 through 2008 (Jeong et al. 2011, Julien and Sobrino 2009). Another study using cold-degree days and satellite imagery found a correlation between increasing midsummer temperatures and later fall senescence, which causes autumn colors (Dragoni and Rahman 2012). The authors also found that end-of-season dates varied by latitude and elevation, with earlier senescence occurring in forests at higher latitudes and elevations (Dragoni and Rahman 2012). For example, despite regional trends toward later senescence from 1989 through 2008, the end of season occurs earlier in the Appalachian range than surrounding areas (Dragoni and Rahman 2012). Increases in the growing season length are causing some noticeable changes in the timing of biological activities, such as bird migration (Box 8).

### Box 8. Phenological Indicators of Change

Changes in growing season length can be observed through studies of phenology. Phenology is the timing of recurring plant and animal life-cycle stages, such as leaf-out and senescence, flowering, maturation of agricultural plants, insect emergence, and bird migration. A few studies examining phenology in the Central Appalachians indicate recent changes:

- In a survey of 270 flowering plants in southwestern Ohio, 60 percent showed earlier spring flowering over the period from 1976 to 2003 of about 10 to 32 days (McEwan et al. 2011). The differences among species may be attributed to differences in sensitivity to climate as a cue to begin flowering as opposed to other indicators such as day length.
- Ten species of native bees in the Northeast (including the entire assessment area) have been emerging an average of 10 days earlier over the last 130 years, with much of the change linked to warming trends since 1970. Bee-pollinated plants are also blooming earlier, suggesting that these generalist species are keeping pace with changes in plant phenological shifts (Bartomeus et al. 2011).
- The purple martin, a long-distance migratory songbird that overwinters in the assessment area, has been declining across North America and Canada (Nebel et al. 2010). Population declines are linked to an increasing mismatch between spring arrival date and timing of food availability (Fraser et al. 2013). A recent study tracking spring migration from the Amazon basin to two breeding sites in Pennsylvania and Virginia found that purple martins were unable to depart earlier, migrate faster, or claim breeding sites earlier in response to earlier green-up and insect emergence.

## CHAPTER SUMMARY

Notable shifts have been observed in climate, extreme weather events, and phenology within the assessment area. Broad regional trends have translated into high spatial variability across the region. Mean and minimum annual, spring, and summer temperatures have increased more in the mountainous parts than in other parts of the assessment area. Minimum temperatures have generally increased, and maximum temperatures have generally decreased in parts of the assessment area. Precipitation increases were detected in the fall season in every part of the assessment area, and changes during other seasons differed with location. Summer precipitation decreased in the far eastern part of the assessment area, but remained relatively stable elsewhere. Drought indices indicate that the frequency and severity of droughts have not changed. Heavy precipitation events have become more frequent and intense. Characteristic winter conditions such as snowfall and lake ice have been diminishing with warmer temperatures. In addition, the growing season has lengthened due to later onset of fall. These trends are generally consistent with regional, national, and global observations related to anthropogenic climate change, but with subtle local differences. Ecological indicators are beginning to reflect these changes as well, as evidenced by changing arrival of migratory birds and changing phenology. Sources of information on historical climate trends and ecological indicators are listed in Box 9.

### Box 9. More Historical Climate Information

Much more information on historical climate trends and ecological indicators for the Central Appalachians region exists than was possible to present in this chapter. Interested readers will be able to find more information from the following resources:

#### National Information

The National Climatic Data Center (NCDC) is the world's largest active archive of weather data. The NCDC's Climate Data Online provides free, downloadable data from the Global Historical Climatology Network. Please note that Web addresses are current as of the publication date of this assessment but are subject to change.

www.ncdc.noaa.gov/oa/ncdc.html

#### Regional Information

The Northeast Regional Climate Center is a cooperative program between the National Climatic Data Center (above) and the state climate offices serving the 12-state region of Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia. It provides high-quality climate data, derived information, and data summaries for the Midwest.

www.stateclimate.org/regional.php?region=northeast

#### State-level Information

State climatologists provide information about current and historical trends in climate throughout their states. Visit your state climatologist's Web site for more information about trends and climate patterns in your particular state:

**Office of the State Climatologist for Ohio**
http://www.geography.osu.edu/faculty/rogers/statclim.html

**West Virginia State Climate Office & Meteorology**
http://www.marshall.edu/met/

**Maryland State Climatologist Office**
http://metosrv2.umd.edu/~climate/

# CHAPTER 4: PROJECTED CHANGES IN CLIMATE, EXTREMES, AND PHYSICAL PROCESSES

In Chapter 3, we examined how climate has changed in the Central Appalachians region over the past 111 years, based on measurements. This chapter examines how climate may change through the end of this century, including changes in extreme weather events and other climate-related processes. General circulation models (GCMs) are used to project future change at coarse spatial scales and are then downscaled in order to be relevant at scales where land management decisions are made. In some cases, these downscaled data are then incorporated into forest species distribution models and process models (see Chapters 2 and 5). Chapter 2 more fully describes the models, data sources, and methods used to generate these downscaled projections, as well as the inherent uncertainty in making long-term projections. In this chapter, we focus on two climate scenarios for the assessment area, chosen to bracket a range of plausible climate futures. Information related to future weather extremes and other impacts is drawn from published research.

## PROJECTED TRENDS IN TEMPERATURE AND PRECIPITATION

The assessment area has experienced changes in temperature and precipitation over the past 100 years, and those changes are projected to increase in intensity over the next 100 years. Projected changes in temperature and precipitation within the assessment area were examined by using a statistically downscaled climate data set for three 30-year time periods through the end of this century (2010 through 2039, 2040 through 2069, and 2070 through 2099) (Stoner et al. 2012). Daily mean, minimum, and maximum temperatures and total daily precipitation were downscaled to an approximately 7.5-mile grid across the United States. For all climate projections, two climate scenarios are reported: GFDL A1FI and PCM B1 (see Chapter 2). The GFDL A1FI climate scenario projects greater changes in future temperature and precipitation than the PCM B1 climate scenario (hereafter referred to simply as PCM B1 and GFDL A1FI). Although both climate scenarios are possible, GFDL A1FI matches current trends in emissions and temperature more closely than PCM B1 (Raupach et al. 2007). It is possible that the future will be different from any of the developed scenarios, and therefore it is important to consider the range of possible climate conditions over the coming decades rather than one particular scenario. The 1971 through 2000 climate averages from ClimateWizard (Girvetz et al. 2009) were used as the baseline from which future departure from current climate conditions was calculated (see Chapter 3 and Appendix 2).

Climate projections are presented in two ways in this chapter. In general assessment area-wide trends are described first, followed by maps that show spatial variation in these trends. When the assessment area is averaged as a whole, the projections of temperature are positive, whereas projections of precipitation are positive and negative, depending on the season and model. When climate data were averaged for each grid cell within the assessment area, groups of pixels on a map begin to show subregional climate trends, such as warming in one area and cooling in another (mainly the Allegheny Mountains section; see also Box 10).

### Box 10. Climate Modeling in Areas of Complex Topography

Areas of complex topography, such as the Allegheny Mountains and Northern Ridge and Valley sections of West Virginia and Maryland, contain some of the highest biological diversity in the world (Hoekstra et al. 2010). Patterns of ridges, valleys, slope, rainshadow effects, cold air pooling, and other fine-scale processes create a complex suite of ecological niches with various temperature and moisture regimes which may actually provide the assessment area with additional resilience to changes (Anderson and Ferree 2010). Terrain creates various levels of decoupling between the climate experienced at a site and the broad climate trends for any given region (Dobrowski 2011, Fridley 2009). Precipitation patterns in mountainous areas are particularly difficult to model, owing to the complexity of atmospheric circulation, wind speed, rainshadow effects, and orographic lifting of moisture to higher elevations. Although we can use the downscaled climate data at the regional level to gain an understanding of broad-scale trends, statistical downscaling often does not capture landscape heterogeneity seen in some portions of the assessment area.

Although few studies have investigated finer scale modeling of mountain ranges in the United States, there have been some studies that may shed light on how downscaled climate models may be overestimating or underestimating temperature and precipitation trends at various elevations and landscape positions. A study in the Oregon Cascades, which is prone to cold-air pooling similar to the Allegheny Mountains, found that temperatures in sheltered valley bottoms are decoupled from the free atmosphere, and consequently are somewhat buffered from changes projected for the whole study area (Daly et al. 2010). Modeled warming of 4.5 °F at closely spaced sites simulated temperature differences of up to 10.8 °F between low-elevation valleys and high-elevation ridge tops. In a study of mountainous terrain at the Hubbard Brook Experimental Forest in New Hampshire, three climate models overestimated observed precipitation by 20 percent for the period 1979 through 2008 (Campbell et al. 2010), so that future projected values were corrected downward by 20 percent. A study in the southern Appalachians found that the winter northwest low-level air flow is nearly perpendicular to the southwest-northeast mountain range, producing orographic lifting and subsequent snowfall on northwest slopes and higher elevations, despite warmer temperatures at lower elevations (Perry and Konrad 2006).

These studies suggest that there are difficulties in accurately modeling areas with complex topography and rapid elevation change. Regional climate models have not performed as well as in areas of relative homogeneity, and some correction may be necessary to account for elevation, slope, aspect, and relative exposure or isolation from the elements. Finer-resolution modeling would help identify biases in the data based on these factors. Until such fine modeling efforts can be executed, the coarse-resolution data sets used in this assessment can provide a broad foundation of plausible future climates from which to consider the caveats above.

## Temperature

The assessment area is projected to experience substantial warming over the 21st century, especially for GFDL A1FI (Fig. 24). Early-century (2010 through 2039) temperature increases are projected to be relatively small when averaged across the assessment area, with little change projected for PCM B1 (0.8 °F) and a modest increase of 2 °F for GFDL A1FI (Fig. 24, Table 16). Projections of temperature do not diverge substantially for the two future scenarios until mid-century (2040 through 2069), when much larger temperature increases are projected for GFDL A1FI than PCM B1 through the end of the century. Compared to the 1971 through 2000 baseline period, the average annual temperature at the end of the century is projected to increase by 1.9 °F for PCM B1 and by 7.8 °F for GFDL A1FI (Table 16). Seasonal changes follow this pattern, with modest changes projected during the early century, and the highest temperature increases projected for GFDL A1FI at the end of the century (see Appendix 3 for projected changes in mean, minimum, and maximum temperatures during the early, mid, and late century for all four seasons).

**Table 16.—Projected changes in annual mean, minimum, and maximum temperatures and precipitation in the assessment area averaged over 30-year periods**

| | Baseline (1971-2000)[a] | Scenario | Departure from baseline 2010-2039 | 2040-2069 | 2070-2099 |
|---|---|---|---|---|---|
| **Mean temperature (°F)** | | | | | |
| Annual | 51.1 | PCM B1 | 0.8 | 1.5 | 1.9 |
| | | GFDL A1FI | 2.0 | 5.3 | 7.8 |
| Winter (Dec-Feb) | 31.2 | PCM B1 | 0.7 | 2.1 | 2.1 |
| | | GFDL A1FI | 1.6 | 4.1 | 5.5 |
| Spring (Mar-May) | 50.2 | PCM B1 | 0.3 | 1.3 | 1.8 |
| | | GFDL A1FI | 0.8 | 4.4 | 7.1 |
| Summer (Jun-Aug) | 70.1 | PCM B1 | 0.9 | 1.4 | 1.8 |
| | | GFDL A1FI | 3.2 | 6.9 | 9.4 |
| Fall (Sep-Nov) | 53.0 | PCM B1 | 1.4 | 1.5 | 1.7 |
| | | GFDL A1FI | 2.5 | 5.5 | 9.0 |
| **Minimum temperature (°F)** | | | | | |
| Annual | 40.0 | PCM B1 | 0.7 | 1.4 | 1.9 |
| | | GFDL A1FI | 1.9 | 5.2 | 7.7 |
| Winter (Dec-Feb) | 21.7 | PCM B1 | 0.6 | 2.1 | 2.3 |
| | | GFDL A1FI | 1.5 | 4.4 | 5.9 |
| Spring (Mar-May) | 38.1 | PCM B1 | 0.5 | 1.3 | 1.9 |
| | | GFDL A1FI | 1.0 | 4.6 | 7.1 |
| Summer (Jun-Aug) | 58.5 | PCM B1 | 0.7 | 1.4 | 1.7 |
| | | GFDL A1FI | 2.8 | 6.5 | 9.0 |
| Fall (Sep-Nov) | 41.6 | PCM B1 | 1.1 | 0.9 | 1.5 |
| | | GFDL A1FI | 2.3 | 5.2 | 8.7 |
| **Maximum temperature (°F)** | | | | | |
| Annual | 62.3 | PCM B1 | 0.9 | 1.7 | 1.9 |
| | | GFDL A1FI | 2.1 | 5.3 | 7.8 |
| Winter (Dec-Feb) | 40.7 | PCM B1 | 0.8 | 2.0 | 1.9 |
| | | GFDL A1FI | 1.6 | 3.9 | 5.2 |
| Spring (Mar-May) | 62.4 | PCM B1 | 0.0 | 1.2 | 1.9 |
| | | GFDL A1FI | 0.6 | 4.2 | 7.2 |
| Summer (Jun-Aug) | 81.6 | PCM B1 | 1.1 | 1.3 | 1.9 |
| | | GFDL A1FI | 3.6 | 7.3 | 9.8 |
| Fall (Sep-Nov) | 64.4 | PCM B1 | 1.7 | 2.1 | 1.9 |
| | | GFDL A1FI | 2.7 | 5.8 | 9.2 |

[a] The 1971 through 2000 value is based on observed data from weather stations.

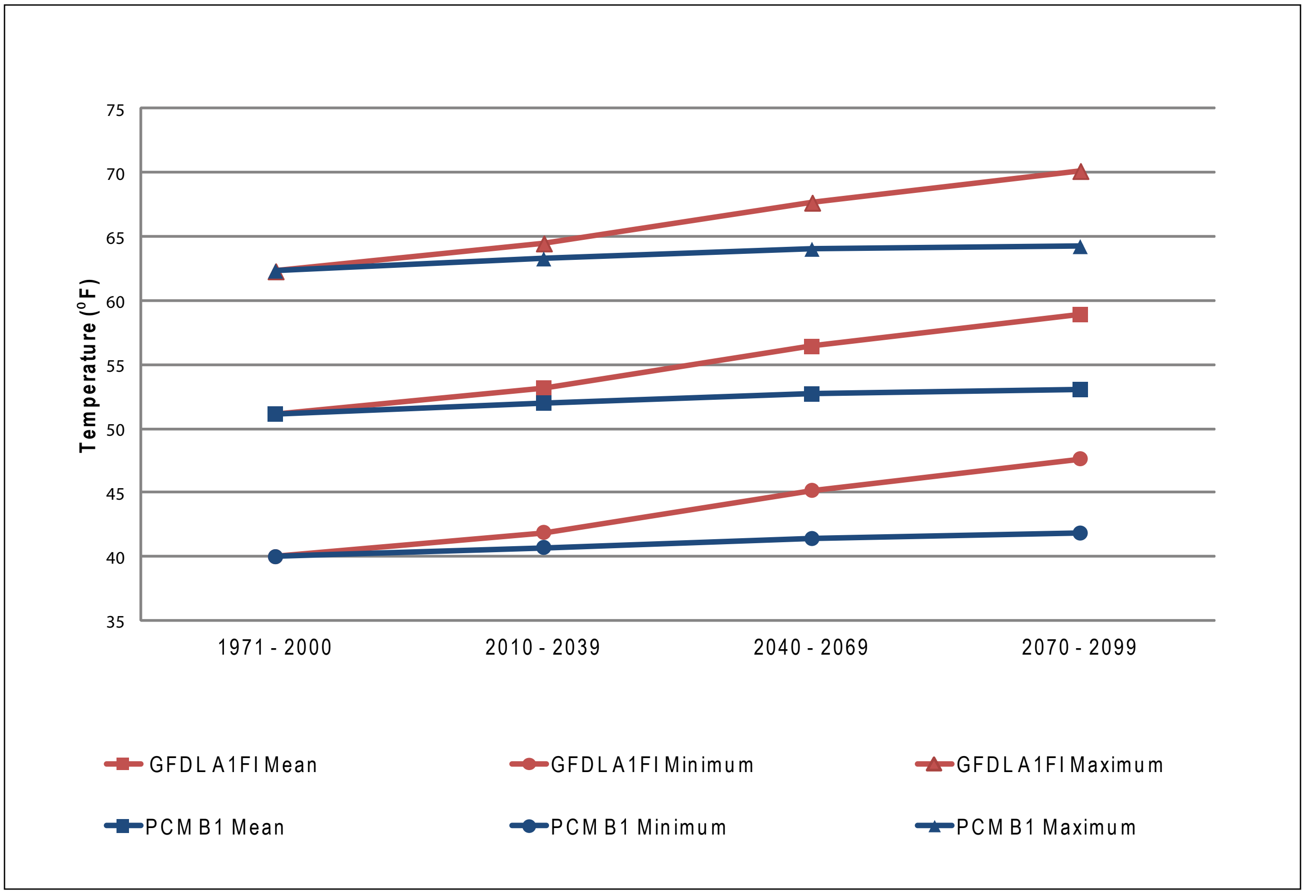


Figure 24.—Projected changes in annual mean, minimum, and maximum temperatures across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations. See Appendix 3 for projected changes by season.

Changes in mean temperature are projected to vary greatly by season. Under PCM B1, winter is projected to warm the most by the end of the century (2.1 °F), followed by spring and summer (1.8 °F), and fall (1.7 °F). For GFDL A1FI, greater increases are projected for summer (9.4 °F) and fall (9.0 °F) than spring (7.1 °F) and winter (5.5 °F). Maximum temperatures are projected to increase more than minimum temperatures for both scenarios across nearly all seasons. Winter is the exception to this trend, with minimum temperature projected to increase by 2.3 °F for PCM B1 and by 5.9 °F for GFDL A1FI by the end of the century (Table 16). Maximum annual temperatures are projected to change by 1.9 °F for PCM B1 and 7.8 °F for GFDL A1FI by the end of the century.

These changes in temperature are projected to differ across the assessment area (Figs. 25 through 27). For example, the Ohio portion is projected to experience larger mean and minimum temperature increases during winter at the end of the century for both scenarios than other locations in the assessment area. The Ohio portion is also projected to experience larger end-of-century increases in maximum temperature during summer. This pattern holds true for early- and mid-century projections in the Ohio portion, with the addition that fall maximum temperature during these periods is also projected to increase (Appendix 3). There are also noticeable areas within the higher-elevation Allegheny Mountains in West Virginia and Maryland (Section M221B) that are projected to cool slightly

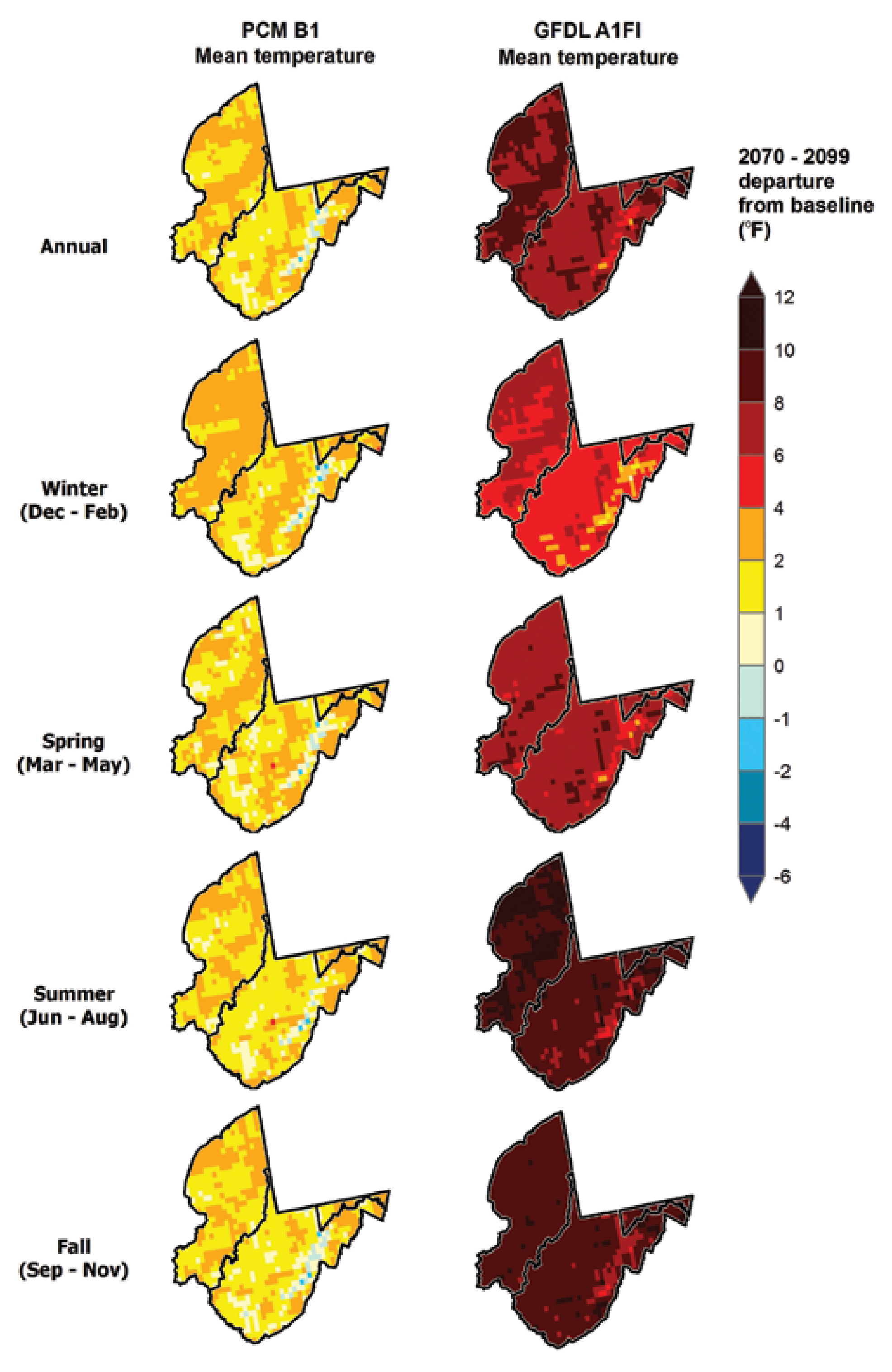


Figure 25.—Projected difference in daily mean temperature at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate scenarios.

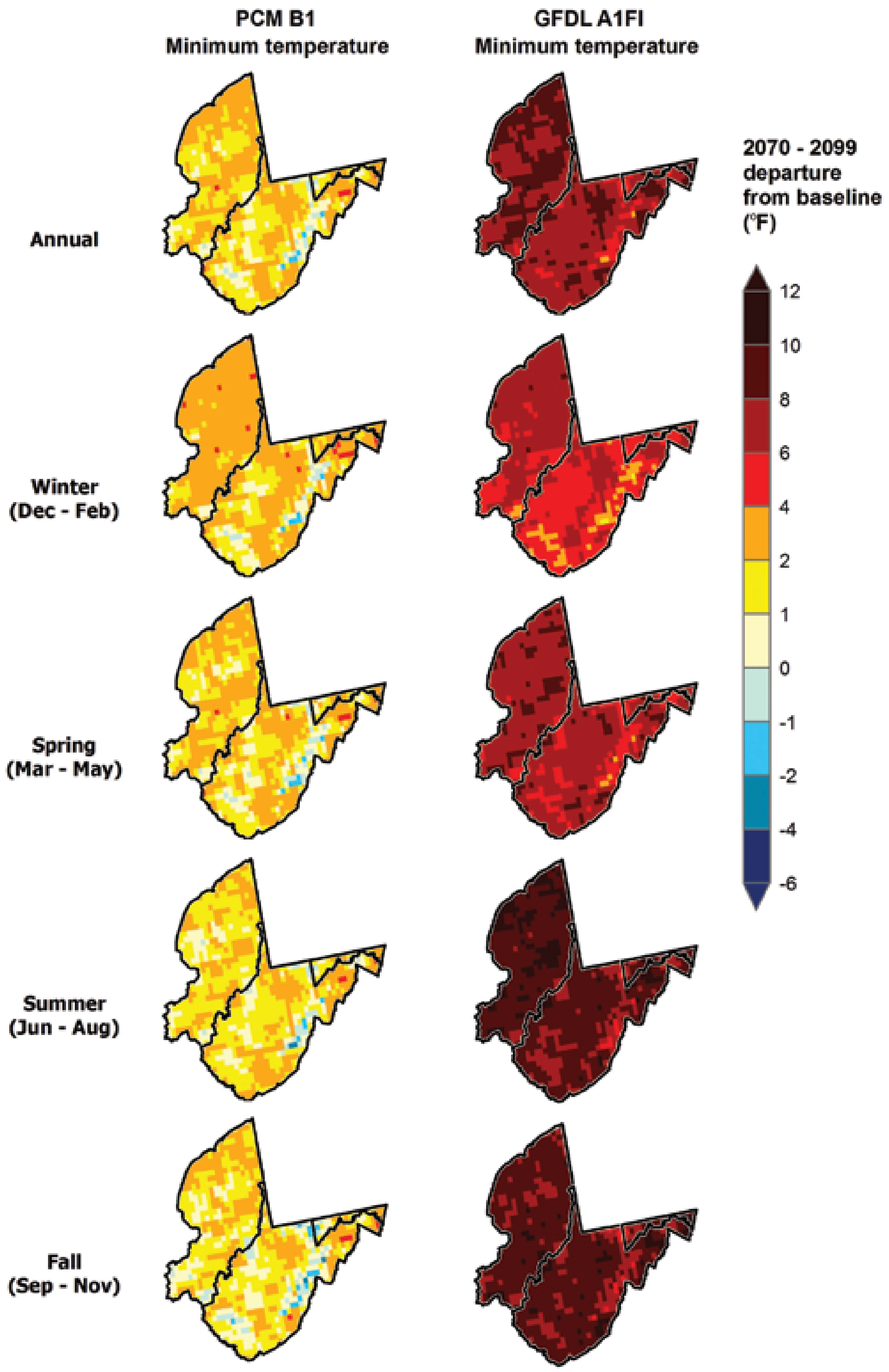


Figure 26.—Projected difference in daily minimum temperature at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate scenarios.

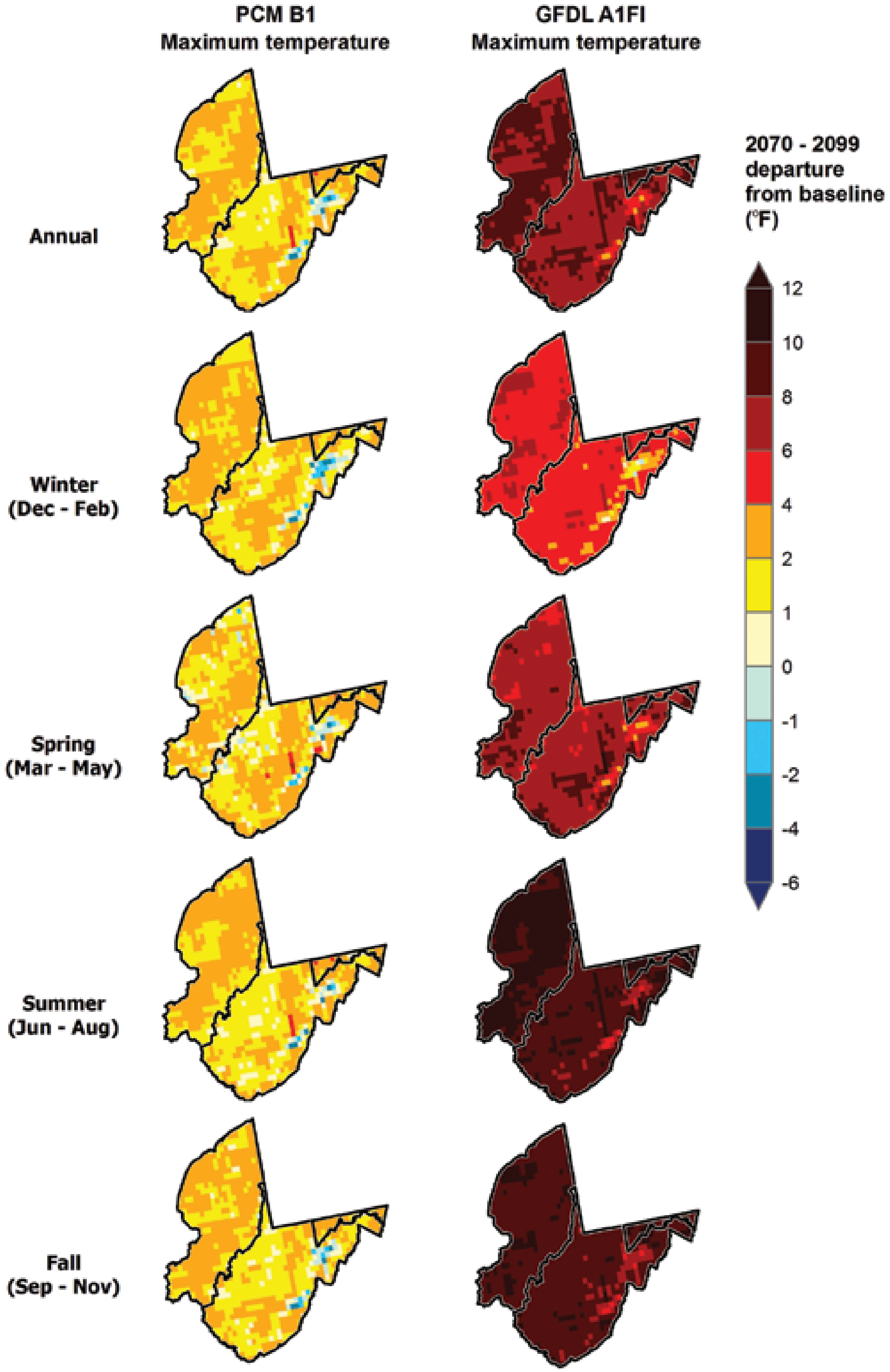


Figure 27.—Projected difference in daily maximum temperature at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate scenarios.

under PCM B1, and warm by several degrees less than lower-elevation areas under GFDL A1FI. The baseline climate (1971 through 2000) of this section is consistently several degrees cooler than surrounding areas (see Chapter 3: Fig. 15), and temperatures at the end of the century are projected to be several degrees cooler. A narrow strip running parallel to the southwest to northeast ridges in this section is projected to be 1 to 3 °F cooler for PCM B1 at the end of the century compared to the baseline climate. This trend is visible for mean, minimum, and maximum temperatures through all seasons. The pattern is also visible for GFDL A1FI, which projects warming in this strip, but several degrees less than surrounding areas.

Although the two climate scenarios project different amounts of warming, they are largely in agreement that mean, maximum, and minimum temperatures will increase throughout much of the assessment area both annually and in all seasons. The two models are less in agreement about projections of seasonal change, with PCM B1 projecting winter temperature to increase the most (1.8 °F increase in mean temperature) and GFDL A1FI projecting summer and fall to increase the most (8.5 °F and 8.1 °F, respectively). See also Box 11.

### Box 11. Revisiting the “Warming Hole”

In Chapter 3, we discussed the “warming hole” that has been observed across the central United States. Although the core of the warming hole is centered on Midwestern states, the effect extends into the assessment area to a lesser degree, characterized by a reduction in summer high temperatures over the past several decades. Will this pattern continue into the future? If we examine only the statistically downscaled GCM data presented in this chapter, we might conclude that the warming hole will be gone in the next century.

However, at least one study suggests that the large grid-scale of GCMs fails to account for regional-scale processes that are important contributors to the warming hole (Liang et al. 2006). Using a dynamical downscaling approach to compare a fine-scale (18.6 miles) regional climate model, CMM5, with the PCM model as an input, this study found a large discrepancy between the downscaled projections and the coarse-scale PCM projections in the central United States. Although both projected an increase in summer temperature, the downscaled CMM5 projected an increase of less than 0.5 °F, whereas the coarse-scale PCM projected a mid-century increase of 5.4 °F or more averaged over 10 years (2041 through 2050). The statistically downscaled projections for PCM presented in this chapter also suggest a more modest mid-century (2040 through 2069) increase of 0.5 °F in mean summer temperature.

So what does this mean for the “warming hole”? These results suggest that, as with past observations, there may continue to be regional climate processes, such as cumulus cloud formation, that reduce the amount of warming experienced during the summer months, at least over the short term. However, dynamical downscaling studies such as this one remain limited, further justifying the consideration of a range of potential future climate scenarios when preparing for future climate change.

## Precipitation

Due to the highly variable nature of precipitation and difficulty in modeling it, projections of precipitation differ considerably from model to model, and generally carry with them a higher level of uncertainty than projections of temperature (Kunkel et al. 2013b, 2013c; Winkler et al. 2012). The two climate model-scenario combinations used in this assessment describe a wide range of possible future precipitation for the assessment area (Figs. 28 and 29). However, other GCM and emissions scenario combinations could project values outside of this range. Within the assessment area, annual precipitation is projected to increase by 2 inches for PCM B1 and only slightly (0.2 inch) for GFDL A1FI at the end of the century (Table 17) (see Appendix 3 for maps of projected changes in early- and mid-century precipitation). It is more important, however, to consider changes by season, as the timing of increases or decreases have the most implications for forest ecosystems. Under PCM B1, precipitation is projected to increase in winter (0.7 inch), spring (0.7 inch), and summer (1.8 inches) and decrease in fall (-1.2 inches). Under GFDL A1FI, precipitation is projected to increase in fall (0.4 inch), winter (2.1 inches), and spring (1.7 inches) and decrease in summer (-4.1 inches). Notably, for GFDL A1FI, an increase of 1.7 inches in spring precipitation is followed by a decrease of 4.1 inches in summer precipitation at the end of the century. That represents a 13-percent increase from baseline precipitation (Chapter 3) in spring, followed by a 48-percent decrease in summer. These projected summer and fall decreases in precipitation, and their timing during the growing season, could have important consequences for tree growth, seedling establishment, and other forest processes that are dependent on adequate soil moisture.

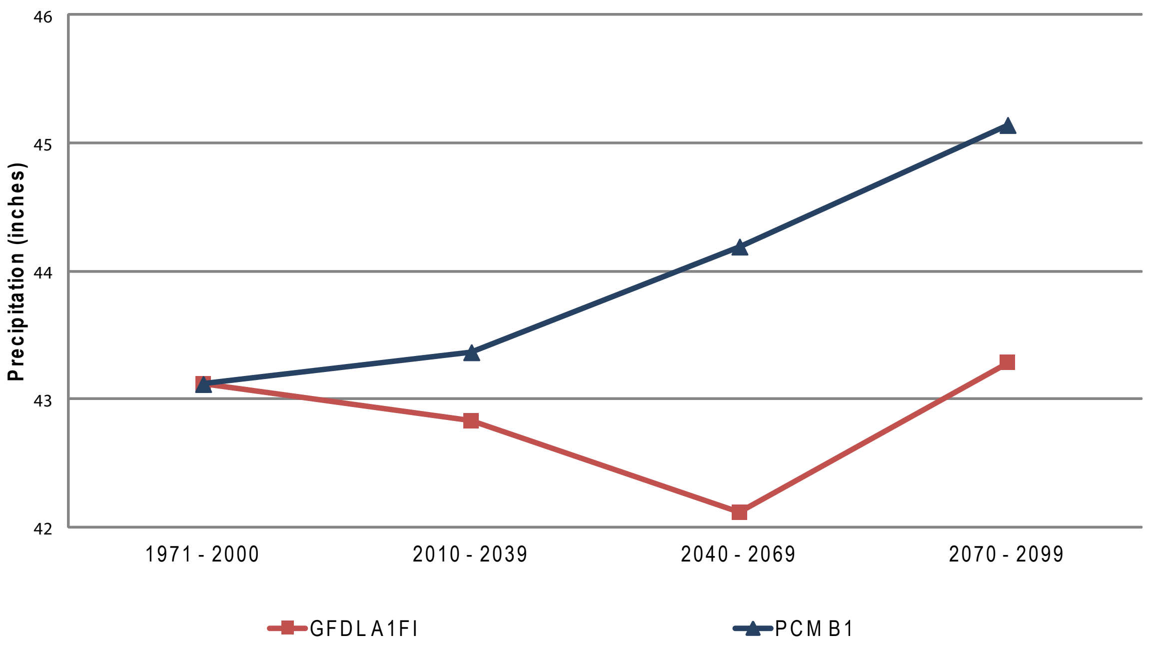


Figure 28.—Projected changes in annual mean precipitation across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations. See Appendix 3 for projected changes by season.

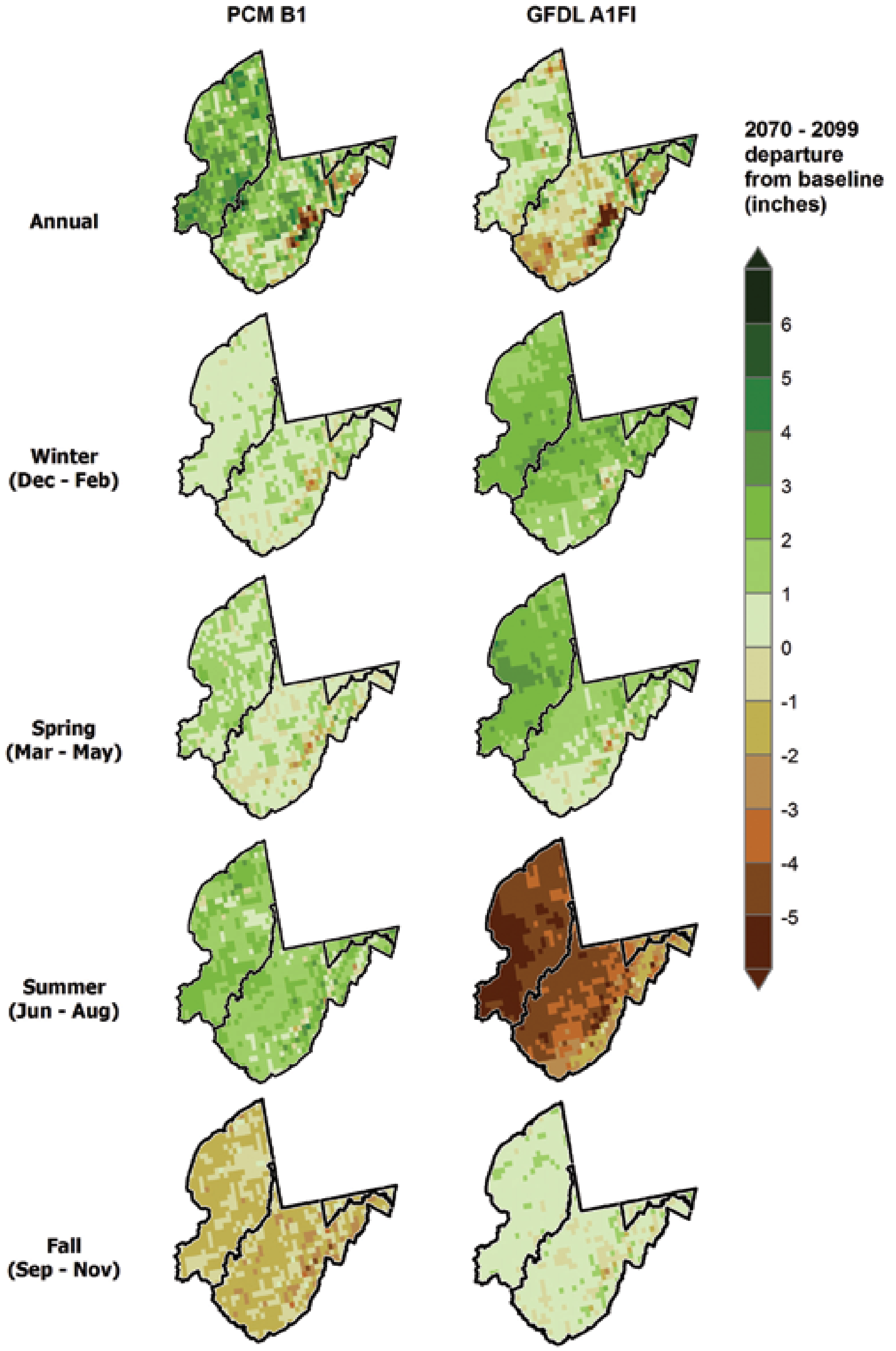


Figure 29.—Projected difference in mean precipitation at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate scenarios.

**Table 17.—Projected changes in mean precipitation in the assessment area averaged over 30-year periods**

| | Baseline (1971-2000)[a] | Scenario | Departure from baseline 2010-2039 | 2040-2069 | 2070-2099 |
|---|---|---|---|---|---|
| **Precipitation (inches)** | | | | | |
| Annual | 43.1 | PCM B1 | 0.2 | 1.1 | 2.0 |
| | | GFDL A1FI | -0.3 | -1.1 | 0.2 |
| Winter (Dec-Feb) | 9.2 | PCM B1 | 0.0 | 0.6 | 0.7 |
| | | GFDL A1FI | 0.9 | 1.2 | 2.1 |
| Spring (Mar-May) | 11.5 | PCM B1 | 0.8 | 1.0 | 0.7 |
| | | GFDL A1FI | 0.7 | 0.5 | 1.7 |
| Summer (Jun-Aug) | 12.7 | PCM B1 | 0.7 | 1.4 | 1.8 |
| | | GFDL A1FI | -1.1 | -2.6 | -4.1 |
| Fall (Sep-Nov) | 9.7 | PCM B1 | -1.3 | -2.0 | -1.2 |
| | | GFDL A1FI | -0.7 | -0.2 | 0.4 |

[a] The 1971 through 2000 value is based on observed data from weather stations.

Annual precipitation across the assessment area is projected to increase throughout the 21st century for PCM B1, with the rate of change increasing after the early century time period. Under GFDL A1FI, precipitation is projected to decrease through mid-century before ultimately increasing slightly at the end of the century (Fig. 28). The seasonal precipitation trends for summer and fall exhibit even more departure from the baseline between the two scenarios (Appendix 3). For example, PCM B1 projects summer precipitation to increase steadily through the end of the 21st century, but GFDL A1FI projects summer precipitation to steadily decrease. Projections for fall follow a similar pattern, but the magnitude of change is less.

These changes in precipitation are projected to vary across the assessment area (Fig. 29). Similar to differences in past and future temperature, there is a noticeable trend of decreased precipitation that corresponds with the higher-elevation Allegheny Mountains in West Virginia and Maryland (Section M221B). The baseline climate (1971 through 2000) of this section is consistently much wetter than surrounding areas (see Chapter 3: Fig. 15), especially in spring and summer. Precipitation at the end of the century, however, is projected to decrease more than surrounding areas, by as much as 4 to 5 inches for both PCM B1 and GFDL A1FI. This trend is visible through all seasons. Precipitation is also projected to vary spatially by season, notably with a projected summer increase followed by the fall decrease for PCM B1. Under GFDL A1FI, this sign change occurs earlier in the season, with a projected spring increase followed by summer decrease.

## PROJECTED TRENDS IN EXTREMES

Mean temperature and precipitation are not the only climatic factors that can have important effects on forest ecosystems. As outliers from the average climate, extreme weather events are difficult to forecast and model reliably. In general, there is less confidence in model projections of extreme events over the next century compared with general temperature and precipitation changes, but recent research is beginning to provide more evidence for the magnitude and direction of change in many extreme weather events across the eastern United States (Kunkel et al. 2013a).

### Extreme Temperatures

In addition to projecting mean temperatures, downscaled daily climate data can be used to estimate the frequency of extreme high and low temperatures in the future. Studies of extreme temperatures often define hot days as days hotter than 95 °F and cold days as days colder than 32 °F. A study of the United States projects an increase in hot days in the next three decades (Diffenbaugh and Ashfaq 2010). However, heat waves are difficult to analyze regionally because a heat wave in one area may be considered within the normal temperature range in another area. To account for anomalies across a broad landscape, temperature extremes are often analyzed using the distribution of temperatures (e.g., 95th percentile of maximum daily temperature) or a specific threshold temperature (e.g., 95 °F). Studies from across the Midwest and Northeast consistently project 20 to 30 more hot days per year by the end of the century (Diffenbaugh et al. 2005, Ebi and Meehl 2007, Gutowski et al. 2008, Intergovernmental Panel on Climate Change [IPCC] 2012, Meehl and Tebaldi 2004, Winkler et al. 2012). Under the A2 emissions scenario (see Chapter 2), the West Virginia and Maryland portions of the assessment area are projected to double their number of hot days by 2050 (Horton et al. 2013). The number of days above 90 °F is projected to increase by 19 days in the Midwest and 26 days in the Northeast by mid-century, and days over 100 °F are projected to increase by 11 and 8 days, respectively (Kunkel et al. 2013b, 2013c). Furthermore, the hottest days that occur every 20 years are projected to occur every other year by the end of the century (Gutowski et al. 2008). The frequency of multi-day heat waves is also projected to increase by 3 to 6 days in southeastern Ohio and northwestern West Virginia (Diffenbaugh et al. 2005).

The frequency of cold days and cold nights in the assessment area is projected to decrease by 12 to 15 days by the end of the century (Diffenbaugh et al. 2005). These trends are consistent with assessments covering the entire Midwest and Northeast regions, which projected that the assessment area could experience 22 to 26 fewer days below 32 °F and 9 to 10 fewer days below 0 °F by the middle of the 21st century (Kunkel et al. 2013b, 2013c).

### Intense Precipitation

As described in Chapter 3, there is a clear trend toward more heavy precipitation events in the Midwest and Northeast (Gutowski et al. 2008, Kunkel et al. 2008, Saunders et al. 2012). Rainfall from these high-intensity events represents a larger proportion of the total annual and seasonal rainfall, meaning that the precipitation regime is becoming more episodic. Climate models project an overall increase in the number of heavy precipitation events globally by the end of the century (IPCC 2007, 2012). Global model projections indicate a potential increase in these events in the central and northeastern United States, especially during winter months (IPCC 2012). Future climate projections for the contiguous United States indicate that the Central Appalachians may experience 2 to 4 more days of heavy (greater than 3 inches) precipitation annually by the end of the century (2070 through 2095) (Diffenbaugh et al. 2005). The same study projected that the frequency of dry days will increase by 8 to 10 days annually by the end of the century.

Multiple models originating from the Climate Model Intercomparison Project (15 models), statistically downscaled models (8 models), and dynamically downscaled models (11 models) were run under a high emissions scenario (A2) and a low scenario to create a range of simulations for comparison of projections of precipitation and extremes. Multiple simulations for the Midwest (including the Ohio portion of the assessment area) generally agree that mid-century heavy precipitation days (greater than 1 inch) could increase by 10 to 20 percent, although models differ widely (Kunkel et al. 2013b). Downscaled projections for the Northeast (including the West Virginia and Maryland portions of the assessment area) indicate increases of up to 30 percent in heavy precipitation events (Kunkel et al. 2013c). Within some areas in West Virginia, more than 50 percent of climate models show increases. Although simulations consistently project an upward trend in extreme events, the magnitude of change is more uncertain, reflecting the high spatial and temporal variability in extreme precipitation data.

It is important to consider this trend in combination with the projected changes in mean precipitation over the 21st century. A given increase or decrease in precipitation is unlikely to be distributed evenly across a season or even a month. Additionally, large-scale modeling efforts have also suggested that climate change will increase the year-to-year variability of precipitation across the Midwest and Northeast (Boer 2009). Further, ecological systems are not all equally capable of holding moisture that comes in the form of extreme events. Areas dominated by very coarse- or very fine-textured or shallow soils may not have the water holding capacity to retain moisture received during intense rainstorms. More episodic rainfall could result in increased risk of drought stress between rainfall events or higher rates of runoff during rainfall events. Landscape position will also influence the ability of a particular location to retain moisture from extreme events; steep slopes shed runoff faster than flatter surfaces.

## Severe Weather: Thunderstorms, Hurricanes, and Tornadoes

The frequency of strong convective storms has increased in recent decades over the entire Midwest region (Changnon 2011a, 2011b; Diffenbaugh et al. 2008). Projected changes in temperature, precipitation, and convective available potential energy are expected to result in more frequent days over the next century with conditions that are favorable for severe storms (Trapp et al. 2007, 2009, 2011). Several model simulations project increases in thunderstorm frequency within the assessment area for both mid-range (A1B) and higher (A2) emissions scenarios (Trapp et al. 2007, 2009). These changes in storm-forming factors are also expected to influence the formation of tornadoes, although a recent synthesis report on extreme weather events stated that “there is low confidence in projections of small spatial-scale phenomena such as tornadoes and hail because competing physical processes may affect future trends and because current climate models do not simulate such phenomena” (IPCC 2012). As the sophistication of global and regional climate models increases, our understanding of how patterns in hail and tornadoes may change in the future will as well. A recent study using five model simulations projected that the frequency of days favorable for tornadoes rated F2 and greater will increase, and that the peak of tornado season may shift earlier in the season, from May to April (Lee 2012).

Projections of hurricane frequency have been associated with too much uncertainty for identifying a clear trend, but it is likely that the spatial distribution of hurricanes will change (Gutowski et al. 2008). For every 1.8 °F increase in sea surface temperature, North Atlantic hurricanes are expected to develop increased wind speeds (1 to 8 percent) and core rainfall rates (6 to 18 percent) (Gutowski et al. 2008). Orographic effects of tropical storms and hurricanes in the mountainous sections of the assessment area also have the potential to increase precipitation and subsequent flooding of river channels (Sturdevant-Rees et al. 2001).

The Allegheny Mountains, home to a diverse array of high-elevation wetlands. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

## PHYSICAL PROCESSES

Information regarding how temperature and precipitation patterns may change across the assessment area can further be used to examine how these changes may affect the cycling of water in forest ecosystems. Across the globe, increases in temperature are projected to intensify the hydrologic cycle, leading to greater evaporative losses and more heavy precipitation events (IPCC 2007). By examining soil moisture, evapotranspiration, and various drought indices, we can gain an understanding of how these changes may affect water availability for trees, understory plants, wetlands, and rivers. In addition, examining changes in runoff and streamflow can help us assess potential flood risks and changes in watershed dynamics.

### Flooding and Streamflow

Floods occur from a combination of hydrologic, climatological, and biogeographical conditions. High-intensity rainfall events are linked to both localized flash flooding and widespread regional floods, and their effects depend on soil saturation and stream levels at the time of the event. Earlier in this chapter, we discussed projected increases in annual precipitation, and more importantly, a shift towards more episodic and extreme precipitation events. The amount of precipitation that exceeds soil water-holding capacity is available as runoff, which ultimately determines streamflow. Therefore, streamflow can be used as an indicator of the potential for increased flooding, in the absence of more direct indicators. A study in the Mid-Atlantic region projected that increases in temperature at the end of the century would lead to increased evapotranspiration and an increase in summer and fall water deficit (Moore et al. 1997). Consequently, mean annual streamflow was projected to decrease across the assessment area by 21 percent, with the most dramatic decreases occurring in the fall and winter (Moore et al. 1997). Another study in the Mid-Atlantic region projected that increases in precipitation in winter and spring will result in increased streamflow early in the year, and that decreases in precipitation in summer will result in decreased streamflow late in the year (Neff et al. 2000).

## Snow and Winter Storms

Recent studies across much of the Midwest and Northeast have shown that the ratio of snow to rain is strongly correlated with daily mean air temperature in winter (Feng and Hu 2007, Kunkel et al. 2002). Within the assessment area, it is projected that winter mean temperatures will increase by 2.1 °F for PCM B1 and by 5.5 °F for GFDL A1FI by the end of the century, so that winter precipitation in the form of rain is likely to increase.

Global models have projected decreases in snow cover across the mid-latitudes with exceptions at high elevation, such as the Sierra Nevada mountain range in the western United States (Hosaka et al. 2005, Kapnick and Delworth 2013). The highest elevations within the assessment area do not produce similar exceptions in these broad-scale models, which project shorter snow duration and decreased snow-water equivalent (IPCC 2007, Lemke et al. 2007). According to two GFDL models, snowfall in the assessment area is projected to decrease by 20 to 50 percent over the next 70 years (Fig. 30) (Kapnick and Delworth 2013). Regional snow cover is projected to decrease by 1.2 to 4 inches by the end of the century for a mid-range emissions scenario (A1B; see Chapter 2) (Hosaka et al. 2005). These are consistent with projections of decreased snow events, snowpack, and snow duration in the Northeast and Midwest (Campbell et al. 2010, Hayhoe et al. 2007, Kunkel et al. 2013a).

In general, warming temperatures may lead to a decrease in the overall frequency of ice storms and snowstorms due to a reduction in the number of days that are cold enough for those events to occur. However, there is research to suggest that snowfall in lake-effect areas may increase over the short term if the necessary conditions are present: reduced ice cover on the Great Lakes must result in increased evaporation from the open water, and winter temperatures must remain cold enough for the movement of increased moisture over the land surface to generate snow (Burnett et al. 2003, Wright et al. 2013). Ice cover has declined in recent years on both Lakes Erie and Michigan (Burns et al. 2005, Wang et al. 2012). Projected increases in air temperatures are expected to drive decreases in ice cover duration and extent on the Great Lakes, potentially allowing more winter evaporation and lake-effect snow (Kling et al. 2003, Wright et al. 2013).

Shifts in winter precipitation and temperature are expected to advance the timing of snowmelt runoff earlier into the year (Hodgkins and Dudley 2006). The ability of soils to absorb this moisture will depend on land cover, infiltration rates, and the soil frost regime (Eisenbies et al. 2007). If soils are able to absorb and retain more of this moisture, soil moisture could be higher at the outset of the growing season. If this moisture is instead lost to runoff,

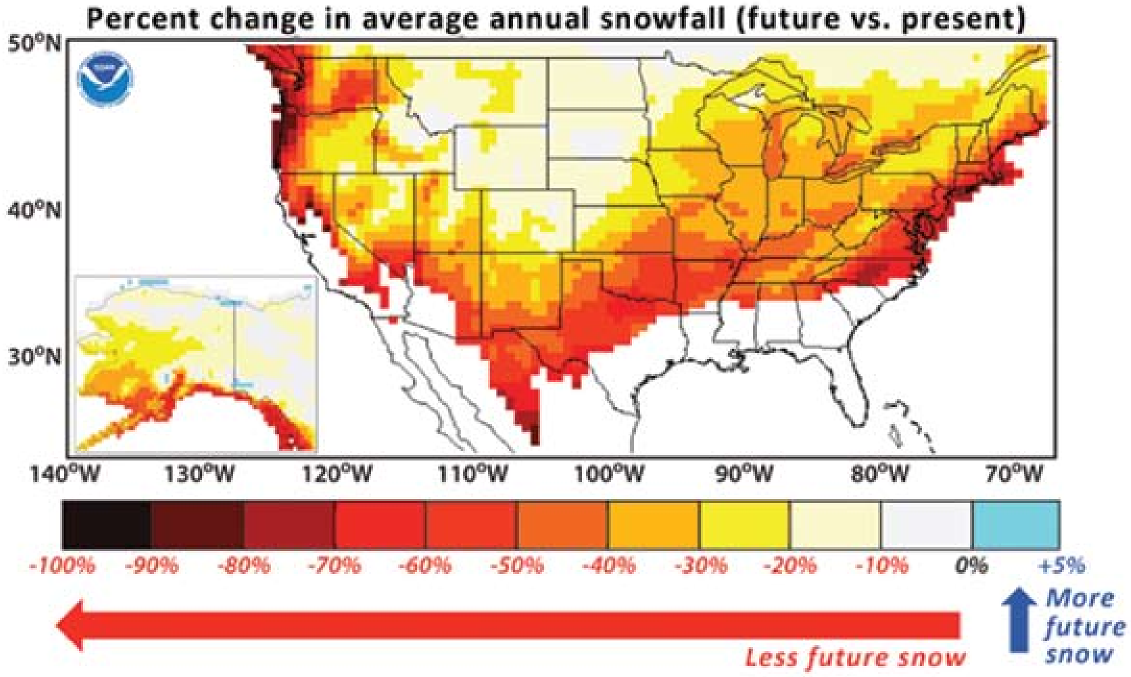


Figure 30.—Projected change in annual mean snowfall across the United States over the next 70 years (Kapnick and Delworth 2013).

forests in the assessment area could be more likely to enter the growing season without sufficient moisture to sustain them throughout the growing season.

## Snow Cover and Soil Frost

The dynamics of snow and frozen soil can have important implications for water availability at the beginning of the growing season. Winter temperatures are projected to increase across the assessment area for both PCM B1 and GFDL A1FI, especially minimum winter temperatures (see Figures 25 through 27). Snow cover typically insulates forest soils, so reduced snowpack could leave the soil surface more exposed to fluctuations in air temperature (Campbell et al. 2010). The degree of warming, and its effects on snowpack, therefore, is likely to determine the impacts on soil temperature, water infiltration, and spring photosynthesis. There are currently no published studies available that have examined this relationship in the assessment area, but studies from adjacent areas can help us understand potential changes. A study that attempted to integrate these complex trends at the Hubbard Brook Experimental Forest used three climate models (Hadley, GFDL, and PCM) for two scenarios (A1FI and B1) through the year 2100 (Campbell et al. 2010). Four of the six scenarios projected increases in total annual and winter precipitation. Although there are no projected changes in soil frost depth, and only a slight increase in freeze-thaw events, the total number of days of soil frost is projected to decline as a direct result of declining snowpack (Campbell et al. 2010). Therefore, it is likely that warmer winter air temperatures will more than counteract the loss of snow insulation and soil frost will generally be reduced across the assessment area. These projections are generally consistent with studies of snowpack and soil frost in the Midwest (Sinha and Cherkauer 2010).

## Drought and Soil Moisture

Changes in soil moisture are largely driven by the balance of precipitation and evapotranspiration, and there is some uncertainty about future precipitation changes, especially in areas of complex topography. Further, projections differ widely among models, and an increase in precipitation (and also soil moisture) is expected during the winter and spring. Conversely, decreases are expected in summer or fall, and late-season droughts may become more frequent and more severe, especially when higher air temperatures increase potential evapotranspiration (Gutowski et al. 2008). Many model simulations have projected an increase in summer drying in the mid-latitudes, indicating increased risk of drought (Gutowski et al. 2008). In a study of the northeastern United States, the frequency of short- (1 to 3 months), medium- (3 to 6 months), and long-term (6 months or longer) drought was projected to increase by 3, 0.4, and 0.04 droughts, respectively, per 30-year time interval (Hayhoe et al. 2007).

The Variable Infiltration Capacity model, used to explore seasonal soil saturation across the United States during 2071 through 2100, also projected summer and fall decreases in soil moisture, with the greatest decrease (10 percent) in the West Virginia portion of the assessment area (Ashfaq et al. 2010). These broad-scale trends can be useful for estimating a range of potential changes; however, local soil moisture responses to changes in temperature and precipitation are likely to be highly variable within the Central Appalachians, depending on landscape position, normal variability in weather events, and degree of climate change.

## Evapotranspiration

Evapotranspiration is an important indicator of moisture availability in an ecosystem and the amount of water available to be lost as runoff. Increased precipitation can provide more water available to be evaporated from the soil or transpired by plants. Increased temperature can also drive increases in evapotranspiration, but only as long as there is enough water available. Projected changes in evapotranspiration differ considerably by hydrologic model and climate models used, and whether changes in vegetation are also considered. A study using a regional climate model to examine changes across the continental United States projected an increase in evapotranspiration across the assessment area in summer, which was closely associated with increased precipitation and soil moisture (Diffenbaugh et al. 2005). Another study examining changes averaged over 2071 through 2100 projected increases in evapotranspiration across the assessment area in spring (Ashfaq et al. 2010). In the summer, the largest increases in evapotranspiration were projected in the Allegheny Mountains. Moderate increases during fall were projected mostly east of the Allegheny Mountains, and there was little to no change in evapotranspiration during winter (Ashfaq et al. 2010).

Projections of evapotranspiration were modeled at a finer scale by Pitchford et al. (2012) within the mountainous Mid-Atlantic Highlands region of the assessment area (covering all but the Ohio portion). This study area is topographically complex, with microclimates that are cooler and warmer than regional averages. As temperatures increased by 1.8 and 9 °F, evapotranspiration increased by 0.2 and 1.3 inches per month, with much of the change occurring in the summer months. These results suggest that increasing temperatures could reduce soil water availability.

As we will discuss in Chapters 5 and 6, climate change is further projected to affect the distribution of trees and other plant species, which could also affect evapotranspiration on the landscape. Increases in carbon dioxide are expected to lead to changes in the water use efficiency of vegetation (Drake et al. 1997), but these changes are not currently accounted for in model projections of evapotranspiration across the region.

## Growing Season Length

The assessment area has experienced shifts in the growing season over the past century, as noted in Chapter 3. Growing seasons are dictated by a variety of factors, including day length, air temperatures, soil temperatures, and dates of first and last frost (Linderholm 2006). Therefore, there are a variety of metrics to describe how growing seasons may continue to change for a range of climate scenarios. A study covering the entire Midwest region (including the Ohio portion of the assessment area) examined the changes in dates for the last spring frost and first fall frost by using two models (PCM and HadCM3) for four climate scenarios (Wuebbles and Hayhoe 2004). This study projected that the growing season will be extended by 30 days for the B1 emissions scenario and 70 days for the A1FI scenarios as the last spring frost dates are projected to shift earlier into the year at approximately the same rate that first fall frost dates will retreat later into the year. A study covering the Northeast (including the West Virginia and Ohio portions of the assessment area) examined changes in the last spring frost and first fall frost by using multiple models with the A2 scenario (which projects lower greenhouse gas emissions than A1FI at mid-century) and predicted that the freeze-free season will increase by 19 days by 2055 (Fig. 31) (Kunkel et al. 2013c). A similar study of the freeze-free season in the Midwest region (including the Ohio portion of the assessment area) projected an increase of 22 to 25 frost-free days (Fig. 31) (Kunkel et al. 2013b). How this translates into the actual length of the growing season, as determined by leaf-out and senescence, has not yet been examined for the region.

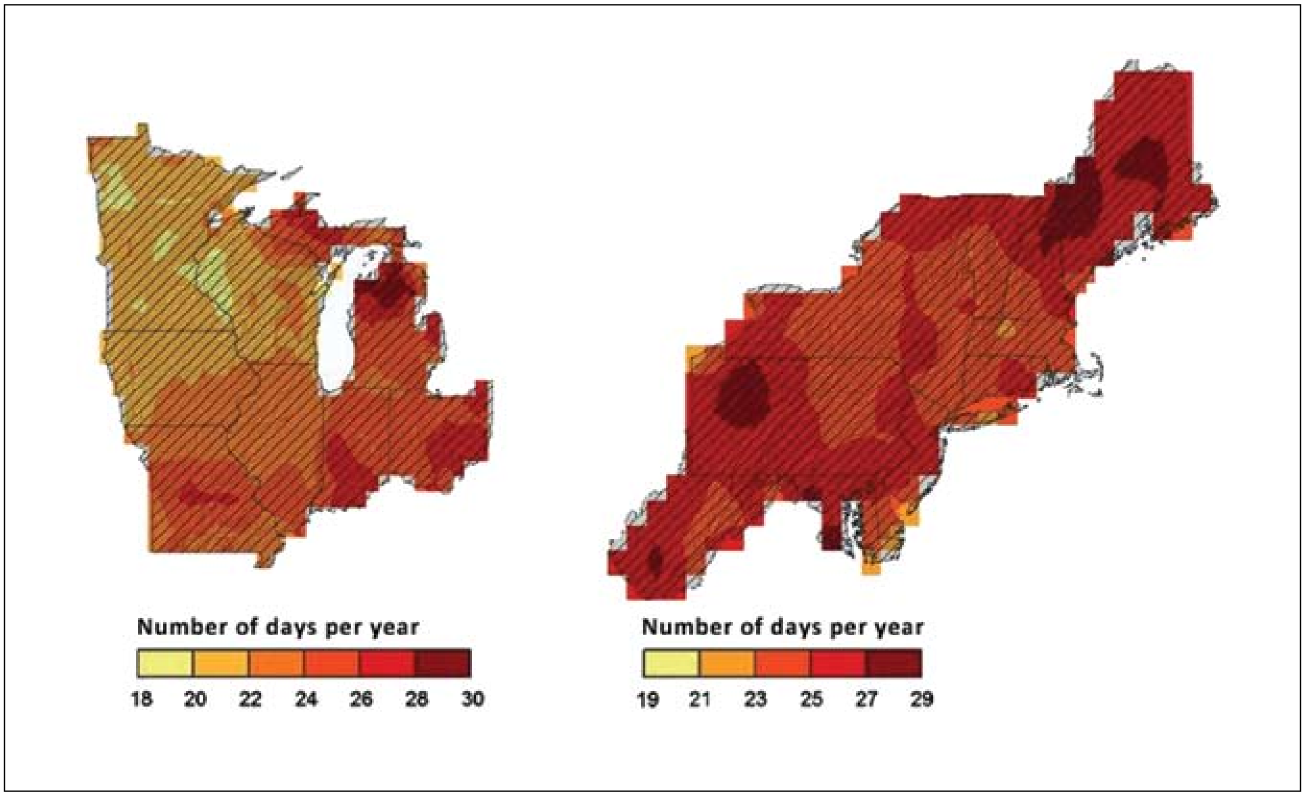


Figure 31.—Projected changes in length of frost-free season across the Midwest (Kunkel et al. 2013b) and Northeast (Kunkel et al. 2013c). Projections from 2041 through 2070 are shown relative to the 1980 through 2000 baseline. Projections are the mean of eight simulations for the A2 scenario. Modified from Kunkel et al. (2013b, 2013c).

## CHAPTER SUMMARY

Projected trends in annual, seasonal, and monthly temperature (mean, minimum, and maximum) and total precipitation indicate that the climate will continue to change through the end of this century. Temperatures are projected to increase across all seasons, with extreme warming for the high emissions scenario over the 21st century. The "worst-case scenario" (A1FI) projects annual temperatures that reach 8 to 10 °F higher than the last 30 years of the 20th century. The PCM B1 scenario, despite projecting only slight increases for other seasons, projects winter minimum temperature to increase by 2 to 4 °F over most of the assessment area. Precipitation is projected to increase in winter and spring by 2 to 5 inches (depending on scenario), leading to potential spring increases in runoff and streamflow. Projections of precipitation differ among climate models in summer and fall; however, higher temperatures during those seasons mean that much of that precipitation will contribute to increased evapotranspiration. Changes in temperature and precipitation are projected to lead to changes in extreme weather events and local hydrology. There is fairly high certainty that heavy precipitation events will increase, snow cover will decrease, and eventually soil frost will decrease as well. However, more uncertainty remains with respect to changes in tornadoes and thunderstorms, seasonal soil moisture patterns, and flooding. In the next chapter, we examine the ecological implications of these anticipated changes on forest ecosystems.

# CHAPTER 5: FUTURE CLIMATE CHANGE IMPACTS ON FORESTS

Changes in climate have the potential to profoundly affect forests of the Central Appalachians region. Many tree species that are currently present may fare worse with warmer temperatures and altered precipitation patterns. Other species may do better under these conditions, and some species not currently present may have the potential to do well if conditions allow them to disperse to newly suitable areas. In addition, climate change can have indirect effects on forests in the region by changing the populations and dynamics of insect pests, pathogens, invasive species, nutrient cycling, and wildfire regimes. In this chapter, we summarize the potential impacts of climate change on forests in the Central Appalachians region over the next century, with an emphasis on changes in tree species distribution and abundance.

## MODELED PROJECTIONS OF FOREST CHANGE

Forest ecosystems in the assessment area may respond to climate change in a variety of ways. Potential changes include shifts in the spatial distribution, abundance, and productivity of tree species. For this assessment, we rely on a combination of three forest impact models to describe these potential changes: the Climate Change Tree Atlas (DISTRIB), LINKAGES, and LANDIS PRO (Table 18). The Tree Atlas uses statistical techniques to model changes in suitable habitat for individual species over broad geographic areas. LINKAGES predicts establishment and growth of trees based on soils and other site information and climate. LANDIS PRO simulates changes in basal area and trees per acre to project the abundance and distribution of individual tree species. No single model offers a comprehensive projection of future impacts on forest ecosystems, but each tool is valuable for a particular purpose or set of questions. Similarities in patterns across models suggest less uncertainty in projections than when patterns differ, and differences in patterns provide opportunities to better understand the nuances of ecological responses given the strengths and limitations of the models. For a more thorough description of the different models, and specifically how they were applied for this assessment, see Chapter 2.

All three research teams used the same downscaled climate projections from two combinations of general circulation models (GCMs) and emissions scenarios described in detail in Chapter 4: GFDL A1FI and PCM B1. Projected changes in temperature and precipitation for GFDL A1FI represent the higher end of the range of changes, and projections for PCM B1 represent the lower end. This consistency in the climate data used in each modeling approach means that the forest impact models describe potential forest changes over the same range of plausible future climates.

These model results are most useful to describe trends across large areas and over long time scales. These models are not designed to deliver precise results for individual forest stands or a particular year in the future, despite the temptation to examine particular data points or locations on a map. Maps are spatially representative but not spatially exact. In this chapter, we present model results for the end of the 21st century. Data for intermediate time periods are provided in Appendix 4.

**Table 18.—Overview of the three models used in this assessment**

| Feature | Tree Atlas | LINKAGES | LANDIS PRO |
|---|---|---|---|
| Summary | Suitable habitat distribution model (DISTRIB) + supplementary information (modifying factors) | Patch-level forest succession and ecosystem dynamics process model | Spatially dynamic forest landscape process model |
| Primary outputs for this assessment | Area-weighted importance values and modifying factors by species | Species establishment and growth maps (% change) | Basal area, and trees per acre by species |
| Model-scenario combinations | GFDL A1FI and PCM B1 | | |
| Assessment area | Central Appalachians assessment area within Ohio, West Virginia, Maryland: Sections 221E and 221F in Province 221; Sections M221A, M221B, and M221C in Province M221 | | |
| Resolution | 12-mile grid | 0.2-acre (1/12-ha) plots representing landforms in subsections | 886-foot grid |
| Number of species evaluated | 94 | 23 | 17 |
| Control/baseline climate | 1971 through 2000 | 1990 through 2009 | n/a |
| Climate periods evaluated | 2010 through 2039, 2040 through 2069, 2070 through 2099 | 1990 through 2009, 2080 through 2099 | 2009 through 2099 |
| Simulation period | n/a | 30 years | 2009 through 2099 |
| Competition, survival, and reproduction | No | Yes | Yes |
| Disturbances | No (but addressed through modifying factors) | No | Timber harvest |
| Tree physiology feedbacks | No | Yes | No |
| Succession or ecosystem shifts | No | No | Yes |
| Biogeochemical feedbacks | No | Yes | No |

## Tree Atlas

Importance values of 134 eastern tree species were modeled for potential habitat suitability in the assessment area by using the DISTRIB model, a component of the Tree Atlas toolset (Landscape Change Research Group 2014). From U.S. Forest Service Forest Inventory and Analysis (FIA) data, the number of stems and the basal area were used to calculate importance values for each 12.4-mile grid cell for each tree species. For an individual grid cell, the importance value for a species can range from 0 (not present) to 100 (completely covering the area). Importance values for each pixel were then summed across the assessment area to calculate the area-weighted importance value for a species; thus area-weighted importance values can be greater than 100. This analysis was conducted for the assessment area and for individual ecological sections within the assessment area. Results for the entire assessment area are presented in the text below. Appendix 4 contains the full set of results summarized by ecological section. More information on Tree Atlas methods can be found in Chapter 2.

Of the 134 species modeled, 93 currently have or are projected to have suitable habitat in the area. The projected changes in suitable habitat for the 93 species were calculated for the years 2070 through 2099 for the GFDL A1FI and PCM B1 scenarios and compared to present values (Table 19). Species were categorized based upon whether the results from the two climate scenarios projected an increase, decrease, or no change in suitable habitat compared to current conditions, or if the model results were mixed. Further, some tree species that are currently not present in the assessment area were identified as having potential suitable habitat in the future for one or both scenarios. See Appendix 4 for complete results from the DISTRIB model for early (2010 through 2039), middle (2040 through 2069), and end (2070 through 2099) of century time periods. Roughly half of the tree species modeled are found in every section of the assessment area, whereas half are missing from at least one section. Section M221B (Allegheny Mountains) contains the highest number of species (74), and Section M221C (Northern Cumberland Mountains) has the lowest number of species (62). This is not an accurate reflection of species diversity, however, because only the most common species were modeled.

Modifying factors have also been incorporated into the Tree Atlas to provide additional information on potential forest change. Modifying factors include life history traits and environmental factors that make a species more or less able to persist in the eastern United States (Matthews et al. 2011b). These factors are not explicitly included in the DISTRIB outputs, and are based on a review of a species' life-history traits, known stressors, and other factors. Examples of modifying factors include drought tolerance, dispersal ability, shade tolerance, site specificity, and susceptibility to insect pests and diseases. Factors are identified for a species throughout its range and do not account for site-specific conditions which may also influence a species' potential for change. For each modifying factor, a species was scored on a scale from -3 (very negative response) through +3 (very positive response), and further weighted by confidence and relevance to future projected climate change. The means of these scores were plotted to determine an overall score of adaptability (see Appendix 4 for detailed methods). Information on adaptability is included in the summary of projected changes in habitat (Table 19), where a plus (+) or minus (-) sign after a species name indicates that certain modifying factors could lead the species to do better or worse, respectively, than DISTRIB model results indicate. As an example, the species with the five highest and five lowest adaptability scores are displayed in Table 20. Appendix 4 contains more information on the specific modifying factors and overall adaptability scores for each species.

**Table 19.—Potential changes in suitable habitat for 93 tree species[a] in the Central Appalachians region**

| Common name | PCM B1 | GFDL A1FI |
|---|---|---|
| **Declines under Both Scenarios** | | |
| Balsam fir (-) | Small Decrease | Large Decrease |
| Bigtooth aspen | Large Decrease | Extirpated |
| Black ash (-) | Large Decrease | Small Decrease |
| Black cherry (-) | Small Decrease | Large Decrease |
| Chokecherry | Small Decrease | Extirpated |
| Pin cherry | Small Decrease | Large Decrease |
| Quaking aspen | Large Decrease | Large Decrease |
| Red pine | Large Decrease | Large Decrease |
| Striped maple | Small Decrease | Large Decrease |
| Yellow birch | Small Decrease | Large Decrease |
| **No Change under Both Scenarios** | | |
| American chestnut | No change | No change |
| American holly | No change | No change |
| American hornbeam | No change | No change |
| Bear oak (scrub oak) | No change | No change |
| Blackgum (+) | No change | No change |
| Cucumbertree | No change | No change |
| Mountain maple (+) | No change | No change |
| Northern pin oak (+) | No change | No change |
| Pignut hickory | No change | No change |
| Pitch pine | No change | No change |
| Serviceberry | No change | No change |
| Southern magnolia | No change | No change |
| Tamarack (native) (-) | No change | No change |
| Yellow buckeye (-) | No change | No change |
| **Increases under Both Scenarios** | | |
| Bitternut hickory (+) | Large Increase | Large Increase |
| Blackjack oak (+) | Small Increase | Large Increase |
| Chinkapin oak | Large Increase | Large Increase |
| Common persimmon (+) | Large Increase | Large Increase |
| Eastern redcedar | Large Increase | Large Increase |
| Eastern redbud | Small Increase | Small Increase |
| Green ash | Small Increase | Large Increase |
| Hackberry (+) | Small Increase | Large Increase |
| Honeylocust | Small Increase | Large Increase |
| Osage-orange (+) | Small Increase | Large Increase |
| Post oak (+) | Large Increase | Large Increase |
| Shagbark hickory | Small Increase | Large Increase |
| Shingle oak | Small Increase | Large Increase |
| Shortleaf pine | Large Increase | Large Increase |
| Southern red oak | Large Increase | Large Increase |
| Sugarberry | Large Increase | Large Increase |
| Sweetgum | Large Increase | Large Increase |
| Winged elm | Large Increase | Large Increase |
| **Mixed Results** | | |
| American basswood | No Change | Large Decrease |
| American beech | No Change | Large Decrease |
| American elm | No Change | Small Decrease |
| Black locust | No Change | Small Decrease |
| Black maple | No Change | Large Decrease |
| Black oak | No Change | Large Increase |
| Black walnut | Small Increase | No Change |
| Black willow (-) | Small Decrease | Large Increase |
| Blue ash (-) | No Change | Small Decrease |
| Boxelder (+) | No Change | Small Increase |
| Bur oak (+) | No Change | Large Increase |
| Butternut (-) | No Change | Extirpated |
| Chestnut oak (+) | No Change | Small Decrease |
| Eastern cottonwood | Small Decrease | Large Increase |
| Eastern hemlock (-) | No Change | Small Decrease |
| Eastern hophornbeam (+) | No Change | Small Increase |
| Eastern white pine | No Change | Large Decrease |
| Flowering dogwood | No Change | Small Decrease |
| Loblolly pine (-) | No Change | Large Increase |
| Mockernut hickory | No Change | Small Increase |
| Northern catalpa | No Change | Small Increase |
| Northern red oak | No Change | Small Decrease |
| Ohio buckeye (-) | No Change | Large Decrease |
| Pawpaw | No Change | Large Decrease |
| Pin oak (-) | No Change | Small Increase |
| Red maple (+) | No Change | Large Decrease |
| Red mulberry | No Change | Large Increase |
| Red spruce (-) | No Change | Large Decrease |
| River birch | No Change | Small Increase |
| Rock elm (-) | No Change | Large Increase |
| Sassafras | No Change | Small Decrease |
| Scarlet oak | No Change | Small Decrease |
| Shumard oak (+) | NA | Large Increase |
| Silver maple (+) | Small Decrease | Large Increase |
| Slippery elm | No Change | Small Decrease |
| Sourwood (+) | Small Increase | Small Decrease |
| Sugar maple (+) | No Change | Large Decrease |
| Swamp white oak | No Change | Large Decrease |
| Sweet birch | No Change | Large Decrease |
| Sycamore | No Change | Small Increase |
| Table Mountain pine (+) | No Change | Small Increase |
| Tulip tree | No Change | Large Decrease |
| Virginia pine | Small Increase | No Change |
| White ash (-) | No Change | Large Decrease |
| White oak (+) | No Change | Small Increase |
| Willow oak | NA | Large Increase |

(continued on next page)

**Table 19 (continued).**

| Common name | PCM B1 | GFDL A1F |
|---|---|---|
| **New Suitable Habitat** | | |
| Black hickory | New Habitat | New Habitat |
| Cedar elm | NA | New Habitat |
| Northern white-cedar | NA | New Habitat |
| Water locust | NA | New Habitat |
| Water oak | NA | New Habitat |

[a]Species are grouped according to change classes (e.g., increase, no change) based on the percentage change in the area-weighted importance value projected for the end of century (2070 through 2099) for two climate-emissions scenarios. Species with the 20 highest or 20 lowest modifying factor scores are marked with plus (+) and minus (-) signs, respectively. Appendix 4 contains descriptions of change classes and complete results for all 93 species for the assessment area and for each ecological section.

When examining these results, it is important to keep in mind that model reliability is generally higher for common species than for rare species. FIA data also tend to undersample riparian areas as they are usually narrow strips within an upland matrix (Iverson et al. 2008). When model reliability is low, less certainty exists for the model results. See Appendix 4 for specific rankings of model reliability for each species.

**Table 20.—Species with the five highest and five lowest values for adaptive capacity based on Tree Atlas modifying factors**

| Species | Factors that affect rating |
|---|---|
| **Highest adaptive capacity** | |
| 1. Red maple | high probability of seedling establishment, wide range of habitats, shade tolerant, high dispersal ability |
| 2. Boxelder | high probability of seedling establishment, shade tolerant, high dispersal ability, wide range of temperature tolerances, drought tolerant |
| 3. Sourwood | good light competitor, wide range of habitats |
| 4. Bur oak | drought tolerant, fire tolerant |
| 5. Eastern hophornbeam | shade tolerant, wide range of temperature tolerances, wide range of habitats |
| **Lowest adaptive capacity** | |
| 1. Black ash | emerald ash borer susceptibility, poor light competitor, limited dispersal ability, poor seedling establishment, fire intolerant, dependent on specific hydrologic regime |
| 2. Butternut | butternut canker, drought intolerant, fire intolerant, poor light competitor |
| 3. Balsam fir | spruce budworm and other insect pests, fire intolerant, drought intolerant |
| 4. White ash | emerald ash borer, drought intolerant, susceptible to fire topkill |
| 5. Blue ash | emerald ash borer susceptibility, limited dispersal ability, fire intolerant, poor light competitor, dependent on specific hydrologic regime |

### Decreases in Suitable Habitat

For the Central Appalachians region, 10 of the 93 modeled species are projected to undergo large or small declines in suitable habitat for the full range of projected climate futures. Projected declines in habitat (as measured by a ratio of potential future importance value to current importance value) are more severe for GFDL A1FI than PCM B1 for most of these species. These reductions in suitable habitat do not imply that all or most mature trees will die or the species will be extirpated; rather, these results indicate that these species will be living outside their ideal climatic envelope. As a result, trees living in less suitable habitats may have greater susceptibility to stressors, and may also be at greater risk of regeneration failure. Generally, the changing climate tends to intensify or add to the stresses that may already exist for the species and increases susceptibility to drought, pests, diseases, or competition from other species including invasives.

Black cherry is currently abundant within the assessment area, but is projected to decline for both scenarios, more so for GFDL A1FI. The nine other species in this category are much less common on the landscape, and are projected to lose a large portion of suitable habitat for GFDL A1FI. Many of the species are currently near the southern limit of their range in the assessment area or exist as disjunct populations. Balsam fir and red pine are glacial relicts that are currently limited to higher elevations in West Virginia, and the majority of these species' ranges are much farther north (Hessl et al. 2011, Potter et al. 2010). Black ash distribution in the assessment area is closely tied to the Greenbrier Limestone. Decreases in suitable habitat may be catastrophic for these highly localized populations. Other species are not geographically limited, and are therefore more widespread throughout the assessment area. Bigtooth aspen and chokecherry are relatively widespread throughout the assessment area, and are projected to lose all suitable habitat for GFDL A1FI. Black ash, pin cherry, quaking aspen, striped maple, and yellow birch are currently rare on the landscape, and their suitable habitat is projected to decrease substantially.

Balsam fir and black ash also have highly negative modifying factors, suggesting that there are life-history traits or disturbance stressors that may cause these species to lose even more suitable habitat than the model results indicate. For example, the expanding presence of emerald ash borer in the assessment area is expected to greatly reduce the importance of black ash in the area; its impact will be much more than the loss that is projected to occur from changing climatic conditions. Modifying factors for balsam fir include susceptibility to balsam woolly adelgid and drought.

### No Change in Suitable Habitat

Fourteen species are projected to undergo less than a 20-percent change in suitable habitat for both scenarios. American hornbeam, blackgum, and pignut hickory are currently abundant across the region and their habitat is not projected to decrease or increase substantially. Blackgum has one of the highest adaptive capacity scores, partially because of its fire tolerance and shade tolerance, and it is likely to do better than projected. Serviceberry, pitch pine, cucumbertree, and yellow buckeye are less common on the landscape, and American chestnut, tamarack, mountain maple, scrub oak, and others are extremely rare (Appendix 4). Tamarack and yellow buckeye have several negative modifying factors, including habitat specificity and susceptibility to fire, insect pests, and drought, suggesting these species may fare worse than projected.

### Mixed Results in Suitable Habitat

The model results projected different outcomes for PCM B1 and GFDL A1FI for almost half of the species (44 of 93). For 23 of these species, DISTRIB projected that suitable habitat will not change or increase for PCM B1 but will decrease for GFDL A1FI, and one species (butternut) was projected to lose all suitable habitat. Many of these species are currently common in the assessment area, including American beech, American elm, black locust, black oak, chestnut oak, flowering dogwood, northern red oak, red maple, sassafras, sugar maple, white ash, white oak, and tulip tree. Chestnut oak, red maple, sugar maple, and white oak all have positive modifying factors that indicate that the species may fare better than the models suggest. This is particularly notable for red maple, which has the greatest strength of positive modifying factors among the 134 species that were assessed across the eastern United States. White ash has negative modifying factors due to emerald ash borer and drought mortality and may have even greater decreases than the model predicts.

For 17 species, DISTRIB projected that suitable habitat will increase for GFDL A1FI while not changing substantially for PCM B1. Black oak, eastern hophornbeam, mockernut hickory, and white oak are currently common in the assessment area. The remaining species are relatively infrequent or rare, including boxelder, bur oak, pin oak, and sycamore. These species are more frequently found southwest of the assessment area, and DISTRIB results suggest that suitable habitat will move northeast for future conditions. Boxelder, bur oak, and white oak have positive modifying factors, suggesting these species may do better than projected.

The remaining six species are projected to change for PCM B1 but have the opposite direction of change or no change for GFDL A1FI. Eastern cottonwood, black willow, and silver maple are projected to lose suitable habitat for PCM B1, but gain suitable habitat for GFDL A1FI. For sourwood, the trend is reversed. Virginia pine and black walnut gain suitable habitat for PCM B1, but maintain their current relative amounts for GFDL A1FI. These species may take advantage of increased temperatures by colonizing habitat at higher elevations that were previously too cool. Sourwood is currently a common species in the assessment area, frequently associated with pine and oak forests. The positive modifying factors associated with this species, including shade tolerance and an ability to occupy a wide range of sites, suggest that it may fare better than what the model projects.

## Increases in Suitable Habitat

Suitable habitat for 18 species is projected to increase for both models by the end of the century. All of these species are considered rare in the assessment area (see Appendix 4 for Tree Atlas rules regarding rare species). Many of these species, such as blackjack oak, chinkapin oak, common persimmon, eastern redcedar, eastern redbud, hackberry, honeylocust, post oak, shingle oak, shortleaf pine, southern red oak, sweetgum, and winged elm are close to the northern or eastern extent of their range.

Several species common to the south of the assessment area may become more widespread throughout the landscape, assuming higher regeneration success for future forest conditions. Because many of the species projected to lose suitable habitat are still expected to be major components of forest ecosystems by the end of the century, forests in the assessment area may have the potential to contain a higher diversity of species in the future, with a blend of southern and temperate species.

A few species within the increase category, such as shortleaf pine and winged elm, have negative modifying factors, which suggest that they may be less able to take advantage of increases in suitable habitat. At the same time, several species have positive modifying factors, such as bitternut hickory, blackjack oak, common persimmon, and post oak, and may be better able to cope with potential changes in climate, beyond what the models suggest.

## New Suitable Habitat

The DISTRIB model projects gains in suitable habitat for five species (black hickory, cedar elm, northern white-cedar, water locust, and water oak) that are currently not present in the assessment area for GFDL A1FI. This result does not necessarily mean that a given species will be able to migrate to newly available habitat and colonize successfully; it indicates instead that conditions may be suitable for a species to occupy the site if it can establish. Habitat fragmentation and the limited dispersal ability of seeds could hinder the northward movement of southern species, despite the increase in habitat suitability (Ibáñez et al. 2008), and most species can be expected to migrate more slowly than their habitats will shift (Iverson et al. 2004a, 2004b).

## Geographic Trends

Projected changes are not uniform across the assessment area, and areas of suitable tree habitat are governed by soils, moisture gradients, and other factors in addition to climate. The geographic and biological complexity of the Central Appalachians region warranted a closer look at the five ecological sections within the broader assessment area (see Chapter 1 for a map). Furthermore, Section 221E was split along the Ohio and West Virginia state lines and Tree Atlas results are available for those two smaller areas. Slightly more than half of the species modeled currently have or are projected to have suitable habitat in all six sections, and one-quarter of the species are modeled in four or five sections. The remaining one-quarter of the species are modeled in three or fewer sections. Among the species projected to have suitable habitat across four or more sections of the assessment area, distinct differences in climate, landform, and other characteristics often result in a variety of projected change classes between sections for a single species. Species showing significant geographic trends include: American elm, American hornbeam, blackgum, blackjack oak, black walnut, black willow, boxelder, butternut, chestnut oak, cucumbertree, eastern hophornbeam, eastern white pine, flowering dogwood, green ash, Ohio buckeye, pignut hickory, pitch pine, sassafras, scarlet oak, silver maple, and slippery elm. Appendix 4 shows a comparison of model results by section.

Outputs from DISTRIB can also be visualized as maps, such as those available online through the Climate Change Tree Atlas Web site (www.nrs.fs.fed.us/atlas), and these maps can provide greater context for interpreting the projected changes in suitable habitat. It is important to note that these maps detect relative change on a more detailed pixel by pixel basis rather than averaged by section within the assessment area, as presented above. For this assessment, the section boundaries were added to regional Tree Atlas maps in order to help orient the reader.

Maps for four species (chestnut oak, sugar maple, eastern white pine, and red spruce) are shown below. Chestnut oak is projected to retain a large amount of suitable habitat in the assessment area for PCM B1, whereas suitable habitat decreases more for GFDL A1FI, with the greatest loss of suitable habitat projected in Section 221F (Fig. 32). Under PCM B1, chestnut oak is projected to gain new suitable habitat in the western portion of the assessment area (221F and 221E Ohio), with no change in the eastern portion (Fig. 32). Sugar maple suitable habitat is projected to decrease across the assessment area, especially around the center of the assessment area (221E Ohio and West Virginia, M221C) for PCM B1, with a much greater loss of habitat projected for GFDL A1FI (Fig. 33). Eastern white pine is currently largely absent or of low importance value across most of the assessment area, with declines projected over most of the current habitat for PCM B1, and complete loss of habitat projected across Province 221 (221F and 221E Ohio and West Virginia). The only suitable habitat remaining for white pine for GFDL A1FI is in Province M221, where suitable habitat is projected to stay the same

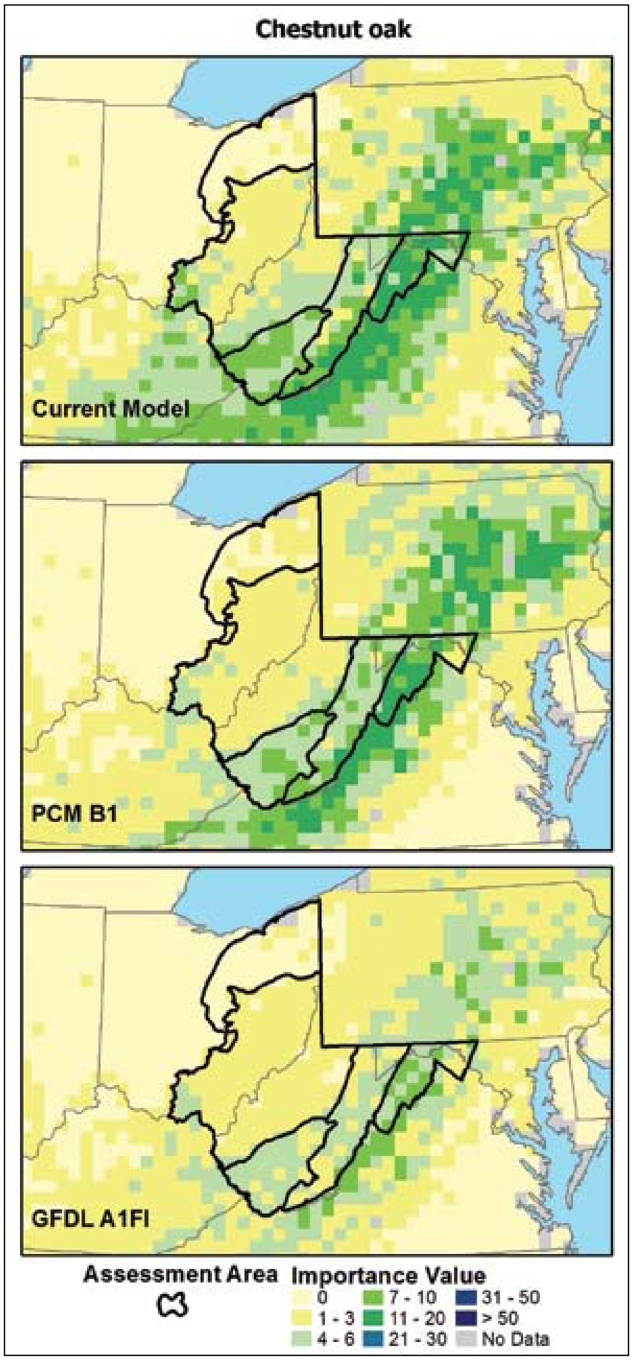


Figure 32.—Modeled importance values for chestnut oak across the assessment area and the larger geographic region for current climate conditions (top) and projected for the end of the century (2070 through 2099) for the PCM B1 (middle) and GFDL A1FI (bottom) climate scenarios, from the Tree Atlas model. Importance values can range from 0 to 100. An importance value of zero (light yellow) indicates that the species is not present currently, or will not have suitable habitat at the end of the century.

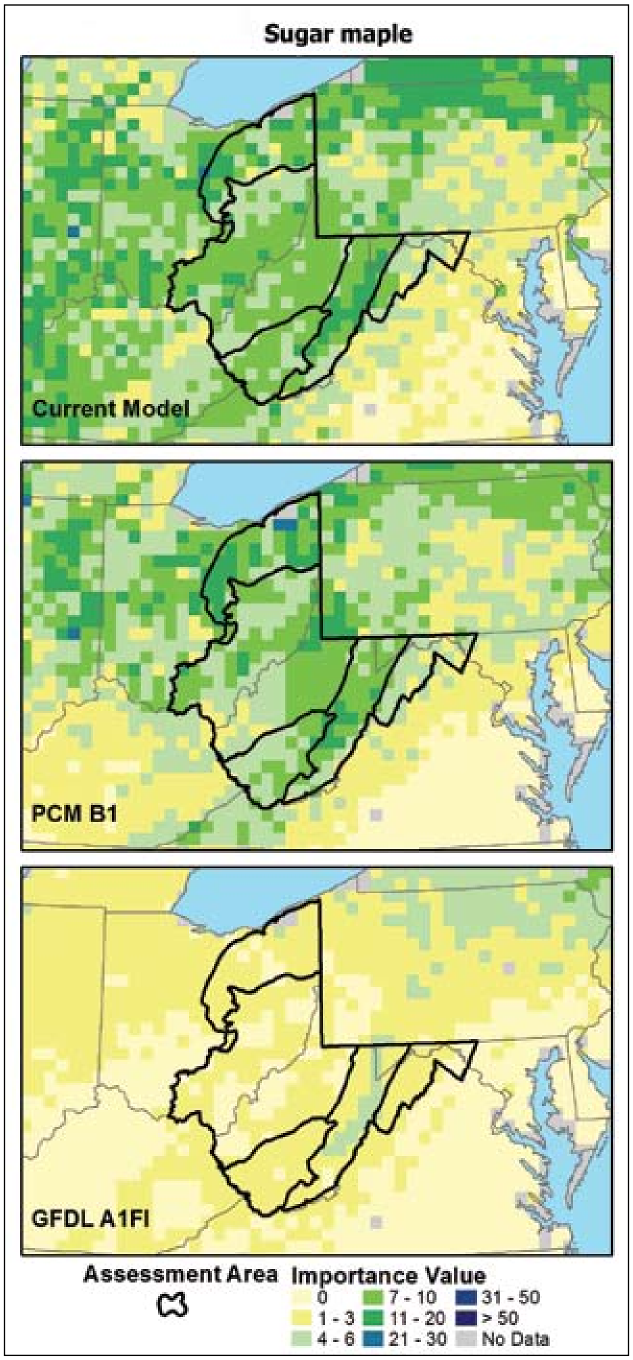


Figure 33.—Modeled importance values for sugar maple across the assessment area and the larger geographic region for current climate conditions (top) and projected for the end of the century (2070 through 2099) for the PCM B1 (middle) and GFDL A1FI (bottom) climate scenarios, from the Tree Atlas model. Importance values can range from 0 to 100. An importance value of zero (light yellow) indicates that the species is not present currently, or will not have suitable habitat at the end of the century.

in M221B and M221C, and decrease in M221A (Fig. 34). Red spruce is even more geographically constrained for current climate, largely limited to Section M221B (eastern West Virginia), and habitat suitability is projected to decrease for GFDL A1FI (Fig. 35). Red spruce is currently recovering from past harvesting and fire disturbance, and is expanding on the landscape to refill its niche (Nowacki et al. 2009, Seidel et al. 2009). Early-century increases in red spruce due to succession and planting efforts may help the species do better than models project in the short term.

These maps should be interpreted carefully. As mentioned above, DISTRIB results indicate only a change in suitable habitat, not necessarily that a given species will be able to migrate to newly available habitat. Additionally, these results do not incorporate the influence of modifying factors (positive for sugar maple and chestnut oak, negative for eastern white pine and red spruce). Suitable habitat maps assessing the whole eastern United States are available online through the Climate Change Tree Atlas Web site (www.nrs.fs.fed.us/atlas) for all the species in this assessment (see Appendix 4). As is the case for interpreting any spatial model outputs, local knowledge of soils, landforms, and other factors is necessary to determine if particular sites may indeed be suitable habitat for a given species in the future. These maps serve only as an illustration of broad trends.

The Allegheny Mountains, home to a diverse array of high-elevation wetlands. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

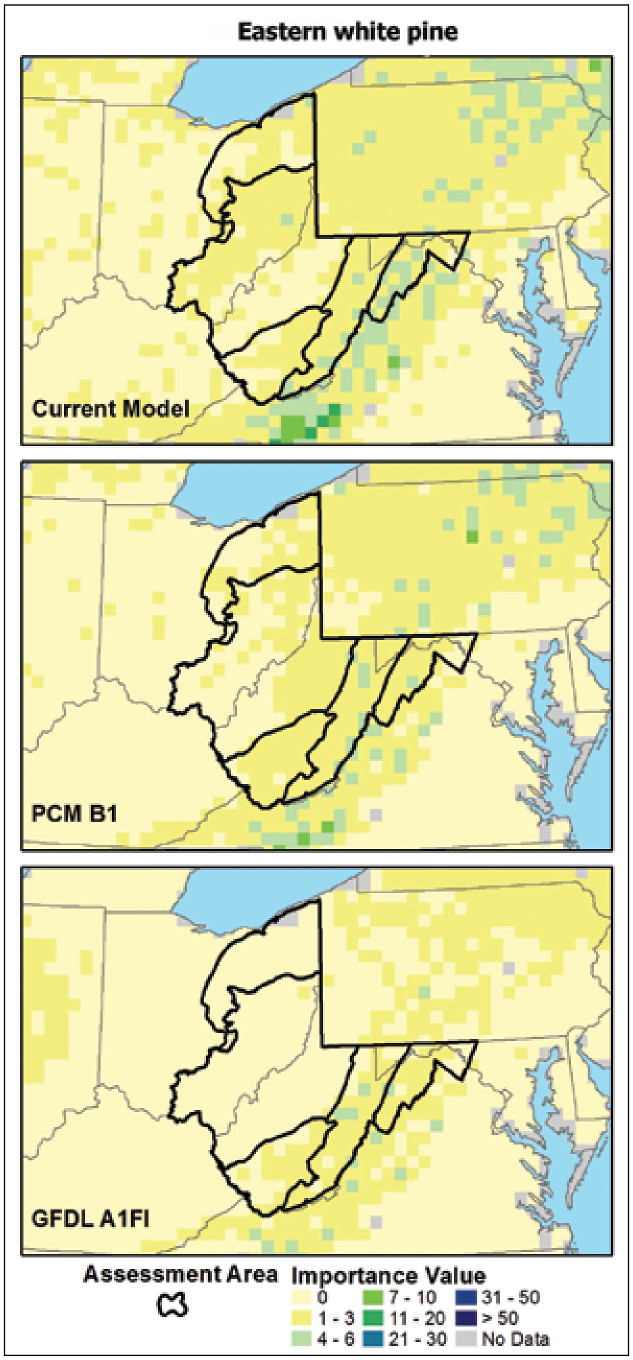


Figure 34.—Modeled importance values for eastern white pine across the assessment area and the larger geographic region for current climate conditions (top) and projected for the end of the century (2070 through 2099) for the PCM B1 (middle) and GFDL A1FI (bottom) climate scenarios, from the Tree Atlas model. Importance values can range from 0 to 100. An importance value of zero (light yellow) indicates that the species is not present currently, or will not have suitable habitat at the end of the century.

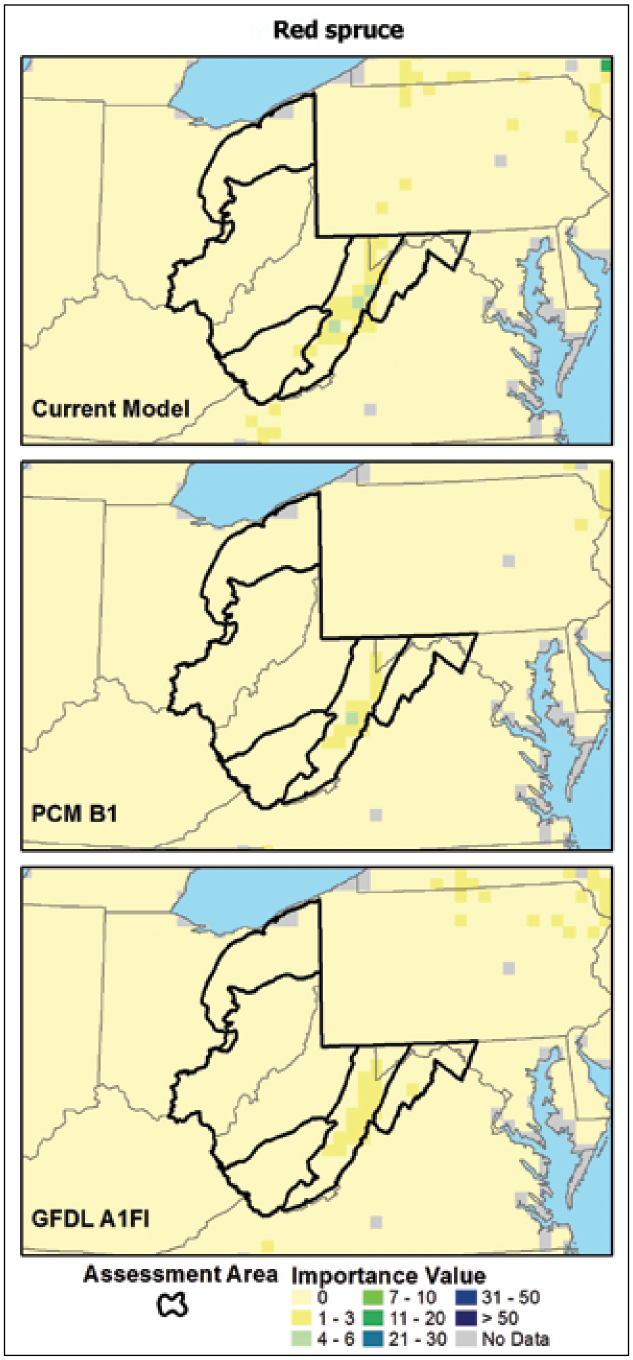


Figure 35.—Modeled importance values for red spruce across the assessment area and the larger geographic region for current climate conditions (top) and projected for the end of the century (2070 through 2099) for the PCM B1 (middle) and GFDL A1FI (bottom) climate scenarios, from the Tree Atlas model. Importance values can range from 0 to 100. An importance value of zero (light yellow) indicates that the species is not present currently, or will not have suitable habitat at the end of the century.

## LINKAGES

The LINKAGES model was used to predict tree growth (biomass) for 23 species within the assessment area after 30 years of establishment and growth on a plot from bare ground (Chapter 2) (Wullschleger et al. 2003). Section-level estimates were derived from the weighted average of 0.2-acre plots within 6 landforms in 26 subsections. We report projected tree growth (biomass) for current climate (1990 through 2009) and projected climate (2080 through 2099) using the PCM B1 and GFDL A1FI climate scenarios. Changes in biomass for PCM B1 and GFDL A1FI are calculated as the difference from projected biomass for a current climate scenario at the end of the century (2080 through 2099). The potential change in biomass for GFDL A1FI and PCM B1 is presented as classes of change in maps for each species (Figs. 36 and 37; Appendix 4).

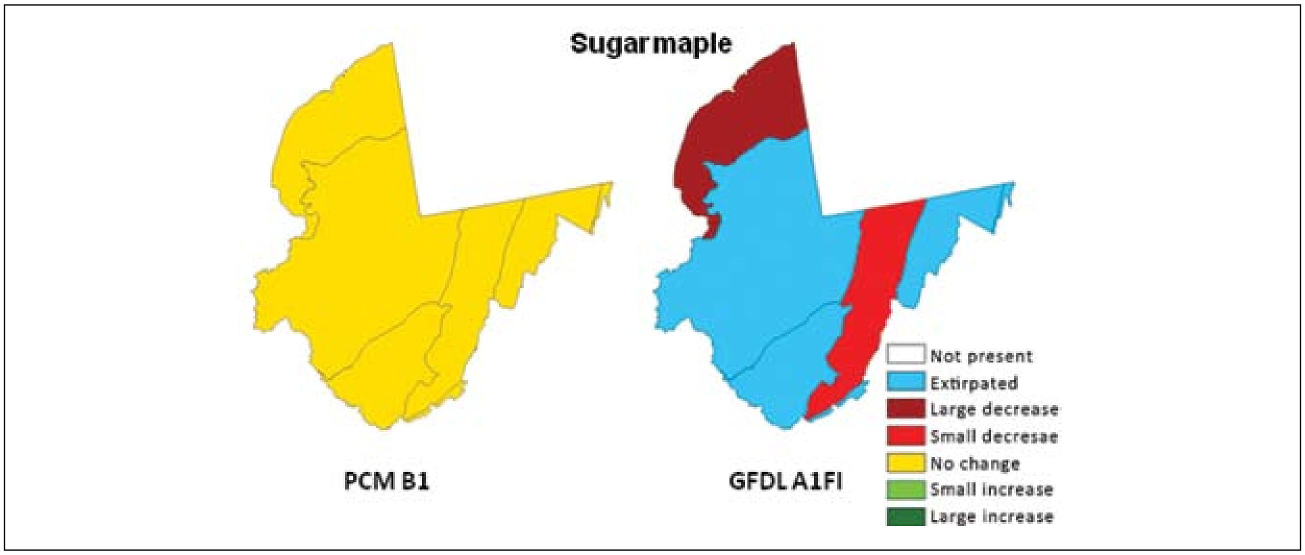


Figure 36.—Projected changes in establishment and growth for sugar maple at the end of the century (2080 through 2099) for two climate scenarios.

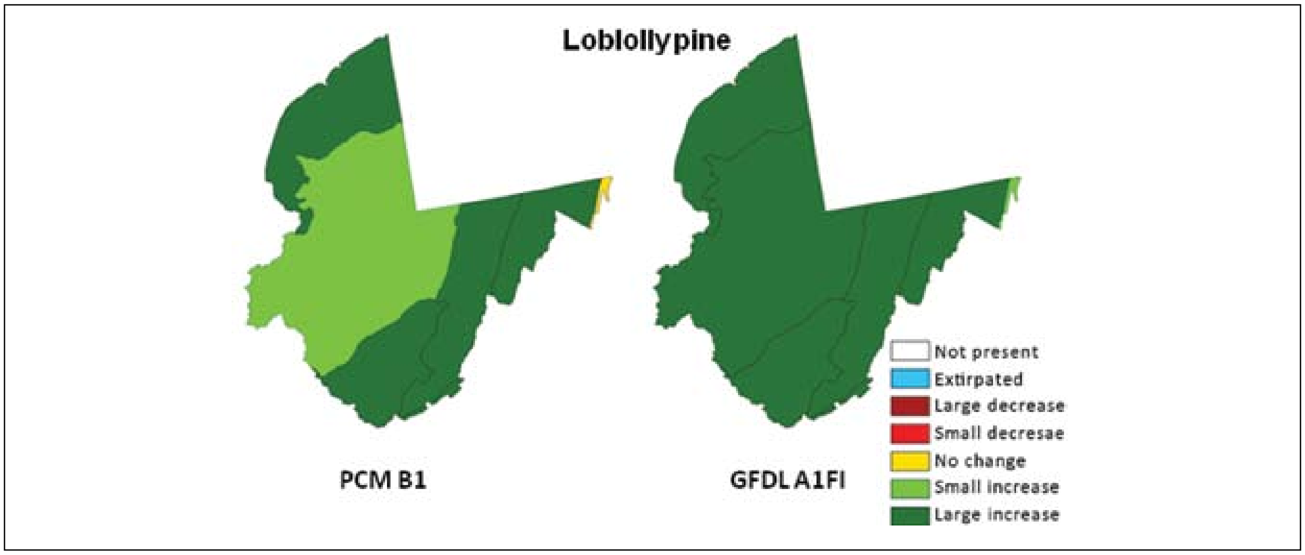


Figure 37.—Projected changes in establishment and growth for loblolly pine at the end of the century (2080 through 2099) for two climate scenarios.

Species establishment probabilities (SEPs) are an important input into the LANDIS PRO model, and were calculated by standardizing the LINKAGES biomass projections across species on a scale from 0 to 1. Absolute and percentage changes in SEP were calculated for the entire assessment area and are presented in Table 21. Results for each of the five sections within the assessment area are provided in Appendix 4. Species establishment probabilities reflect the ability of a species to establish and grow on a site and can be thought of as a measure of habitat suitability, but they do not account for the effects of interspecific competition and disturbance. Because SEPs are derived from the LINKAGES estimates of biomass, the percentage change in SEPs is largely congruent with the mapped changes in biomass; minor differences exist for some species due to the rescaling and rounding involved in calculating the SEPs.

**Table 21.—Projected changes in mean species establishment probability (SEP) values[a] from current climate at year 2100 across the assessment area**

| | | Future climate | | | |
|---|---|---|---|---|---|
| | Current climate | PCM B1 | | GFDL A1FI | |
| Species | SEP | SEP | % change | SEP | % change |
| American beech | 0.22 | 0.22 | 0.0 | 0.02 | -90.9 |
| American elm | 0.14 | 0.16 | 14.3 | 0.18 | 28.6 |
| Balsam fir[b] | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| Black cherry | 0.28 | 0.30 | 7.1 | 0.30 | 7.1 |
| Blackgum | 0.16 | 0.19 | 18.8 | 0.21 | 31.3 |
| Black oak | 0.19 | 0.20 | 5.3 | 0.13 | -31.6 |
| Chestnut oak | 0.20 | 0.20 | 0.0 | 0.12 | -40.0 |
| Eastern redcedar | 0.20 | 0.24 | 20.0 | 0.26 | 30.0 |
| Eastern hemlock | 0.13 | 0.13 | 0.0 | 0.01 | -92.3 |
| Eastern white pine | 0.34 | 0.35 | 2.9 | 0.04 | -88.2 |
| Flowering dogwood | 0.05 | 0.08 | 60.0 | 0.10 | 100.0 |
| Loblolly pine | 0.13 | 0.29 | 123.1 | 0.51 | 292.3 |
| Northern red oak | 0.29 | 0.31 | 6.9 | 0.18 | -37.9 |
| Pignut hickory | 0.35 | 0.37 | 5.7 | 0.36 | 2.9 |
| Post oak | 0.05 | 0.10 | 100.0 | 0.17 | 240.0 |
| Red maple | 0.31 | 0.34 | 9.7 | 0.37 | 19.4 |
| Red spruce[b] | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| Scarlet oak | 0.17 | 0.17 | 0.0 | 0.04 | -76.5 |
| Shortleaf pine | 0.08 | 0.22 | 175.0 | 0.35 | 337.5 |
| Sugar maple | 0.51 | 0.50 | -2.0 | 0.05 | -90.2 |
| Tulip tree | 0.76 | 0.83 | 9.2 | 0.86 | 13.2 |
| White ash | 0.43 | 0.53 | 23.3 | 0.41 | -4.7 |
| White oak | 0.32 | 0.35 | 9.4 | 0.35 | 9.4 |

[a] SEP absolute values were rounded to two decimal places.

[b] Absolute values are small enough that percentage changes are more important.

Projected changes in both biomass and SEPs represent a species' potential growth based on site and climate factors (Chapter 2). Both positive and negative changes in potential growth were consistently greater for GFDL A1FI than PCM B1 (Table 21). Suitable habitat was projected to decrease or be extirpated for PCM B1 for only two species: balsam fir and red spruce. American beech, balsam fir, eastern hemlock, eastern white pine, red spruce, and sugar maple suitable habitat was potentially extirpated from all or portions of the assessment region for GFDL A1FI. Scarlet oak potential growth was projected to decrease across the region for GFDL A1FI. Modest to large increases in potential growth are projected for GFDL A1FI, and to a lesser extent for PCM B1, for American elm, blackgum, eastern redcedar, flowering dogwood, loblolly pine, post oak, shortleaf pine, and tulip tree. Results for other species varied between sections, increasing or decreasing for black cherry, black oak, chestnut oak, northern red oak, pignut hickory, and white ash (Appendix 5). Loblolly and shortleaf pine are projected to have the largest increases in potential growth, partly because their biomass and SEP were very low for current climate and even a small increase could double the biomass. As mentioned above, LINKAGES results indicate only potential growth, not necessarily that a given species will be able to colonize newly available habitat. Some species showing large increases in potential growth are currently absent from the region or have very limited distributions. It would take a long time for them to respond (especially without planting) to this increase in potential growth and establishment. For example, loblolly pine is currently rare and exists mostly in plantations within the assessment area. Future potential growth is projected to increase for both climate scenarios and more so for GFDL A1FI, suggesting that habitat will become more favorable for this southern species.

Projected changes in both biomass and SEPs do not represent actual current or future distributions. Furthermore, LINKAGES is not spatially dynamic and does not simulate tree dispersal or any other spatial interaction, such as competition, among grid cells. Rather, this spatial interaction is examined by using LINKAGES results as input in the LANDIS PRO model.

## LANDIS PRO

The LANDIS PRO model was used to simulate changes in basal area (BA) and trees per acre (TPA) for 17 species over 90 years (2009 through 2100). Basal area and number of trees per acre were simulated for each 886-foot grid cell and then summarized for ecological sections and the entire assessment area. The LANDIS PRO model used the SEPs from LINKAGES (see above) to link tree establishment and growth to climate and additional parameters that reflect species life histories and landscape processes such as succession and competition, seed dispersal, and timber harvest. Parameters were initially based on current known silvics for each species, and then adjusted so that simulations using current climate produced values for species abundance that are consistent with FIA data and earlier growth studies in the region. Forest management was simulated as tree harvest on 8 to 13 percent of the forested area per decade, with the older stands harvested first. The model did not include wind or fire disturbance; that is, simulations represent forests with succession and management but without mortality from fire, wind, insects, disease, or other disturbances. The LANDIS PRO model differs substantially from the Climate Change Tree Atlas and LINKAGES because it simulates tree, stand, and landscape dynamics over time; therefore, the composition and structure of a pixel can be examined for any point in time in the simulation. Furthermore, LANDIS PRO accounts for natural stand dynamics in addition to climate effects on establishment and growth and is a prediction of actual forest composition and structure for a future year.

Future forest composition and structure were reported as BA and TPA for each tree species. Basal area is the area of tree stems at breast height per acre. High BA can be driven by many large-diameter trees, an even greater number of small-diameter trees, or a combination of the two. Therefore, TPA is also included as another measure of abundance and density, regardless of tree size (see Appendix 4 for area graphs of BA and TPA for PCM B1 and GFDL A1FI). A low BA with a high TPA indicates many small trees. A high BA with a low TPA indicates a higher proportion of large trees.

Projected change in BA and TPA is presented in area charts for current climate (Figs. 38 and 39) and future climate for PCM B1 and GFDL A1FI through 2100 (Appendix 4). Estimates of percentage change in BA and TPA for current climate were calculated as the change from observed 2009 values and represent change due to succession and management over the time period. Percentage change in BA and TPA for PCM B1 and GFDL A1FI at 2040, 2070, and 2100 was calculated as the change from current climate in the same model year (2040, 2070, or 2100) and represents the change due to the alternative climate, which is in addition to change due to succession and management. Percentage change in BA and TPA at year 2100 is presented in Table 22.

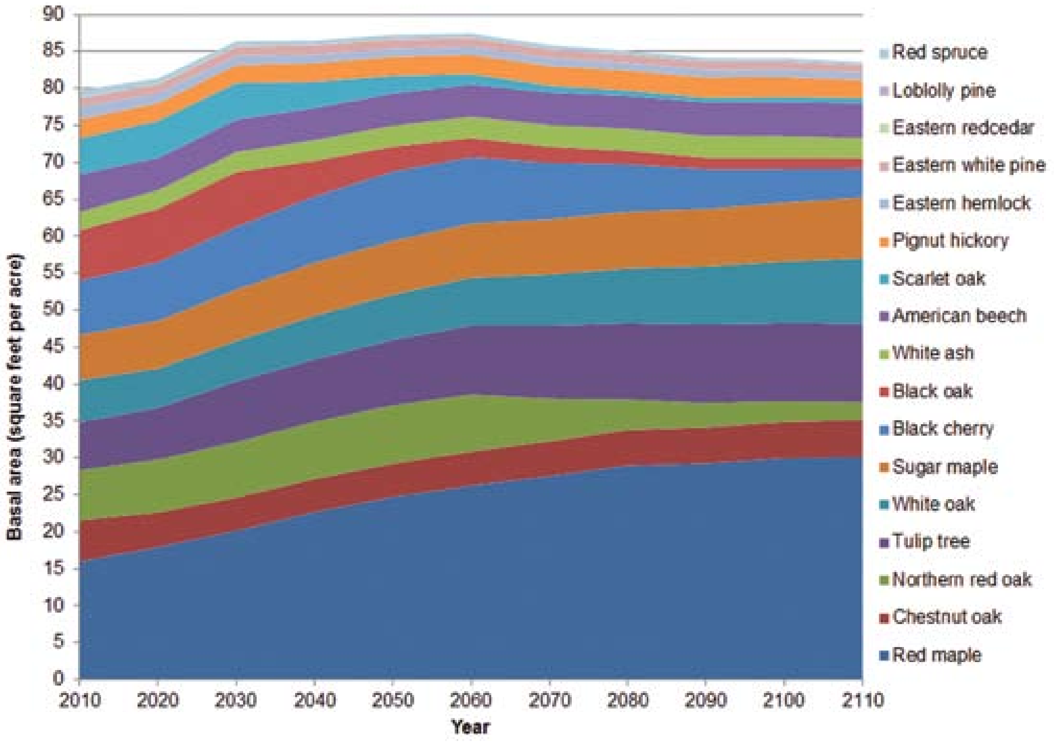


Figure 38.—Projected changes in basal area for 17 species across the assessment area under the current climate scenario. Assessment area values were derived from the weighted average of sections. The width of the colored line represents the relative basal area for each species through the year 2110. For example, red maple had the highest basal area in 2010, and basal area is projected to increase due to natural succession and management for current climate.

**Table 22.—Absolute and percentage change in basal area (BA) (square feet per acre) and trees per acre (TPA) predicted by the LANDIS PRO model for 17 species for current and future climate scenarios for the assessment area in year 2100**

| | BA by year and climate scenario[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Current | | PCM B1 | | GFDL A1FI | |
| Tree species | BA in 2009 | BA in 2100 | Change from year 2009 | BA year 2100 | Change from current climate[b] | BA year 2100 | Change from current climate[b] |
| American beech | 5.1 | 4.6 | -9% | 4.6 | 0% | 4.2 | -10% |
| Black cherry | 7.3 | 4.6 | -38% | 4.6 | 1% | 4.5 | -1% |
| Black oak | 6.8 | 1.5 | -78% | 1.5 | 1% | 1.5 | -2% |
| Chestnut oak | 5.6 | 4.9 | -12% | 5.1 | 3% | 4.6 | -5% |
| Eastern hemlock | 1.7 | 1.1 | -35% | 1.1 | 1% | 1.0 | -9% |
| Eastern redcedar | 0.1 | 0.0 | -89% | 0.0 | 0% | 0.0 | 0% |
| Eastern white pine | 1.2 | 1.0 | -13% | 1.0 | 0% | 0.9 | -7% |
| Loblolly pine | 0.1 | 0.2 | 127% | 0.2 | 0% | 0.2 | 0% |
| Northern red oak | 6.8 | 2.8 | -58% | 3.3 | 15% | 3.1 | 9% |
| Pignut hickory | 2.6 | 2.7 | 5% | 2.8 | 3% | 2.7 | 1% |
| Red maple | 16.0 | 30.0 | 88% | 30.5 | 2% | 30.3 | 1% |
| Red spruce | 1.0 | 0.3 | -67% | 0.3 | 0% | 0.3 | 0% |
| Scarlet oak | 4.8 | 0.7 | -86% | 0.7 | 8% | 0.7 | -2% |
| Sugar maple | 6.1 | 8.0 | 30% | 8.0 | 0% | 7.3 | -9% |
| Tulip tree | 6.5 | 10.5 | 62% | 10.8 | 3% | 10.8 | 3% |
| White ash | 2.5 | 2.9 | 18% | 3.0 | 4% | 2.9 | 0% |
| White oak | 5.7 | 8.4 | 46% | 8.6 | 2% | 8.3 | -1% |

| | TPA by year and climate scenario[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Current | | PCM B1 | | GFDL A1FI | |
| Tree species | TPA year 2009 | TPA year 2100 | Change from year 2009 | TPA year 2100 | Change from current climate[b] | TPA year 2100 | Change from current climate[b] |
| American beech | 26.8 | 14.2 | -47% | 13.9 | -2% | 8.1 | -43% |
| Black cherry | 18.9 | 7.2 | -62% | 7.3 | 2% | 7.3 | 2% |
| Black oak | 8.4 | 2.0 | -77% | 2.0 | 1% | 1.8 | -10% |
| Chestnut oak | 14.9 | 30.9 | 108% | 32.6 | 5% | 25.0 | -19% |
| Eastern hemlock | 6.1 | 3.8 | -38% | 3.6 | -6% | 2.0 | -47% |
| Eastern redcedar | 0.8 | 0.1 | -91% | 0.0 | 0% | 0.1 | 87% |
| Eastern white pine | 7.3 | 2.5 | -66% | 2.4 | -2% | 1.3 | -46% |
| Loblolly pine | 0.5 | 0.2 | -68% | 0.2 | 43% | 0.3 | 81% |
| Northern red oak | 11.9 | 3.6 | -70% | 6.0 | 68% | 5.2 | 45% |
| Pignut hickory | 7.3 | 5.4 | -27% | 5.6 | 4% | 5.6 | 4% |
| Red maple | 77.4 | 66.9 | -13% | 70.3 | 5% | 74.5 | 11% |
| Red spruce | 5.1 | 0.4 | -92% | 0.4 | 0% | 0.2 | 0% |
| Scarlet oak | 4.0 | 1.1 | -72% | 1.2 | 3% | 0.9 | -17% |
| Sugar maple | 54.1 | 53.6 | -1% | 50.8 | -5% | 23.4 | -56% |
| Tulip tree | 22.9 | 104.3 | 356% | 112.1 | 8% | 114.8 | 10% |
| White ash | 11.9 | 7.3 | -39% | 7.9 | 8% | 6.8 | -7% |
| White oak | 12.8 | 57.7 | 349% | 60.9 | 6% | 60.8 | 5% |

[a] Assessment area values were derived from the weighted average of sections.

[b] Change represents the difference from current climate in 2100 and represents potential change due to climate change.

Several notable changes are predicted for current climate by the end of the century due to succession and management. Changes for current climate generally represent decreases in BA or TPA of short-lived and relatively shade intolerant species and increases in longer-lived, more shade tolerant, or faster growing species. For example, eastern redcedar, black oak, scarlet oak, black cherry, pignut hickory, and eastern white pine are projected to decline in BA and TPA whereas the more shade-tolerant or longer lived white oak, sugar maple, and red maple are projected to increase (Figs. 38 and 39). The fast-growing and competitive species, such as tulip tree, increased more in TPA than BA, indicative of regeneration and growth after mortality.

With a few exceptions, there were small to moderate differences in BA and TPA predicted for PCM B1 and GFDL A1FI compared to current climate by the end of the century (Table 22). Differences tended to be greater for GFDL A1FI than PCM B1, which is consistent with the Tree Atlas and LINKAGES results, and is attributed to the projections of higher average temperatures at the end of the century. The modest size of differences due to climate by the year 2100, especially given the potential for change indicated by the Tree Atlas and LINKAGES, is partly because trees are long-lived and turnover in species composition takes time. Species that showed declines across the region in BA (between 2 and 10 percent) and in TPA (between 17 and 56 percent) for GFDL A1FI by 2100 were American beech,

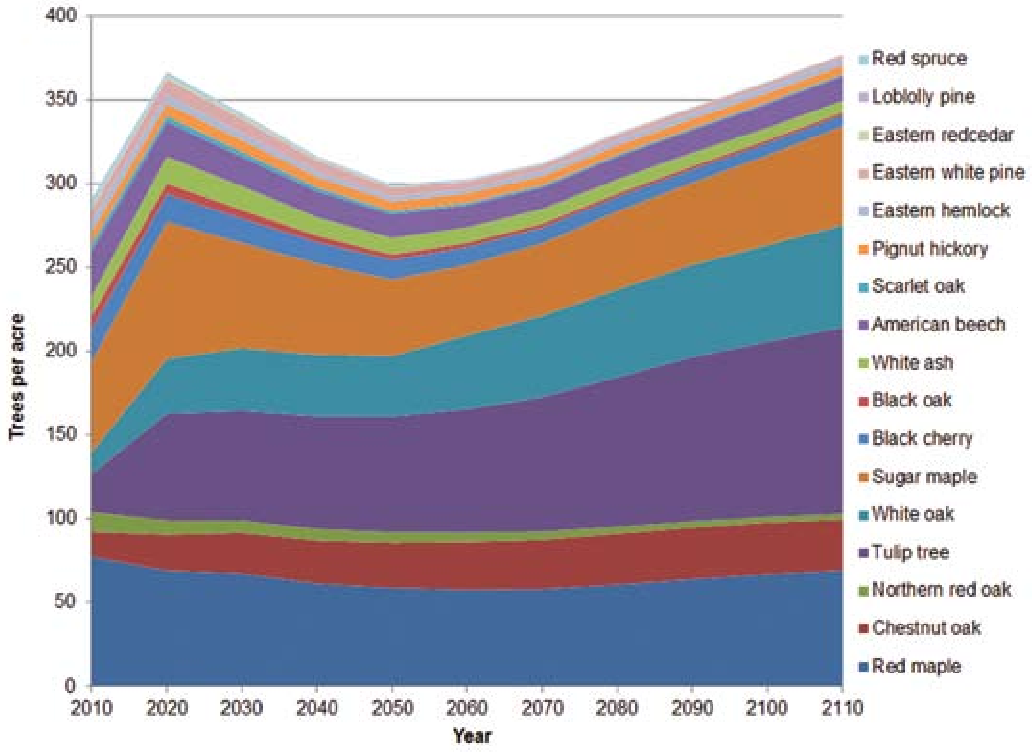


Figure 39.—Projected changes in trees per acre for 17 species across the assessment area for the current climate scenario. Assessment area values were derived from the weighted average of sections. The width of the colored line represents trees per acre for each species at various points through time. For example, red maple had the most trees per acre in 2010, but American beech is projected to become most abundant by the end of this century.

eastern hemlock, eastern white pine, scarlet oak, and sugar maple. The LINKAGES model predicted large decreases in potential growth for these species, for some to zero (extirpation). Species that generally increased in BA (up to 9 percent) and in TPA (up to 87 percent) for GFDL A1FI by the end of the century were loblolly pine, northern red oak, red maple, and tulip tree. The LINKAGES model also predicted large increases in potential growth for loblolly pine and tulip tree, and decreases or increases in northern red oak depending on section. Simulations by LANDIS PRO for 300 years into the future are not presented here because they are outside the scope of this assessment, but they show additional changes in species abundances in the directions suggested by the Tree Atlas and LINKAGES. Care should be used when interpreting values of percentage change because a large percentage change can occur for a small absolute change in BA or TPA if the initial values of BA or TPA were very small (Appendix 4).

## Geographic Trends

The geographic and biological complexity of the assessment area warranted a closer look at the five ecological sections within the broader assessment area (see Appendix 4 for complete model results). For some species, BA or TPA are projected to increase in some sections while decreasing in others. For example, although northern red oak is projected to increase within the assessment area, these increases are largely concentrated in sections in northern Ohio (221F), and the easternmost sections (M221A and M221B) (Appendix 4). Although eastern hemlock is projected to decrease across the assessment area, most of the decrease in BA is projected in section 221E. Likewise, much of the decrease in basal area for chestnut oak is projected for GFDL A1FI in 221E (decrease of 14 percent), with no change projected in 221F and a 9-percent increase in M221A.

Outputs from LANDIS PRO can be visualized spatially, and can provide greater context for interpreting the projected changes in tree volume. Figure 40 illustrates projected changes in basal area for northern red oak. It is important to note that these maps detect relative change on a pixel by pixel basis rather than averaged by section within the assessment area, as presented above.

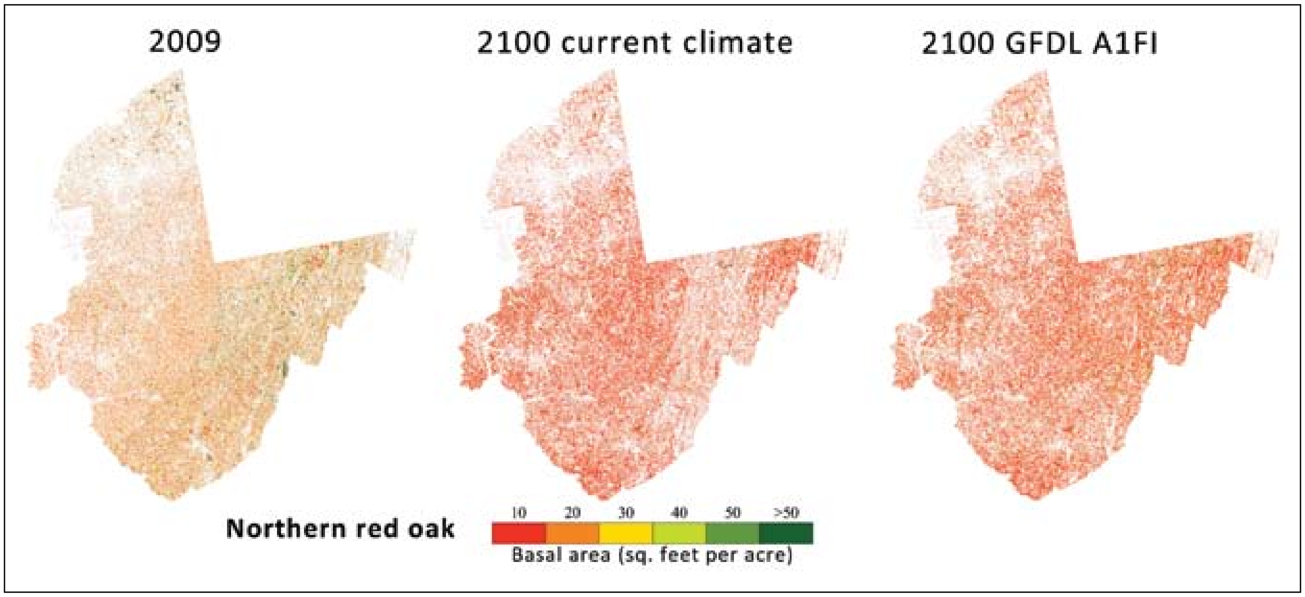


Figure 40.—Projected changes in basal area of northern red oak in 2100 compared to basal area in 2009. Basal area in 2100 under current climate represents the change in basal area attributable to succession and management. Basal area in 2100 for GFDL A1FI represents the total change in basal area attributable to succession and management plus high greenhouse gas emissions.

## DISCUSSION OF MODEL RESULTS

The three different models used in this assessment represent different facets of potential forest change as a result of a changing climate. Therefore, the ability to make comparisons between the different models facilitates a deeper understanding of which parts of a forest ecosystem may be most responsive or vulnerable to change. However, the differences between the models, in terms of design, outputs, strengths, and weaknesses, also make direct comparisons among model results difficult. This section describes areas of agreement and disagreement between the results and provides context for how the results from multiple models can be integrated to better understand forest change.

### Agreements

The DISTRIB model used by the Tree Atlas allowed the most species to be modeled, and the LANDIS PRO model allowed the fewest. Therefore, only 17 species can be compared across all three models. The LANDIS PRO model demonstrates that forests are changing due to succession and management even without climate change. Succession and management will likely continue to be the most significant drivers of change over the next century, but actions that accelerate succession (e.g., management or natural disturbances) can facilitate climate-related changes. The LANDIS PRO model shows the beginnings of change in the directions suggested by LINKAGES and the Tree Atlas, but climate-related changes are too small to be conclusive for many of the species modeled. Where the Tree Atlas and LINKAGES are consistent with each other, results have the most certainty.

All three models suggest that conditions for some species (e.g., American beech, eastern hemlock, eastern white pine, red spruce, and sugar maple) will become unfavorable by the end of the century for the higher climate scenario (GFDL A1FI). At the same time, all three models suggest that conditions for other species (e.g., eastern redcedar and loblolly pine) will become more favorable by the end of the century, especially for GFDL A1FI. Additionally, both the Tree Atlas and LINKAGES tend to agree that many species will remain stable or increase for PCM B1 conditions and decrease for GFDL A1FI. These results support the idea that GFDL A1FI represents a future climate that is beyond the tolerance of many species. Additionally, these results suggest that many temperate species currently present in the assessment area could tolerate a mild degree of warming with corresponding increase in growing season precipitation, as represented by the PCM B1 scenario.

### Disagreements

There do not appear to be any major discrepancies between individual species when LANDIS PRO and Tree Atlas results are compared, although there are some differences. The LANDIS PRO model projects changes (increase or decrease) in basal area of less than 20 percent for each species, but larger changes in trees per acre, particularly for GFDL A1FI, suggesting that young trees on the landscape will increase for several species. Whereas LANDIS PRO projects northern red oak to increase for GFDL A1FI, the DISTRIB and LINKAGES models project small decreases in suitable habitat and potential growth. This may be explained by LANDIS PRO's ability to simulate changes in tree growth and biomass, whereas DISTRIB and LINKAGES describe potential suitable habitat that is available to a species. Although the amount of suitable habitat may decline, the remaining habitat may continue to be favorable for northern red oak, including the regeneration of northern red oak (in the absence of herbivory, competition, or other stressors).

For many of the species above, LINKAGES and DISTRIB suggest great potential for landscape change in terms of basal area and trees per acre. However, LANDIS PRO results suggest that much of the change in forests in the next 100 years will be due to succession, management, and disturbance; climate-related changes may take longer to manifest because trees are long-lived and disperse slowly. Changes in species establishment probability, and the consequences of losing habitat suitability, may not become evident by the end of the century, although changes in climate may already be setting the stage for substantial long-term changes in species composition that may include extirpation of some species and large expansion for others.

### Limitations

All models are simplified representations of reality, and no model can fully consider the entire range of ecosystem processes, stressors, interactions, and future changes to forest ecosystems. Each model omits processes or drivers that may critically influence ecosystem change in the future. Future uncertainty is not limited to climate scenarios; there is also uncertainty associated with future human interactions with forests. Examples of factors that are not considered in these models are:

- Land management and policy responses to climate change or impacts to forests
- Land-use change or forest fragmentation
- Future changes in forest industry, including products and markets
- Changes in phenology and potential timing mismatches for key ecosystem processes
- Responses of understory vegetation, soil microorganisms, or soil mycorrhizal associations
- Extreme weather events, which are not captured well in climate data or forest impact models
- Future wildfire behavior, fire suppression, and ability to apply prescribed fire
- Novel successional pathways for current forest ecosystems
- Major insect pests or disease agents
- Future herbivory pressure, particularly from white-tailed deer
- Interactions among all these factors

Most of these factors could drive large changes in forest ecosystems throughout the assessment area, depending on how much change occurs in the future. The potential for interactions among these factors adds layers of complexity and uncertainty. Despite these limitations, impact models are still the best tools available and can simulate a range of possible future outcomes. It is important to keep the above limitations in mind when weighing the results from different models and use them to inform an overall assessment. In the following section, we draw upon published literature to address other factors that may influence how forest ecosystems in the assessment area respond to climate change.

## SUMMARY OF CURRENT SCIENTIFIC KNOWLEDGE ON FOREST IMPACTS

The results presented above provide us with important projections of tree species distributions across a range of future climates, but these models do not account for all factors that may influence species and communities for a changing climate. Climate change has the potential to alter the distribution, abundance, and productivity of forests and their associated species in a variety of ways. These can broadly be divided into the *direct* effects of temperature and precipitation on forests and the *indirect* effects on forests through the alteration of current stressors or the development of additional stressors. For the most part, models such as the ones described above consider only direct effects such as average temperature and precipitation. Changes to forest management methods and their interaction with climate change may yield different outcomes. It is also important to note that some of the impacts may in fact be positive or beneficial to native forest ecosystems. The remainder of this chapter summarizes the current state of scientific knowledge on additional direct and indirect effects of climate change on forests in the assessment area and throughout the eastern United States.

## Drought Stress and Mortality

There is evidence for an increased risk of future drought stress in the assessment area (see Chapter 4). Temperatures are expected to rise over the next century, and evapotranspiration in ecosystems is expected to increase as a result. Moisture stress may occur when increases in evapotranspiration are not offset by a corresponding increase in precipitation and soil moisture. Within the assessment area, the potential for more frequent droughts and moisture stress during the growing season appears to be much greater for the GFDL A1FI scenario (Chapter 4). However, for the milder PCM B1 scenario, warmer temperatures may also lead to increased evapotranspiration and physiological stress if increases in precipitation do not correspond to temperature increases. Additionally, there is evidence that precipitation is more likely to occur during larger precipitation events, which may increase the interval between rainfall events (Diffenbaugh et al. 2005).

Drought can affect forests in many ways, including altering ecosystem processes, reducing forest productivity, increasing susceptibility to other stressors, and increasing tree mortality (Dale et al. 2001). Nearly all forests are susceptible to drought. For example, a recent study found that forests in both wet and dry environments around the world typically operate within a relatively narrow range of tolerance for drought conditions (Choat et al. 2012). Drought stress causes air bubbles to form in the xylem of growing trees (cavitation), which reduces the ability of trees to move water and causes reduced productivity or mortality. Forest species from rain forests, temperate forests, and dry woodlands all show a similarly low threshold for resisting drought-induced cavitation (Choat et al. 2012).

The potential effects of drought on forests will depend upon a number of factors, including drought duration and severity, as well as site-level characteristics of the forest. High stand density may compound susceptibility to moisture stress because high-density stands face increased competition for available moisture (Keyser and Brown 2014, Olano and Palmer 2003). Additionally, drought-stressed trees are typically more vulnerable to insect pests and diseases (Dukes et al. 2009).

## Blowdowns

Together with fire and ice, wind is a primary natural disturbance within the assessment area (Franklin et al. 2007, Ohio Department of Natural Resources [ODNR] 2010b). Blowdowns from large and small windstorms can have an important influence on the structure and species composition of forests (Abrams et al. 1995, Peterson 2000). Although tornadoes are relatively infrequent, intense winds generated from hurricanes, micro-bursts, and other storms can cause small patches of trees to uproot, especially on steep slopes (ODNR 2010b; Ulbrich et al. 2008, 2009). Hurricanes affecting the east coast can cause significant wind damage and blowdowns as far inland as western Maryland and West Virginia, where wind speeds can reach 50 miles per hour (Boucher et al. 2005). To date, the amount of evidence of changes in extreme storms in this region is rather limited (Dale et al. 2001, Intergovernmental Panel on Climate Change [IPCC] 2012). Some model projections suggest there may be an overall increase in the average wind speed in the area, but models disagree on whether trends in extreme cyclone frequency and intensity are increasing or decreasing (IPCC 2012, Ulbrich et al. 2009). If wind speeds do increase, the species that are most susceptible to blowdowns will likely differ by location across the assessment area. Blowdowns appear to disproportionately affect larger trees, shallow-rooted species, and thinned stands (Boucher et al. 2005, Dale et al. 2001). Sugar maple, sweet birch, and yellow birch are generally more wind resistant than black cherry, red maple, and tulip tree (Peterson et al. 2013). More frequent or widespread blowdown events can be expected to release the understory and accelerate the transition to shade-tolerant species (Abrams and Scott 1989). This is especially the case in fire-dependent communities where shade-tolerant understories have developed in the absence of fire (Abrams and Nowacki 1992, Holzmueller et al. 2012). Gap-creating events may open up opportunities for regeneration of intermediate shade-tolerant species such as white oak, flowering dogwood, and various hickory species, especially at higher elevations (Abrams et al. 1998, Campbell et al. 2005). Blowdowns will continue to be an important ecological process in many Central Appalachians ecosystems, but existing scientific literature provides no clear indication of how blowdowns will be affected by the changing climate.

## Winter Storm Damage

Snow and ice damage occurs occasionally across the area, and varies substantially with topography, elevation, exposure, and extent (ODNR 2010b). The most common cause of ice formation is when a winter warm front passes over much colder air. As rain falls from the warm layer through the layer at or below 32 °F, it becomes supercooled and able to freeze onto any surface it encounters (Turcotte et al. 2012). Although the number of days cold enough for snow and ice is projected to decrease, the intensity of these events when they do occur is projected to increase (Chapter 4). The decurrent growth habit (a wide crown with secondary trunks emerging from a main trunk) of many northern hardwoods makes them more vulnerable to ice damage than trees with a central leader (Turcotte et al. 2012). Species such as oaks, hickories, maples, and ashes appear to be particularly susceptible to branch and stem breakage, whereas conical species such as spruce are less susceptible. A study of a 2003 ice storm in Ohio found that oaks were more likely to show dieback than maples, and red maples were more likely to show dieback than sugar maples (Turcotte et al. 2012). Within species, damage appears to be greater in older, taller individuals, with higher mortality in sawtimber size classes than in pole or sapling size classes (Turcotte et al. 2012). These events also create gaps, allowing regeneration of species such as red maple. If these events decrease or are eliminated from the area, new recruitment opportunities from this disturbance type may be limited.

Although snow and ice will likely decrease across the area, some evidence suggests that storm events will actually increase during the winter months (Wang and Zhang 2008). With the projected increase in winter temperature, these events will more likely result in flooding and wind damage than in snow and ice damage, suggesting winter storms will function more like summer storms across the region.

## Hydrologic Impacts on Forests

Hydrology is tightly linked to the health and function of forest ecosystems, whether through maintenance of soil moisture during the growing season, seasonal flooding, creating necessary decomposition conditions, or other processes. Many forest systems in the assessment area have particular soil moisture requirements for the seasonality and extent of saturation. Additionally, certain species such as eastern cottonwood, eastern hemlock, and red spruce have particular seedbed requirements that are tightly linked to hydrologic conditions (Burns and Honkala 1990, Cornett et al. 2000).

Climate change is likely to alter hydrologic regimes throughout the assessment area. As discussed in Chapters 3 and 4, heavy precipitation events have been increasing across the assessment area over the past century and this trend is expected to continue. In addition to more episodic precipitation events, future climate scenarios also project a wide possible range of seasonal precipitation and soil moisture (Chapter 4). Such variability may expose forest ecosystems to greater risk of hydrologic extremes: water-logging and flooding on one hand, and moisture stress and drought on the other. Forests that are accustomed to seasonal or annual variations in water availability may be better able to tolerate this variability.

A stream meandering through a small stream riparian forest. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

In a review of the consequences of precipitation variability on forests, Knapp et al. (2008) proposed that extreme precipitation events with longer intervals between events could have positive or negative impacts on a system, depending on its typical state in regards to soil moisture thresholds (Knapp et al. 2008). For example, xeric systems (adapted to dry conditions) would generally be less affected by dry periods because they are already limited by moisture stress, and larger precipitation events could recharge soil water levels, allowing for slightly longer periods of moisture. On the other end of the spectrum, hydric (i.e., wetland) systems are limited by anoxia rather than soil moisture, so longer dry periods between precipitation events would lower the water table, allowing oxygen to reach the roots of aquatic plants and ultimately increasing biomass productivity. Mesic systems (adapted to moderately moist conditions) would be the most affected by the increasing duration and severity of soil water stress because they are not well adapted to prolonged dry periods. This conceptual framework does not incorporate modifiers like soil texture and root depth, but the general principles are useful.

Flooding can affect forest systems differently, depending on the frequency and duration of floods, and the soil, vegetation, and topographic complexity of the landscape. In mountainous areas, floods are generally brief and intense, with floodwaters funneling rapidly down steep slopes and into valley streams (Eisenbies et al. 2007, Swanson et al. 1998). These swift, fierce floods often damage trees by breaking stems and limbs, and scouring vegetation. In lowland areas, floods are generally more gradual and last longer, with longer periods of soil saturation and less tree breakage. Extreme or very heavy precipitation events can also have important consequences on riparian and lowland systems when they result in flooding, which can increase erosion and transport of nutrients, contaminants, and pathogens (Groffman et al. 2014). Disturbances caused by floods, drought, scouring by ice, and river channeling often drive tree species and forest diversity, especially in lowland and riparian forests (Vadas and Sanger 1997).

## Soil Erosion

As climate change continues to intensify the hydrologic cycle, the increase in heavy rainfall events is projected to continue across the assessment area. One of the potential impacts of this trend is that soil erosion rates will increase (Nearing et al. 2004). Soil erosion is considered one of the major threats to the Central Appalachians region, but many studies examining the effects of climate change on soil erosion have focused on agricultural settings, rather than forest ecosystems (Pennsylvania Department of Environmental Protection [PDEP] 2012). Although additional vegetative cover and root stabilization in forest systems may make forests less prone to soil erosion, not all forest soils will be equally protected. Reductions in vegetative cover due to a variety of climate-related impacts, such as prolonged drought, could lead to an increase in susceptibility to erosion. Additionally, the intensification of precipitation changes combined with orographic effects may increase risk or severity of erosion in mountainous areas (Beniston 2003, Sturdevant-Rees et al. 2001).

Soil erosion is also closely correlated with precipitation. One study estimates that for every 1-percent increase in rainfall, runoff could increase by 2 percent, and erosion could increase by 1.7 percent (Nearing et al. 2004). Another study examined changes in erosivity across the United States at a very large grid scale and found that erosion may increase or decrease in the assessment area depending on the climate model used (Nearing 2001). This study looked only at broad-scale changes in precipitation, and does not account for other factors that may affect the vulnerability of soil to erosion such as vegetation cover, slope, or soil type. Reductions in biomass and vegetative cover due to climate change impacts or land-use changes (e.g., forest roads) could also lead to an increase in erosion susceptibility (Nearing 2001).

## Wildfire

Wildfire was historically an important driver for some forest ecosystems in the assessment area, although it has been largely suppressed since the 1930s. In contrast to the large wildfires that occur periodically in the western United States, contemporary wildfire events in the eastern United States consist of numerous small fires in the wildland-urban interface (Peters et al. 2013). Development and fragmentation in the form of high housing density are the biggest source of ignition, but access to the surrounding infrastructure allows wildfires to be extinguished relatively quickly (Bar Massada et al. 2009). Ignitions are caused primarily by humans and less frequently by lightning (National Interagency Fire Center 2013). The conditions responsible for wildfire behavior are the result of weather, topography, and fuels (Moritz et al. 2012). Climate can directly affect the frequency, size, and severity of fires, and indirectly affect fire regimes through effects on vegetation vigor, structure, and composition (Moritz et al. 2012, Sommers et al. 2011).

Invasive species may also interact with climate to increase the frequency, intensity, or length of the fire season (Brooks and Lusk 2008). Invasive shrubs and herbs may increase the density of the understory, thereby increasing fuel. On the other hand, many invasive shrubs and herbs begin growing earlier in spring than native plants. This early green-up may reduce the flammability of fire-adapted communities during the spring fire season (Brooks and Lusk 2008). Invasive pests can also interact with climate and wildfire by altering forest fuels and forest structure (Ehrenfeld 2010, Krist et al. 2007, Lovett et al. 2006, Szlavecz et al. 2010).

An analysis of fire probability across the globe using 16 downscaled climate models found low agreement among projections of climate change effects on fire probability in the central United States in the near term (2010 to 2039), but most models projected an increase in wildfire probability by the end of the century (2070 to 2099) (Moritz et al. 2012). This agreement is particularly high for temperate coniferous forests and temperate broadleaf and mixed forests, where fire probability models were most sensitive to mean temperature of the warmest month. If temperature and evapotranspiration increase drying of the forest floor in spring, amplify the effects of declining precipitation, or overwhelm modest precipitation increases, the annual area burned and length of the fire season will likely increase. Projected increases in lightning-producing convective storms may also increase ignition frequency (Sommers et al. 2011). Another global study using a sensitive model and a high emissions scenario projected increased fire potential across the United States, including the assessment area (Liu et al. 2010). Duration of the fire season is projected to lengthen by several months by the end of the century, primarily due to warming (Liu et al. 2010).

How a change in fire risk across the region translates to effects at local scales in forests of the assessment area also depends on land use and management decisions. Fire suppression has already been linked with mesophication in eastern forests, and fire management is expected to continue to drive vegetation and succession in the future (Nowacki and Abrams 2008). To understand how climate change may interact with wildfire in the United States, model simulations of vegetation cover types were conducted for high and low emissions scenarios (A2 and B2; see Chapter 2) with wildfire suppressed and unsuppressed for the period 2070 through 2099 (Lenihan et al. 2008). Under both suppressed and unsuppressed wildfire, the range of temperate deciduous forest across the eastern United States was projected to shift northward, with a large loss of cool mixed forest. Under unsuppressed wildfire, some forest just outside the assessment area in Ohio was projected to transition to a woodland or savanna type, and there is potential that existing woodlands and savannas may expand where they do occur (Lenihan et al. 2008). Fire suppression does not allow this expansion; cool mixed forest is projected to be largely replaced by temperate deciduous forest as both biomes shift northward.

Many aspects of the fire regime within the assessment area will likely be affected by changes in climate, with response to climate change varying over time and space. Dry-mesic oak, dry oak and pine-oak, and dry calcareous forests are often tied to wildfire dynamics, but fire could also become an increasing source of disturbance in other forest types if climatic shifts over the 21st century result in different fire behavior. Forest ecosystems adapted to dry habitat conditions (e.g., oak, pine, and hickory) may be the most likely areas to burn. Forest systems adapted to habitats with abundant moisture (e.g., northern hardwoods), and those reliant on ground seepage at higher elevations may be able to better compensate for increased evapotranspiration and higher temperatures. However, even these systems may be more likely to burn if projected temperature increases result in drier habitat conditions. Fire effects on nutrient availability depend not only on species composition but also on the intensity and duration of the fires (Certini 2005). Low-intensity fire can release nutrients, but higher fire temperatures may result in mineralization and volatilization, especially on acidic soils, which dominate most of the higher elevation portion of the assessment area (Gray and Dighton 2006). A watershed-scale study of prescribed fire in southeastern Ohio found that periodic low-intensity prescribed fire can return nutrient cycling and microbial activity to presettlement levels, which can restore ecosystem functions of mixed oak forests (Boerner 2006). Authors of a review paper on climate and wildfire conclude that fire-related impacts may be more important to some ecosystems than the direct effects of climate change on species fitness and migration (Sommers et al. 2011). Fire could have a greater influence because it can be a catalyst for change in vegetation, perhaps prompting more rapid change than would be expected based only on the changes in temperature and moisture availability. As with wind disturbances, the potential exists for novel successional pathways after wildfire if climatic conditions, seed sources, or management decisions favor different forest types.

## Increases in Carbon Dioxide

In addition to effects on climate, carbon dioxide itself can affect plant productivity and species composition. Elevated carbon dioxide may enhance growth and water use efficiency of some species (Ainsworth and Rogers 2007, Norby et al. 2005), potentially offsetting the effects of drier growing seasons. This is commonly called "carbon dioxide fertilization." There is already some evidence for increased forest growth in the eastern United States (Cole et al. 2010, McMahon et al. 2010, Pan et al. 2009), but it remains unclear if long-term enhanced growth can be sustained (Bonan 2008, Foster et al. 2010). Nutrient and water availability, ozone pollution, and tree age and size all play major roles in the ability of trees to capitalize on carbon dioxide fertilization (Ainsworth and Long 2005). Ecosystem community shifts may take place as some species are genetically better able to take advantage of carbon dioxide fertilization than others (Souza et al. 2010). Some models account for changes in carbon dioxide, but these models tend to focus on nutrient cycling and general vegetation types, and not specific species (Lenihan et al. 2008, Ollinger et al. 2008). Therefore, this assessment is not able to combine the effects of carbon dioxide fertilization with the effects of temperature and precipitation on particular species.

## Changes in Nutrient Cycling and Acid Deposition

As air temperatures warm and precipitation patterns change, the way nutrients are cycled between plants, soils, and the atmosphere may also change. The long-term effects of acid deposition have an added effect that makes this cycle more complex and hard to predict in the future. Increases in droughts and floods, changes in phenology, and the interaction among these factors can also impair nutrient cycling and the availability of nitrogen to trees and other vegetation (Rennenberg et al. 2009).

Decomposition of vegetation is carried out primarily by enzymes released from bacteria and fungi. These enzymes are sensitive to changes in temperature, and thus there is generally a positive effect of temperature on the rate of enzymatic activity as long as moisture is also sufficient (Brzostek et al. 2012, Finzi et al. 2006, Rustad et al. 2001). A number of studies have examined the effects of extended dry periods followed by moisture pulses on nutrient cycling (Borken and Matzner 2009). Although these moisture pulses do lead to a flush of mineral nitrogen, it is not sufficient to compensate for the lack of microbial activity during dry periods. Thus, an increase in wet-dry cycles appears to lead to a reduction in nutrient availability for trees.

Although warmer temperatures have the potential to increase enzymatic activity and nutrient cycling, acidification will remain an important consideration. Anthropogenic emissions of nitrogen and sulfur have increased over the last century, peaking in the 1970s. These emissions undergo chemical transformations that produce nitrates and sulfates, which are eventually deposited on the ground (Elliott et al. 2013). These sulfur and nitrogen compounds are also deposited at high concentrations through rain and snow in the eastern United States, particularly in high-elevation sites (Pardo et al. 2011). In forest ecosystems, hydrogen ions associated with nitrogen and sulfur deposition replace nutrient base cations of calcium, magnesium, and potassium, depleting these nutrients and allowing them to leach into drainage waters. At the same time, toxic cations of aluminum are mobilized, and the combined effects of nutrient depletion and increased toxicity have been proven to reduce the health and productivity of forests and streams through acidification (Elliott et al. 2013, Long et al. 2013, Schaberg et al. 2006). Nitrogen saturation has also been shown to reduce carbon allocation to plant roots and mycorrhizae (Pardo et al. 2011). Acid deposition has likely contributed to the increased susceptibility of forests to drought and insect attack, and is expected to contribute to reduced ability to withstand climate changes (Friedland et al. 1984, McNulty and Boggs 2010, Pardo et al. 2011).

Researchers simulating the effects of nitrogen and sulfur deposition on wilderness areas in North Carolina found that even with dramatic reductions in acid deposition, ecosystems will take decades to recover from the effects of acidification (Elliott et al. 2013). Future levels of nitrogen and sulfur deposition can be controlled through efforts to significantly reduce air pollution by 2064 (e.g., through the Clean Air Act amendments of 1977). In the interim, projected increases in winter and spring precipitation could facilitate the deposition of air pollutants. The effects of climate change on nutrient cycling will likely be overshadowed by the impacts of nitrogen and sulfur deposition in the assessment area over the next 50 years or longer.

## Invasive Plant Species

As described in Chapter 1, nonnative invasive species are a major threat to all forest ecosystems across the eastern United States. Many invasives are able to establish rapidly following a disturbance, and are able to outcompete native vegetation for growing space, water, nutrients, and light (Brown and Peet 2003, Dukes et al. 2009). Wetland and riparian areas are particularly susceptible to nonnative plant invasion, partially due to passive seed dispersal via surface waters (Nilsson et al. 2010). Invasive species in riparian areas are likely better competitors for nutrient pulses supplied by runoff (PDEP 2004). Some of the most prolific riparian invasives are the mile-a-minute vine, purple loosestrife, Japanese knotweed, common reed, Japanese stiltgrass, and reed canarygrass.

Many invasive species that currently threaten forests in the Central Appalachians region may benefit directly from projected climate change or benefit from the slow response of native species (Rebbeck 2012). Increases in carbon dioxide have been shown to have positive effects on growth for many plant species, including some of the most invasive weeds in the United States (Ziska 2003). Experiments with carbon dioxide fertilization on kudzu seedlings have indicated increased growth, increased competition with native species, and range expansion (Sasek and Strain 1988, 1989). Models have also projected that increased carbon dioxide emissions and subsequent warmer winter temperatures will likely expand the

Native grasses and forbs, dominant plants in this flat, wet area. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

northern ranges of bush honeysuckle (Sasek and Strain 1990), privet, kudzu, and cogongrass (Bradley et al. 2010). Cogongrass in the southeastern United States has contributed to altered fire regimes and is expected to advance northward with warmer temperatures (Lippincott 2000). Some invasive species are tolerant of drought and fire, and may be at an even greater advantage for future climate conditions. Ailanthus and bush (amur) honeysuckle are woody invasives that currently have negative impacts on forests across the assessment area (Hutchinson and Vankat 1998). In addition to directly outcompeting native oak-hickory trees by rapid growth, ailanthus and bush honeysuckle have allelopathic effects on soils, exuding a toxin that discourages the growth of other plants (ODNR 2011b, Williams 2005). Other species, such as garlic mustard and Japanese stiltgrass, are not particularly drought-tolerant, but their persistent seed banks enable them to recover in wetter years (Fryer 2011, Munger 2001).

Milder winters may allow some invasive plant species to survive farther north than they had previously (Dukes et al. 2009). For example, kudzu is a drought-tolerant invasive vine that has invaded forests in the southeastern United States and has already appeared within the assessment area (Munger 2002). The northern distribution of kudzu is limited by cold winter temperatures, and models have projected that warmer temperatures will result in expansion northward (Bradley et al. 2010). Chinese and European privet are invasive flowering shrubs that crowd out native species and form dense thickets. Habitat models project increased risk for privet invasion into Ohio, West Virginia, and Maryland by the end of the century (Bradley et al. 2010).

## Insect Pests and Pathogens

Warmer temperatures, moisture deficit, and compounding stressors may increase the susceptibility of trees to insect pests and pathogens (Weed et al. 2013). Warmer winter temperatures may also result in increased abundance of pests and pathogens that are currently present in the assessment area. For example, hemlock woolly adelgid populations are currently limited by low winter temperatures and freeze-thaw cycles, and populations of hemlock woolly adelgid have increased or expanded northward during mild winters (Pennsylvania Department of Conservation and Natural Resources 2013). The emerald ash borer, currently devastating populations of ash species, has been observed to produce more generations under warmer conditions (DeSantis et al. 2013, Venette and Abrahamson 2010, Wei et al. 2007). Other pest outbreaks, including those of native species (e.g., forest tent caterpillar and spruce budworm), are more common when trees are stressed by factors such as drought (Babin-Fenske and Anand 2011, Gray 2008). The interacting effects of drought and increased pests and pathogens may result in increased risk of oak decline, which is largely driven by insect pests and pathogens predisposed to invasion in drought conditions (Clatterbuck and Kauffman 2006, McConnell and Balci 2014).

There is evidence that other species may be disadvantaged by climate change; for example, the hatching of gypsy moth eggs is dependent on the budburst of host trees. Changes in phenology could result in starvation if the eggs hatch before budburst (Ward and Masters 2007). Tree pathogens, such as the fungus *Armillaria mellea*, can also potentially increase in abundance and range, and may result in increased disease that stresses or kills forest trees. *Armillaria* populations will likely increase with increasing temperatures, and become a more severe threat during drought periods, when host trees are more susceptible to root diseases (Kliejunas 2011).

Warmer temperatures will also increase the susceptibility of tree species to pests and diseases that are not currently a problem in the assessment area (Logan et al. 2003). Projections of gypsy moth population dynamics for a changing climate suggest substantial increases in the probability of establishment in the coming decades (Logan et al. 2003). Oak species that would otherwise do well in a changing climate could consequently be at risk. In addition, future northward range expansion attributed to warming temperatures has been projected for southern pine beetle (Ungerer et al. 1999). A recent outbreak of southern pine beetle in New Jersey has already been attributed to warmer temperatures (Weed et al. 2013). Southern pine beetle could become a threat if shortleaf pine expands in the region.

### Effects of Vertebrate Species

Herbivory, seed predation, and disturbance by vertebrates can be important stressors in the Central Appalachians region. Currently, little is known about how these factors could be affected by climate change. Deer overbrowsing and seed predation may reduce the overall success of species that are otherwise projected to do well under future climate change (Ibáñez et al. 2008). For example, white oak is projected to increase in habitat suitability and basal area, but the models mentioned earlier in this chapter do not account for the herbivory of young oak regeneration by deer. Currently, there is little evidence to indicate how deer and other vertebrate species will respond to climate change in the assessment area. An analysis of climate change impacts on white-tailed deer in Wisconsin suggests that deer in that area will likely be subject to a mixture of positive impacts from milder winters coupled with negative impacts from increased disease outbreaks (Wisconsin Initiative on Climate Change Impacts 2011). How these two factors may influence deer populations in Ohio, West Virginia, and Maryland remains unknown.

## CHAPTER SUMMARY

Although models are useful for exploring potential future changes, all models are simplified representations of reality, and no model can fully consider the entire range of ecosystem processes, stressors, interactions, and future changes to forest ecosystems. The DISTRIB (Tree Atlas), LINKAGES, and LANDIS PRO models suggest that conditions for some species (e.g., American beech, eastern hemlock, eastern white pine, red spruce, and sugar maple) will become unfavorable by the end of the century for GFDL A1FI. At the same time, all three models suggest that conditions for other species (e.g., eastern redcedar and loblolly pine) will become more favorable by the end of the century, especially for GFDL A1FI. Additionally, the Tree Atlas and LINKAGES tend to agree that many species will remain stable or increase for PCM B1 and decrease for GFDL A1FI. These results support the idea that GFDL A1FI future climate is beyond the tolerance of many species, but that many species could tolerate a mild degree of warming with a corresponding increase in growing season precipitation, as represented by PCM B1.

Generally, the changing climate tends to intensify the stressors that may already exist for many species and increases susceptibility to drought, pests, diseases, or competition from other species. It is the interaction among all these factors that will drive the response of forests to climate change. All of these factors need to be taken into account when evaluating the vulnerability of Central Appalachians forests to climate change. The vulnerability of nine forest ecosystems is described in Chapter 6.

# CHAPTER 6: FOREST ECOSYSTEM VULNERABILITIES

Changes in species distribution and abundance due to climate change can have important implications for the habitats in which those species live, leading to shifts in community composition and changes in ecosystem processes (Janetos et al. 2008, Vose et al. 2012). In addition, climate change itself can alter ecosystem drivers and exacerbate or ameliorate current stressors (Janetos et al. 2008, Vose et al. 2012). This chapter describes the climate change vulnerability of nine major forest ecosystems in the Central Appalachians assessment area (see Chapter 1 for a description of the nine forest ecosystems). Vulnerability is the susceptibility of an ecosystem to the adverse effects of climate change (Intergovernmental Panel on Climate Change [IPCC] 2007). It is a function of the potential impacts (a combination of exposure and sensitivity) to an ecosystem and the adaptive capacity of the ecosystem to tolerate those impacts (Fig. 41). We consider a forest ecosystem to be vulnerable if it is at risk for no longer being recognizable as that ecosystem, or if the ecosystem is anticipated to suffer substantial declines in health or productivity. We considered the vulnerability of an ecosystem to climate change independent of the economic or social values associated with the ecosystem, even though forest management, land-use changes, and human population pressures can have dramatic and immediate effects on ecosystems. The ultimate decision of whether to use resources to try to conserve a vulnerable ecosystem or allow it to shift to an alternate state will depend on the individual objectives and resources of land management organizations.

This chapter is organized into two sections. First, we present an overall synthesis of potential climate impacts on forest ecosystems, organized according to drivers and stressors, ecosystem impacts, and factors that influence adaptive capacity. This synthesis is based on the current scientific consensus of published literature (Chapters 4 and 5). In the second section, we present individual vulnerability determinations for the nine forest ecosystems considered in this assessment.

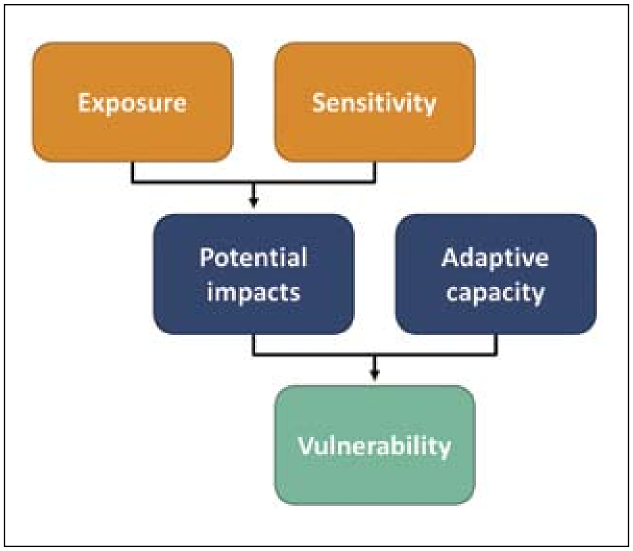
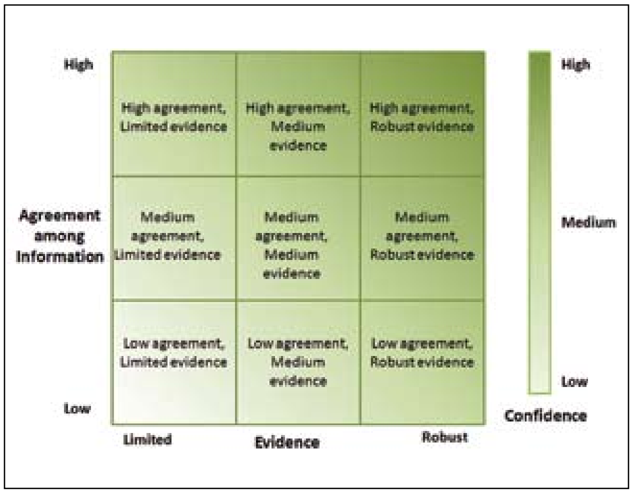


Figure 41.—Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity. Adapted from Glick et al. (2011).

# A SYNTHESIS OF CLIMATE CHANGE IMPACTS ON FOREST ECOSYSTEMS

Potential impacts are the direct and indirect consequences of climate change on individual ecosystems. Impacts are a function of an ecosystem's exposure to climate change and its sensitivity to those changes. Impacts could be beneficial to an ecosystem if the changes result in improved health or productivity, occupation of an expanded area, or a tendency to maintain the current identity of the ecosystem. Negative potential impacts would include declining health and productivity, reduced area occupied, or a composition shift that leads to a substantially different identity of the ecosystem.

Throughout this chapter, statements about potential impacts and adaptive capacity factors are qualified with a confidence statement. These confidence statements are formatted according to a confidence determination diagram from the IPCC's recent guidance for authors (Mastrandrea et al. 2010) (Fig. 42). Confidence was determined by gauging both the amount of available evidence and the level of agreement among that evidence. Evidence was robust when multiple lines of evidence were available in addition to an established theoretical understanding to support the vulnerability determination. Agreement refers to the agreement among the available sources of evidence, not among authors of this assessment. If theories, observations, and models tended to suggest similar outcomes, the sum of the evidence resulted in a high level of agreement.



| | | | |
|---|---|---|---|
| High | High agreement, Limited evidence | High agreement, Medium evidence | High agreement, Robust evidence |
| | Medium agreement, Limited evidence | Medium agreement, Medium evidence | Medium agreement, Robust evidence |
| Low | Low agreement, Limited evidence | Low agreement, Medium evidence | Low agreement, Robust evidence |

Figure 42.—Confidence determination diagram used in the assessment. Adapted from Mastrandrea et al. (2010).

## Potential Impacts of Climate Change on Drivers and Stressors

Many physical and biological factors contribute to the current state of forest ecosystems in the Central Appalachians region. Some of these factors serve as drivers, or defining features that determine the identity of an ecosystem. Other factors can serve as stressors, reducing the health, productivity, and integrity of specific ecosystems. Many factors, such as flooding or fire, may be drivers in one ecosystem and stressors in another.

**Temperatures will increase (robust evidence, high agreement).** *All downscaled climate models project that average temperatures will increase across much of the assessment area.*

A large amount of evidence from across the globe shows that average temperatures have been increasing and will continue to increase due to human activities (Chapter 2). Temperatures across the assessment area have already been changing over the last century (Chapter 3), and temperature increases are projected even under the most conservative climate scenario, with dramatic increases projected under the high climate scenario (Chapter 4).

**Growing seasons will get longer (robust evidence, high agreement).** *There is high agreement among evidence that projected temperature increases will continue the current trend of longer growing seasons in the assessment area.*

Evidence at both global and regional scales indicates that growing seasons have been getting longer, and this trend is likely to become even more pronounced over the next century (Chapters 3 and 4). Longer growing seasons have the potential to affect the timing and duration of ecosystem and physiological processes across the region (Dragoni and Rahman 2012). As seasons shift so that spring arrives earlier and fall extends later into the year, plant species may respond to changes in temperature regimes with changes in the timing of leaf-out, reproductive maturation, and other developmental processes (Schwartz et al. 2006a, Walther et al. 2002), and some of these changes have already been observed (McEwan et al. 2011). Longer growing seasons, especially those that are extended in the fall, could also result in greater growth and productivity of trees and other vegetation, but only if balanced by available water and nutrients (Chapter 5). Longer growing seasons could also lead to changes in the distributions of plant and animal species (Iverson et al. 2008b).

**The amount and timing of precipitation will change (medium evidence, high agreement).** *All downscaled climate models agree that there will be changes in precipitation patterns across the assessment area.*

For the climate projections used in this assessment (Chapter 4) and other publications, projected changes in precipitation are highly variable (Kunkel et al. 2013a, 2013b). The PCM B1 scenario projects annual precipitation to increase over most of the assessment area, but decrease sharply in the Allegheny Mountains section. The GFDL A1FI scenario projects increases over much of the Ohio and Maryland portions of the assessment area, and widespread decreases over larger areas of West Virginia, including the Allegheny Mountains (Chapter 4). Models also project changes in precipitation patterns between seasons (Kunkel et al. 2013b). Precipitation increases are expected under both scenarios in winter and spring, with larger increases under GFDL. Summer and fall precipitation projections suggest a wide range of potential responses, from decreases to increases, depending on the climate scenario (Chapter 4).

**Intense precipitation events will continue to become more frequent (medium evidence, medium agreement).** *There is some agreement that the number of heavy precipitation events will continue to increase in the assessment area. If so, impacts from flooding and soil erosion may also become more damaging.*

Total precipitation in the assessment area has increased the most in fall, by 2.3 inches over the last century. The timing and magnitude of precipitation events have shifted, however, so that more rain is falling during larger events, and light rainfall events are becoming less common (Chapter 3). Rainfall from these high-intensity events represents a larger proportion of the total rainfall, meaning that the precipitation regime is becoming more episodic with potentially longer dry spells between events. Climate models project this trend to continue through the end of the century, with an additional increase in the number of heavy precipitation events throughout the central and northeastern United States (IPCC 2012). Ecosystems are not all equally capable of holding moisture that comes in the form of extreme events. Increases in runoff after heavy precipitation events could also lead to an increase in soil erosion, specifically channel erosion (Nearing et al. 2004).

**Severe storms will increase in frequency and severity (medium evidence, medium agreement).** *There is some agreement that future climate change will destabilize atmospheric circulation patterns and processes, leading to increased risk of severe weather.*

Although the positive trend in historic storm frequency is muddled with greater public awareness, reporting, and recent advances in technology, future trends can be predicted by using atmospheric models. Projected increases in temperature, precipitation, and convective available potential energy over the next century are expected to result in more frequent days when conditions are favorable for severe storms (Trapp et al. 2007, 2009, 2011). Many storms affecting the assessment area are generated in the southwestern United States and from the Atlantic Ocean; therefore changes in conditions in these regions may contribute to increased frequency and severity of storms within the assessment area (Trapp et al. 2007).

**Soil moisture patterns will change (medium evidence, high agreement), with drier soil conditions later in the growing season (medium evidence, medium agreement).** *Studies show that climate change will have impacts on soil moisture, but there is some disagreement among climate and impact models on how soil moisture will change during the growing season.*

As discussed above, seasonal changes in precipitation are expected across the assessment area. Due to potential decreases in summer and fall precipitation and increases in winter and spring precipitation, it is likely that soil moisture regimes will also shift. Longer growing seasons and warmer temperatures may also result in greater evapotranspiration losses and lower soil-water availability later in the growing season (Chapter 4). The Variable Infiltration Capacity model projected summer and fall decreases in soil moisture, with the greatest decrease (10 percent) in the West Virginia portion of the assessment area (Ashfaq et al. 2010). How these broad trends affect the Central Appalachians region will depend greatly on landscape and topographic position and therefore exposure to climate changes. South-facing slopes may be particularly vulnerable to soil drying in late summer or fall. Seedlings will be more vulnerable to these effects than mature individuals; just one severely dry growing season per decade may greatly reduce regeneration success of most species (Gómez-Aparicio et al. 2008).

**Climate conditions will increase wildfire risk by the end of the century (medium evidence, medium agreement).** *Some national and global studies suggest that wildfire risk will increase in the region, but few studies have specifically looked at wildfire potential in the assessment area.*

Although there is greater uncertainty around future fire behavior for the near term, model simulations tend to agree that there will be global increases in fire activity by the end of the 21st century (Moritz et al. 2012). The duration of the fire season in the Central Appalachians is closely linked with increases in average temperature during the summer (Liu et al. 2010). Interactions between complex patterns of land use and ownership, forest fragmentation, and both human and natural ignition sources, make it difficult to determine how an increase in fire weather conditions might be manifested. In addition to the direct effects of temperature and precipitation, increases in fuel loads from pest-induced mortality, exotic species invasion, or blowdown events could also increase fire risk (Lovett et al. 2006, Weed et al. 2013). Forest fragmentation and unknown future wildfire management decisions may limit individual fires even as fire risk increases.

**Certain insect pests and pathogens will increase in occurrence or become more damaging (medium evidence, high agreement).** *Evidence indicates that an increase in temperature will lead to increases in pest and pathogen outbreaks, but research to date has examined few species in the assessment area.*

Changes in climate may allow some pests and pathogens to expand their ranges, or to become a larger threat. Changes in climate may also increase tree species' susceptibility to the entire suite of native and nonnative pests and pathogens, including hemlock woolly adelgid, southern pine beetle, and forest tent caterpillar. Pests and pathogens are generally more damaging in drought-stressed ecosystems, so there is high potential for these agents to interact with other climate-mediated stressors. For example, susceptibility of trees to sudden oak death is linked to periods of drought stress. The fungus *Phytophthora ramorum*, a known contributor to sudden oak death in California and Europe, is currently spread through nurseries and has appeared in nursery samples in Connecticut. The climate of the assessment area is favorable to this fungus, which is likely to increase in abundance and extent in association with wetter springs (Kliejunas 2011). Furthermore, the abundance of potential host species in the assessment area increases the threat from introduction of this new disease (Ockels et al. 2004). Unfortunately, we lack basic information on the climatic thresholds that apply to many forest pests, and our ability to predict the mechanisms of infection, dispersal, and transmission for disease agents remains low. It is also not possible to predict all future nonnative species, pests, or pathogens that may enter the assessment area during the 21st century.

**Many invasive plants will increase in extent or abundance (medium evidence, high agreement).** *Evidence indicates that an increase in temperature and more frequent disturbances will lead to increases in many invasive plant species.*

Many invasive species that currently threaten forests in the Central Appalachians region may benefit directly from projected climate change or benefit from the slow response of native species (Rebbeck 2012). Increases in carbon dioxide have been shown to have positive effects on growth for many plant species, including some of the most invasive weeds in the United States (Ziska 2003). Changes in climate may allow some invasive plant species to expand their ranges northward, such as bush honeysuckle, privet, kudzu, and cogongrass. Milder winters may allow some invasive plant species to survive farther north than they had previously (Dukes et al. 2009). Some invasive species are tolerant of drought and fire, and may be at an even greater advantage for future climate conditions. Future increases in fire or flooding are likely to benefit the many invasive plants that are able to establish quickly and outcompete native vegetation on disturbed sites (Brown and Peet 2003, Dukes et al. 2009). Increases in riparian flooding is expected to contribute to more frequent disturbance, and therefore higher impacts from invasive species.

## Potential Impacts of Climate Change on Forests

Shifts in drivers and stressors mentioned above will naturally lead to changes in forest ecosystems throughout the assessment area. Indirect impacts of climate change may be indicated by shifts in suitable habitat, species composition, or function of forest ecosystems.

**Suitable habitat for northern species will decline (medium evidence, high agreement).** *All three impact models project a decrease in suitability for northern species such as eastern hemlock, red spruce, and sugar maple, compared to current climate conditions.*

Across northern latitudes, past periods of warmer temperatures have resulted in changes in species distribution northward and to higher elevations (Chen et al. 2011, Parmesan and Yohe 2003). The ranges of eastern hemlock and red spruce are largely to the north of the assessment area, but these species currently persist in microhabitats that remain cool and moist enough to support them. Red spruce is more limited within the assessment area, occurring at high elevations in the Allegheny Mountains section of West Virginia. Hemlock is more widespread, occupying cool and wet sites at lower elevations. As these species' ranges continue to shift northward, they may become rare or extirpated from the area. In the absence of other mortality agents, long-lived individuals already established in cool, wet microhabitats may persist for many years, even when habitat becomes unsuitable for regeneration or growth (Iverson and Prasad 1998). Due to the geographic limitations of these species' current habitat, however, they are unlikely to migrate even if newly suitable habitat becomes available elsewhere in the assessment area. Results from climate impact models also suggest declines in suitable habitat

Eastern hemlock. This species is threatened by the hemlock woolly adelgid. Photo by Patricia Butler, Northern Institute of Applied Climate Science (NIACS) and Michigan Tech, used with permission.

for northern species that are not as geographically limited, such as sugar maple (Chapter 5). These species near the southern edge of their range may also be able to persist in southern refugia if potential new competitors from farther south are unable to colonize these areas, although they are expected to have reduced vigor and be under greater stress (Iverson et al. 2008b).

**Habitat is projected to become more suitable for southern species (medium evidence, high agreement).** *All three impact models project an increase in suitability for southern species such as eastern redcedar and loblolly pine, compared to current climate conditions.*

Model results project that tree species currently at their northern range limits south of the assessment area will become more abundant and more widespread under a range of climate futures (Chapter 5). The range of eastern redcedar is widespread throughout the eastern United States, but currently occupies a small portion of its range within the assessment area. The range of loblolly pine lies entirely south of the assessment area, although disjunct populations have been planted in some locations within Ohio and Maryland. Models agree that loblolly pine will fare well in terms of habitat and basal area, especially under GFDL A1FI. Post oak and shortleaf pine are also projected to fare well under both scenarios. The ranges of both species are largely south and west of the assessment area, with populations most abundant to the west. Blackjack oak, common persimmon, osage-orange, southern red oak, sugarberry, sweetgum, and winged elm are also projected to increase, but were modeled only by the Tree Atlas. Several species that do not currently exist within the assessment area are projected to have new suitable habitat: water oak, water locust, and cedar elm. However, habitat fragmentation and the limited dispersal ability of seeds are expected to hinder movement of these southern species despite the increase in habitat suitability (Ibáñez et al. 2008). Most tree species can be expected to migrate more slowly than their habitats will shift (Davis and Shaw 2001). Indeed, in a simulation for five tree species, a maximum of 15 percent of newly suitable habitat would have a chance of getting colonized over 100 years (Iverson et al. 2004a, 2004b). Pests and diseases such as fusiform rust, annosus root rot, and southern pine beetle may also limit the expansion of loblolly pine. As suitable habitat increases for some tree species and decreases for others, there will be new opportunities for species to become new components of novel forest types or commercial plantations (Iverson et al. 2008a).

**Species composition will change across the landscape (limited evidence, high agreement).** *Although few models have specifically examined how species composition may change, model results from individual species, paleoecological data, and ecological principles suggest that recognized communities may dissolve to form new mixes of species.*

Decoupling of the drivers, stressors, and dominant tree species that define forest ecosystems is expected to lead to a rearrangement of suitable conditions for tree species within the assessment area. This rearrangement may result in the dissolution of current plant community relationships, which paleoecological evidence shows occurred in the past (Davis et al. 2005, Root et al. 2003, Webb and Bartlein 1992). Canopy and understory species composition is closely tied to soil moisture, aspect, slope position, and other environmental variables (Hix and Pearcy 1997). Shifts in overstory and understory structure may follow somewhat predictable pathways based on shifts in soil moisture, fire frequency, and disturbance regime, but will still be strongly correlated to landscape position (Iverson et al. 1997). For example, on the Wayne National Forest, dominant tree species are expected to be oaks on dry ridge tops, and tulip tree and black cherry on mesic sites (Iverson et al. 1997). The model results presented in Chapter 5 raise the possibility for potentially large differences in species' responses across the Central Appalachians. Generally, the models indicate that climate trends may favor oaks and pines, although ecological lag times and management decisions may slow conversions of forest types. Repeated harvesting, grazing, and other large-scale disturbances have already created atypical relationships among the canopy and understory species in many areas, lending more uncertainty to future community composition (Root et al. 2003). If associated species such as pollinators and mycorrhizae do not migrate into newly suitable areas, further constraints could be placed on native species colonization (Clark et al. 1998). Furthermore, nonnative invasive plants may be better able to fill newly created niches (Hellmann et al. 2008).

**A major transition in forest composition is not expected until after the middle of the century (2040 to 2069) (medium evidence, medium agreement).** *Although some models indicate major changes in habitat suitability, results from spatially dynamic forest landscape models indicate that a major shift in forest composition across the landscape may take 100 years or more in the absence of major disturbances.*

Model results from the Tree Atlas and LINKAGES (Chapter 5) indicate substantial changes in habitat suitability or establishment probability for many species on the landscape, but do not account for migration constraints or differences among age classes. Forest landscape models such as LANDIS PRO can incorporate spatial configurations of current forest ecosystems, seed dispersal, and potential interactions between native species and the invasion and establishment of nonnative plant species (He et al. 1999, 2005). In addition, forest landscape models can account for differences among age classes, and have generally found mature trees to be more tolerant of warming (He and Mladenoff 1999). Because mature trees are expected to remain on the landscape, and recruitment of new species is expected to be limited, it is not expected that major shifts in species composition will be observed by the middle of the century, except in areas that undergo more intensive harvesting or major stand-replacing disturbance events (Ryan et al. 2008). Climate change is projected to increase the intensity, scope, or frequency of some stand-replacing events such as wildfire, ice storms, and insect outbreaks, promoting major shifts in species composition where these events occur.

**Climate change is expected to affect early growth and regeneration conditions (medium evidence, medium agreement).** *Seedlings are more vulnerable than mature trees to changes in temperature, moisture, and other seedbed and early growth requirements.*

Evidence of climate change impacts on forest ecosystems is more likely to be seen in seedlings and early growth than in mature individuals. Temperature and moisture requirements for seed dormancy and germination are often much more critical than habitat requirements of an adult tree (Kitajima and Fenner 2000). Predicted changes in temperature, precipitation, growing season onset, and soil moisture may alter the duration or manifestation of germination conditions. For example, regeneration failure in balsam fir populations has been attributed, at least partially, to climate change (Abrams et al. 2001). For species with seeds that disperse successfully, these changes may result in redistribution on the landscape as seeds germinate only where conditions are met (Walck et al. 2011). Others species may fail to regenerate under altered future conditions, or may germinate without having sufficient conditions to develop. Warmer winters may promote the establishment of eastern redcedar and other southern species, although warmer temperatures alone are unlikely to drive their establishment (Abrams 2003). After establishment, advance regeneration (i.e., saplings) are still more sensitive than mature trees to drought, heat stress, frost, and other disturbances, such as fire, flooding, and herbivory (Kitajima and Fenner 2000).

**Increased fire frequency and harvesting will accelerate shifts in forest composition across the landscape (medium evidence, medium agreement).** *Studies from other regions show that increased fire frequency can accelerate the decline of species negatively affected by climate change and can accelerate the northward migration of southern tree species.*

Days with conditions that are suitable for wildfire ignition are expected to become more frequent, although the occurrence of wildfire will depend on both ignition and human response (Chapter 5). Frequent, low-intensity fires in certain forest ecosystems (e.g., beech-maple) can reduce or inhibit seedling establishment of tree species projected to decline under climate change (e.g., sugar maple, American beech). In other forest ecosystems (e.g., dry-mesic oak), fire can be beneficial for restoration and to promote regeneration. In some ecosystems (e.g., dry oak-pine), infrequent, high-intensity fires can promote regeneration and release growing space for tree species that may be better adapted to future conditions. Fire (including low-intensity prescribed fire) is expected to accelerate changes in forest composition, promoting faster changes than those caused by increased temperature or moisture availability (He et al. 2002, Shang et al. 2004).

**Net change in forest productivity is expected to be minimal (medium evidence, low agreement).** *A few studies have examined the impact of climate change on forest productivity, but they disagree on how multiple factors may interact to influence it.*

Changes in productivity will likely be mixed and localized. Increases in drought, invasive plants, insects, disease, and wildfire are expected to negatively affect forest productivity in some parts of the region (Hanson and Weltzin 2000). Longer growing seasons, with adequate moisture, may lead to greater annual productivity. Future increases in carbon dioxide may enhance growth rates and water use efficiency of some species through carbon dioxide fertilization (Ainsworth and Rogers 2007, Norby et al. 2005), potentially offsetting the effects of drier growing seasons. Sulfur dioxide, a component of acid deposition, has been shown to reduce carbon dioxide fertilization effects in eastern redcedar in West Virginia (Thomas et al. 2013). Decreases in sulfur dioxide after the Clean Air Act of 1970 are allowing a slow recovery, which is expected to result in increased carbon uptake by trees. There is already some evidence for increased forest growth in the eastern United States (Cole et al. 2010, McMahon et al. 2010, Pan et al. 2009), but it remains unclear if long-term enhanced growth can be sustained (Bonan 2008, Foster et al. 2010). Nutrient and water availability, ozone pollution, and tree age and size all play major roles in the ability of trees to capitalize on carbon dioxide fertilization (Ainsworth and Long 2005). Productivity in the Central Appalachians is already affected by acid deposition, especially in those forests at the highest elevations (Elliott et al. 2013). Modeling results from LANDIS PRO, which do not include the possible effects of carbon dioxide fertilization or reductions in acid deposition, project minimal changes in basal area across the assessment area, even for GFDL A1FI, but large changes for some species in certain locations (Appendix 4). Elevation and aspect, and their influence on soil water availability, will also be a major driver of local ecosystem response (Vanderhorst et al. 2008).

## Adaptive Capacity Factors

Adaptive capacity is the ability of a species or ecosystem to accommodate or cope with potential climate change impacts with minimal disruption (Glick et al. 2011). Below, we summarize factors that could reduce or increase the adaptive capacity of forest ecosystems within the assessment area. Greater adaptive capacity tends to reduce climate change vulnerability, and lower adaptive capacity tends to increase vulnerability (Appendix 5).

**Low-diversity ecosystems are at greater risk (medium evidence, high agreement).** *Studies have consistently shown that diverse ecosystems are more resilient to disturbance, and low-diversity ecosystems are more vulnerable to change.*

In general, species-rich ecosystems have exhibited greater resilience to extreme environmental conditions and greater potential to recover from disturbance than less diverse ecosystems (Tilman 1996, 1999). Consequently, less diverse ecosystems are inherently more susceptible to future changes and stressors (Swanston et al. 2011). Conversely, ecosystems that have low species diversity or low functional diversity (where multiple species occupy the same niche) may be less resilient to climate change or its associated stressors (Peterson et al. 1998, Walker 1992, Walker et al. 1999). Forest stands with low diversity of species, age classes, and genotypes have been more vulnerable to insect and disease outbreaks than diverse stands (Raffa et al. 2008). Genetic diversity within species is also critical for the ability of populations to adapt to climate change, because species with high genetic variation are more apt to have individuals that can withstand a wide range of environmental stressors (Reusch et al. 2005).

**Species in fragmented landscapes will have less opportunity to migrate long distances in response to climate change (limited evidence, high agreement).** *Evidence suggests that species may not be able to disperse over the distances required to keep up with climate change, but little research has been done in the region on this topic.*

Habitat fragmentation can hinder the ability of tree species to migrate to more suitable habitat on the landscape, especially if the surrounding area is nonforested (Ibáñez et al. 2006, Iverson et al. 2004). It is estimated that a plant would need to migrate 90 miles north or 550 feet in altitude in order to escape a 1.8 °F increase in temperature (Jump and Peñuelas 2005). Modeling results indicate that suitable habitat for tree species will migrate between 60 and 350 miles by the year 2100 under a high emissions scenario and between 30 and 250 miles under milder climate change scenarios (Iverson et al. 2004). Based on gathered data of seedling distributions, it has been estimated that tree species could possibly migrate northward at a rate of up to 100 miles per century (Woodall et al. 2009), and other evidence indicates that natural migration rates could be far slower for some species (Iverson et al. 2004a, McLachlan et al. 2005, Murphy et al. 2010). This research also suggests that range migration has already begun; centers of seedling densities were often more than 12 miles north of species' centers of biomass (Woodall et al. 2009). Fragmentation makes migration even more challenging, because the landscape is essentially less permeable to migration (Jump and Peñuelas 2005, Scheller and Mladenoff 2008).

**Ecosystems that are highly limited by hydrologic regime or geological features may be topographically constrained (limited evidence, medium agreement).** *Our current understanding of the ecology of Central Appalachians ecosystems suggests that some species will be unable to migrate to new areas due to topographic constraints.*

Communities that require specific hydrologic regimes, unique soils or geology, or narrow elevation ranges may not be able to shift across the landscape, even if conditions are favorable. For example, high-elevation spruce/fir ecosystems are found exclusively in the highest elevations of the Allegheny Mountains, as remnant populations surviving in the coolest and wettest habitats in the region (Byers et al. 2007). These ecosystems, which range from wetlands to uplands, are already restricted to the highest elevations, and if habitat becomes unsuitable, it is doubtful that there will be alternate sites or that they would be able to migrate over unsuitable habitat to reach potential northern sites (Nowacki et al. 2009).

**Ecosystems that are tolerant of disturbance or are disturbance-adapted have less risk of declining on the landscape (medium evidence, high agreement).** *Basic ecological theory and other evidence support the idea that systems that are adapted to more frequent disturbance will be at lower risk.*

Disturbances such as drought, flooding, wildfire, and insect outbreaks have the potential to increase in the assessment area (Chapters 4 and 5). Several ecosystems (e.g., Appalachian [hemlock]-northern hardwood and north-central interior beech-maple forests) are adapted to frequent gap-phase disturbances, but undergo stand-replacing events on the scale of hundreds or thousands of years. Therefore, these systems may be less tolerant of more frequent stand-level disturbances, such as drought or fire. Mesic ecosystems can create conditions that could buffer against fire and drought to some extent (Nowacki and Abrams 2008). However, even species in mesic ecosystems could decline if soil moisture declines significantly. Forest ecosystems that are more tolerant of drought, flooding, or fire (e.g., dry oak and oak/pine forest and woodland) will likely be better able to withstand climate-driven disturbances (Wagner et al. 2012). This principle holds true only up to a point, because it is also possible for disturbance-adapted ecosystems to undergo too much disruption. For example, oak and pine ecosystems might cover a greater extent under drier conditions with more frequent fire, but these systems might also convert to barrens or open grasslands if fire becomes too frequent or drought becomes too severe.

**Fire-adapted ecosystems will be more resilient to climate change (high evidence, medium agreement).** *Studies have shown that fire-adapted ecosystems are better able to recover after disturbances and can promote many of the species that are expected to do well under a changing climate.*

In general, fire-adapted ecosystems that have a more open structure and composition are less prone to high-severity wildfire (Shang et al. 2004). Frequent low-severity fire has also been shown to promote many species projected to do well under future climate projections, such as shortleaf pine, pitch pine, and a number of oak species (Aldrich et al. 2010, Brose and Waldrop 2006, Brose et al. 2013, Patterson 2006). In these ecosystems, fire suppression has resulted in sometimes heavy encroachment of woody species in the understory that compete with oak and pine regeneration (Nowacki and Abrams 2008, Patterson 2006, Sharitz et al. 1992). In addition, fire suppression in fire-adapted ecosystems can lead to increased susceptibility to damaging insect infestations (McCullough et al. 1998). Since the mid-1900s, suppression of fire has led to an increase in red maple and sugar maple across the eastern forests (Abrams 1998, Nowacki and Abrams 2008). These species are not projected to fare well under climate change, largely due to regeneration failure (Chapter 5), and the opportunity may arise to restore fire-suppressed ecosystems. However, the effects of fire on seedling establishment, tree growth, and nutrient cycling can vary by site conditions, species, and burn regime (Brose et al. 2013, McCullough et al. 1998).

**Ecosystems occupying habitat in areas of high landscape complexity have more opportunities for persistence in pockets of refugia (medium evidence, medium agreement).** *The diversity of landscape positions occupied by forest may provide opportunities for natural refugia, for example where cool air and moisture accumulate in valley bottoms.*

Species diversity in the Central Appalachians has been linked to geophysical diversity of the area (Anderson and Ferree 2010). With increasing topographic and landform complexity come a greater number of landscape characteristics and microhabitats that buffer against climate changes

(Anderson et al. 2012, Fridley 2009). Many areas across West Virginia and Maryland, such as the Allegheny Mountains, have a high diversity of landscape characteristics, such as geophysical setting, landscape complexity, and connectivity, that contribute to the high species diversity (Anderson et al. 2012). This diversity of landscape features supports a variety of rare, endemic, and localized plant and animal species, some of which are restricted to a single geology (Anderson and Ferree 2010). The Tree Atlas modeled the most common tree species, but did not model many of the rare species (Chapter 5). Even the relatively flat areas of the assessment area contain complex ridge systems and associated soil moisture regimes that support a high diversity of species. Although climate will largely determine a species' potential range, it is the influence of geology that creates areas of microhabitat offering refugia against the effects of climate change (Anderson and Ferree 2010).

## VULNERABILITY DETERMINATIONS FOR INDIVIDUAL FOREST ECOSYSTEMS

Climate-induced shifts in drivers, stressors, and dominant tree species will result in different impacts to forest ecosystems within the assessment area. Some ecosystems may have a greater capacity to adapt to these changes than others, whereas some may be susceptible to relatively minor impacts. Therefore, it is helpful to consider these factors for individual forest ecosystems in addition to describing general principles related to vulnerability and adaptive capacity. Table 23 presents a summary of current major drivers and stressors for each forest ecosystem covered in this assessment.

The following vulnerability determinations draw on the information presented in previous chapters, as

**Table 23.—Vulnerability determination summaries for forest ecosystems considered in this assessment**

| Forest ecosystem | Potential impacts | Adaptive capacity | Vulnerability | Evidence | Agreement |
|---|---|---|---|---|---|
| Appalachian (hemlock)/ northern hardwood forest | Negative | Low-Moderate | High | Medium | Medium |
| Dry calcareous forest, woodland, and glade | Neutral-Negative | Low-Moderate | Moderate-High | Limited-Medium | Medium |
| Dry oak and oak/pine forest and woodland | Positive | Moderate-High | Low | Medium | Medium-High |
| Dry/mesic oak forest | Positive-Neutral | High | Low- Moderate | Medium | Medium-High |
| Large stream floodplain and riparian forest | Negative | Low | High | Medium | Medium |
| Mixed mesophytic and cove forest | Neutral-Negative | Moderate-High | Moderate | Limited-Medium | Medium |
| North-central interior beech/maple forest | Neutral | Moderate | Moderate | Limited-Medium | Medium |
| Small stream riparian forest | Negative | Moderate | Moderate-High | Medium | Medium |
| Spruce/fir forest | Negative | Moderate | High | Limited-Medium | Medium |

well as an expert panel assembled from a variety of organizations and disciplines across the assessment area. The 19 panelists evaluated anticipated climate trends for the assessment area and ecosystem model projections (Chapter 5), in combination with their own expertise. For each forest ecosystem, panelists considered the potential impacts and adaptive capacity to assign a vulnerability determination (Fig. 43) and a level of confidence in that determination using the same confidence scale described above. For a complete description of the methods used to determine vulnerability, see Appendix 5.

Overall vulnerability determinations were rated lowest for dry oak and oak/pine forest and woodland and highest for Appalachian (hemlock)/northern hardwood, spruce/fir, and large stream floodplain and riparian forests (Table 23). Impacts were rated as being most negative for Appalachian (hemlock)/northern hardwood, large stream floodplain and riparian, and spruce/fir forests. Impacts were rated most positive for dry oak and oak/pine forest. Several negative and positive impacts were identified for north-central interior beech/maple forest, which was given an overall rating of neutral impacts. Adaptive capacity was rated lowest for large stream floodplain and riparian forest, and highest for dry/mesic oak forest.

Panelists tended to rate the amount of evidence as limited to medium (between limited and robust) for most forest ecosystems. Incomplete knowledge of future wildfire regimes, interactions among stressors, and precipitation regimes were common factors limiting this component of overall confidence. The ratings of agreement among evidence also tended to be in the medium range. Contrasting information related to precipitation regimes under the high and low climate change scenarios was one factor that limited the level of agreement among evidence. The way that forest ecosystems were organized and described for this assessment also limited the agreement in some instances. In general, ratings were slightly higher for agreement than for evidence. Evidence appears not to be as robust as the experts would prefer, but the various information sources that are available tend to support similar conclusions.

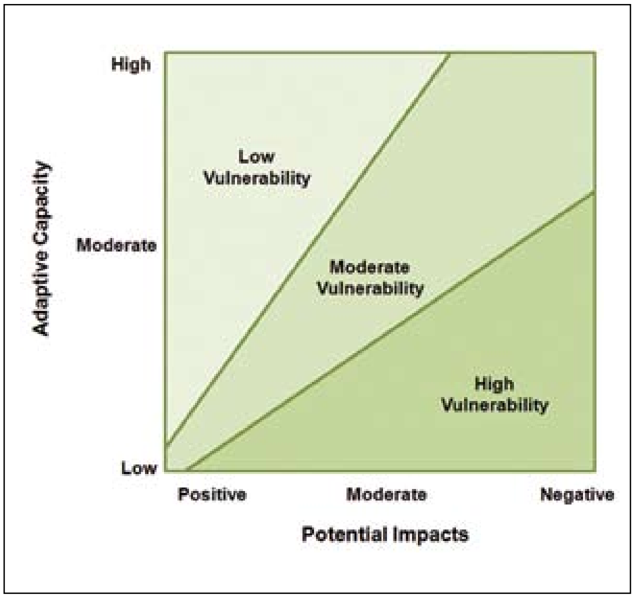


Figure 43.—Vulnerability diagram used in the assessment.

In the sections that follow, we summarize the climate-related impacts on drivers, stressors, and dominant tree species that were major contributors to the vulnerability determination for each forest ecosystem. In addition, we summarize the main factors contributing to the adaptive capacity of each ecosystem. For a list of common tree species in each forest ecosystem, see Chapter 1.

## Appalachian (Hemlock)/Northern Hardwood Forest

### High Vulnerability (medium evidence, medium agreement)

Climate change may intensify several interacting stressors, such as drought, forest pests, and invasive species. Any increased wildfire activity would be detrimental to the health of this forest type. Reduced species diversity may decrease resilience to the future climate. Valley bottoms and other microsites in areas of complex topography may be buffered from the effects of climate change, providing refugia.

### Negative Potential Impacts

**Drivers:** Decreased precipitation and increased temperatures may interact to ultimately decrease soil moisture during summer and fall. Increased heat and moisture stress, exposure to insect pests and pathogens, and more frequent disturbances are expected to interact and place increased stress on this ecosystem. Climate change may also alter the gap-phase dynamics that enable the regeneration of many shade-tolerant species if damaging storms, pest outbreaks, or wildfires become more frequent or widespread.

**Dominant Species:** Model results indicate that American beech, eastern hemlock (considered a keystone species where it occurs), and sugar maple will remain relatively stable for PCM B1, but will lose suitable habitat, growth potential, and volume in the assessment area for GFDL A1FI (Chapter 5). These species are vulnerable to the direct changes in temperature and precipitation, and are susceptible to moisture stress, beech bark disease, hemlock woolly adelgid, and other climate and nonclimate stresses. Results are mixed for red maple, tulip tree, black cherry, and white ash, which are projected to lose suitable habitat but maintain potential growth and volume. Although the amount of suitable habitat may contract, models agree that remaining suitable habitat may allow regeneration of these species in the absence of other stressors. Red spruce, considered a minor component in the eastern part of the assessment area, is projected to experience a dramatic decline in growth potential and suitable habitat, especially for GFDL A1FI, although established adults are likely to persist even after they no longer regenerate successfully.

**Stressors:** Climate change may amplify several major stressors to northern hardwoods, particularly for stands occurring on southwest slopes or marginally suitable soils. Hemlock woolly adelgid, beech bark disease, emerald ash borer, and other pests currently attack many species in this ecosystem and may cause more frequent and severe damage in climate-stressed forests. Pests such as Asian longhorned beetle and gypsy moth may present new risks if they are able to expand from established locations adjacent to the assessment area (Chapter 5). With the exception of spruce/fir forests, acid deposition afflicts this ecosystem more than any other due to its distribution across acid-sensitive geologies (USDA 2006). Acid deposition damages ecosystem health, and it is unclear how climate change may affect the ability of ecosystems to cope with acid deposition in the future. Increases in wildfire risk would be a severe impact for this ecosystem because many tree species within this ecosystem do not tolerate fire. Interactions between stressors, such as drought, pests, acid deposition, invasive species, and wildfire are likely to have greater impacts than temperature or precipitation alone.

## Low-Moderate Adaptive Capacity

This ecosystem typically supports a variety of plant species on gentle to steep slopes in diverse and complex terrain, but is limited to the highest elevations in the Allegheny Mountains. This ecosystem is often found on soils with high water-holding capacity in areas that normally receive abundant moisture from precipitation and ground seepage. However, the combined effects of acid deposition, drought, and defoliation have already resulted in lower species diversity and reduced adaptive capacity (Chapter 5). Eastern hemlock is currently susceptible to widespread mortality from hemlock woolly adelgid, which is expected to dramatically reduce eastern hemlock populations over the next few decades. Red spruce is currently expanding on the landscape, and may persist where cool, wet conditions provide refugia. Sites on moist soils that continue to receive abundant moisture may be buffered from seasonal moisture stress, whereas sites on exposed slopes may be more sensitive to moisture stress. The diversity of landscape positions occupied by this forest may also provide opportunities for natural refugia, for example, where cool air and moisture pool in north-facing pockets and valley bottoms.

A hemlock stand in Wooster Memorial Park, Ohio. Photo by David M. Hix, Ohio State University, used with permission.

An Appalachian (hemlock)/northern hardwood forest. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

An Appalachian (hemlock)/northern hardwood forest. Photo by Brian Streets, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## Dry Calcareous Forest, Woodland, and Glade

### Moderate-High Vulnerability (limited-medium evidence, medium agreement)

Many of the species in this ecosystem are projected to do well under a range of plausible climate futures. However, this ecosystem's occupation of extreme habitat on unique soil types implies that it is geographically limited, and unable to shift freely on the landscape.

### Neutral-Negative Potential Impacts

**Drivers:** Drought and fire have been important factors in maintaining the open form of this ecosystem, and increased drought is not expected to harm many species, unless it becomes too severe. Wildfire potential could increase under drier conditions, although fire intensity will determine whether it is a positive or negative impact. Low-intensity fire could benefit this ecosystem by reducing the eastern redcedar component in the woodland portions of this ecosystem that are becoming overgrown. However, high-intensity fire that results in widespread mortality of eastern redcedar will dramatically change this ecosystem.

**Dominant Species:** Projected changes in climate are expected to benefit many of the common tree species in this ecosystem. Models project that eastern redcedar, white oak, and post oak will remain relatively stable or increase in suitable habitat, potential growth, and volume under both climate scenarios (Chapter 5). White oak is long-lived and able to persist in the shaded understory until openings are naturally created in the canopy. Eastern redcedar, and to a lesser extent white oak, is dependent on disturbance and expected to benefit from soil moisture deficits, fire, and other disturbances. Chinkapin oak, eastern redbud, eastern hophornbeam, and shagbark hickory were modeled only by the Tree Atlas, and were similarly projected to increase in suitable habitat.

**Stressors:** Increased drought duration and extent may increase susceptibility to oak decline, or may combine with insect and disease factors to increase stress or mortality. Invasive species are also common in this forest ecosystem, and climate change is expected to promote establishment and growth of invasives, resulting in increased competition with the many rare native plants in this ecosystem. Increases in invasive species such as cheat grass, stilt grass, and bush honeysuckles could increase fire fuels in this type, leading to potentially more-intense fire when it does occur.

### Low-Moderate Adaptive Capacity

This ecosystem is characterized by high species diversity, but has been affected by limestone quarrying, agriculture, and fragmentation. The co-occurrence of the dominant species is tightly linked to the unique soils derived from limestone, and movement on the landscape is limited to landscape positions where those soils form. Many of these species tolerate temperature and moisture extremes, especially on exposed landscape features, allowing them to outcompete other species. Severe drought, projected temperature increases, and increased fire may allow expansion of the woodland and glade elements at the expense of the forested areas.

A north-central Appalachian circumneutral cliff and talus ecosystem. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A dry calcareous outcrop at Castle Rock, West Virginia. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A dry calcareous woodland. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## Dry Oak and Oak/Pine Forest and Woodland

### Low Vulnerability (medium evidence, medium-high agreement)

This ecosystem is the most resilient to heat and drought, with many of the species currently doing well, and projected to do well under future climate. Periodic conditions that limit regeneration may be buffered by oak's ability to resprout. Increased drought and fire are likely to benefit this ecosystem, discourage invasive species, and maintain an open structure that promotes oak and pine regeneration.

### Positive Potential Impacts

**Drivers:** This dry ecosystem is characterized by thin, droughty, and nutrient-poor soils. Soils can become hydrophobic for short periods of time, which can be made worse by fire. Fire frequency was historically higher than it is currently, largely due to fire suppression over the last 50 years. Drier soil conditions in summer and fall, especially on south-facing slopes, may increase the risk of wildfire (Chapter 5). Shale barrens and ridge tops are especially exposed to extreme temperatures. Increased frequency of extreme weather events (e.g., windstorms and ice storms) may lead to more frequent disturbances.

**Dominant Species:** Many of the common species in this ecosystem are projected to remain relatively stable in total volume, but volume is expected to shift from many smaller trees in younger age classes to fewer larger trees in older age classes. Many of the species in this ecosystem will require active management, such as prescribed fire, to stimulate regeneration. Models project that suitable habitat, potential growth, and trees per acre for chestnut oak and scarlet oak will remain stable for PCM B1 and decrease for GFDL A1FI. Black oak is projected to remain stable for PCM B1, but for GFDL A1FI suitable habitat is expected to increase while growth potential and trees per acre decrease. Models project increases in suitable habitat and potential growth for only one species, loblolly pine, which is expected to benefit from increased temperatures under both scenarios. Pitch pine, Table Mountain pine, and Virginia pine were modeled only by the Tree Atlas, which projected suitable habitat to remain stable or increase for both scenarios.

**Stressors:** Increased drought conditions, especially during the growing season, may increase susceptibility to red oak borer, gypsy moth, armillaria root disease, and other insect pests and diseases. Southern pine beetle outbreaks have been observed in New Jersey and Pennsylvania systems recently, and may increase due to warmer temperatures. Ailanthus, Japanese stiltgrass, multiflora rose, bush honeysuckle, autumn olive, and Japanese barberry often outcompete native herbs and shrubs in this ecosystem, and are also likely to benefit from warmer temperatures and increased disturbance. Invasive shrubs in the understory may provide additional ladder fuels and increase fire intensity where wildfire occurs; impacts will depend on severity of fire.

## Moderate-High Adaptive Capacity

This ecosystem is the most resilient to extreme heat and moisture deficits of the ecosystems examined in the assessment area. Many pine and oak species are fire adapted and drought-tolerant, some requiring high-intensity fire to regenerate (Vose et al. 1993). A history of fire suppression and succession has contributed to a reduced pine component in favor of oak species. Increased wildfire frequency could help regenerate and promote both oak and pine species. Low-severity late-season drought generally favors oak species, although severe drought may hinder regeneration, or combine with other stressors to make individuals more susceptible to mortality or reduced productivity. This ecosystem benefits from disturbance regimes, such as fire and windthrow, which promote conditions for regeneration. This ecosystem's wide distribution on a range of habitat conditions makes it well-poised to take advantage of new habitat that may become too dry for other species.

A dry oak forest ecosystem with rhododendron in the understory. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A dry oak forest ecosystem with an open canopy. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A dry oak forest ecosystem. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

An oak/pine woodland. The understory of this dry site is dominated by sedge and grasses. Photo by Brian Streets, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## Dry/Mesic Oak Forest

### Low-Moderate Vulnerability (medium evidence, medium-high agreement)

This ecosystem supports a high number of tree species and occurs over a wide range of habitats. Many species are tolerant of dry soil conditions and fire, although young regeneration may be sensitive to severe drought and fire. Southern oak and hickory species are likely to benefit from projected changes in climate.

### Positive-Neutral Potential Impacts

**Drivers:** Fire frequency was historically higher than it is currently, largely due to fire suppression over the last 50 years. Drier soil conditions in summer and fall, especially on south-facing slopes, may increase the risk of wildfire. Increased frequency of extreme weather events (e.g., windstorms and ice storms) may lead to more frequent large-gap disturbances. Increases in extreme precipitation events may increase the potential for erosion and channeling.

**Dominant Species:** Of the many species modeled, suitable habitat was generally projected to increase for the southern oaks and hickories, whereas other common species are projected to persist over a smaller extent. Models project that habitat suitability, basal area and trees per acre, and potential growth for pignut hickory and white oak will remain relatively stable or increase slightly under both scenarios. Results for northern red oak are highly variable across the assessment area, but suggest positive effects on regeneration where suitable habitat remains. Other common species are not expected to do as well, especially for GFDL A1FI: models project that suitable habitat, potential growth, and trees per acre will decrease for chestnut oak and scarlet oak. Black oak is projected to remain stable for PCM B1, but for GFDL A1FI suitable habitat is expected to increase while growth potential and trees per acre decrease. Mockernut hickory and shagbark hickory were modeled only by the Tree Atlas, and both are projected to increase in suitable habitat.

**Stressors:** Increased drought risk, especially during the growing season, may increase susceptibility to red oak borer, ambrosia beetle, gypsy moth, armillaria root disease, and other insect pests and diseases. Ailanthus, Japanese stiltgrass, and garlic mustard, which often outcompete native herbs and shrubs in this ecosystem, are expected to do well in warmer temperatures. Low-severity late-season drought generally favors oak species, although severe drought may hinder regeneration, or combine with other stressors to make individuals more susceptible to mortality or reduced productivity.

### High Adaptive Capacity

A history of fire suppression and timber harvesting has facilitated a shift to more mesic soils and associated hardwood species (e.g., sugar maple, American beech, tulip tree). Increased fire frequency could help regenerate oak species and restore the understory composition. However, very frequent fires have the potential to kill young seedlings of any species, even those species that have relatively fire-resistant, thick bark as adults. This ecosystem is widely distributed, representative of a range of habitat conditions, and likely to expand on the landscape. American chestnut was historically a dominant canopy tree but now cannot grow past sapling size due to chestnut blight. Blight-resistant American chestnut variants are currently under development and experimental planting is already occurring, resulting in increased species diversity in select areas (Jacobs et al. 2013).

A mesic oak forest with maple regenerating in the understory. Photo by Brian Streets, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A dry oak forest with grasses dominating the open understory. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A dry/mesic oak forest. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## Large Stream Floodplain and Riparian Forest

### High Vulnerability (medium evidence, medium agreement)

Climate change is expected to alter the water regimes in riparian systems, and may amplify the effects of insect pests, invasive species, and pollution. Dependence on periodic inundation, combined with competition from invasive species, may result in a reduced ability of native tree species to tolerate increased disturbances.

### Negative Potential Impacts

**Drivers:** Potential changes to the precipitation regime could intensify peak streamflow and shift the timing to earlier in the spring. Reduced precipitation in the summer and fall would result in drier conditions, increasing the potential for late-summer drought. An increase in intense precipitation events is likely to result in more frequent flooding. Wildfire, currently episodic and human-caused, could increase under drier conditions, although the extent would be limited by the fragmented nature of riparian and floodplain ecosystems.

**Dominant Species:** Many riverine species in this forest type were modeled only by the Tree Atlas; thus evidence is somewhat limited regarding dominant species. Black willow, green ash, sweetgum, and sycamore are projected to increase in suitable habitat over much of the assessment area. Silver maple had mixed results, but is projected to generally decrease in suitable habitat for PCM B1 and increase for GFDL A1FI. Eastern cottonwood and bur oak occurred at sufficient densities to be modeled only in the Ohio portion of the assessment area, and are projected to decrease slightly for PCM B1 and increase for GFDL A1FI. Pin oak, also adequately abundant only in Ohio, is projected to increase and expand into West Virginia, where pin oak swamps currently exist in isolated locations. These species are all tightly linked to moisture availability, and are especially threatened by potentially drier soil conditions.

**Stressors:** Climate change is expected to intensify several key stressors for large stream riparian and floodplain forests. Many invasive plant species currently threaten this ecosystem and are expected to benefit from climate change and outcompete native species. Drought-stressed trees may become more susceptible to insect pests such as emerald ash borer and diseases such as thousand cankers and elm yellows. Interactions among multiple stressors may also lead to more severe climate change impacts. Increases in storm intensity and flooding events have the potential to increase soil erosion and sedimentation, and compound anthropogenic stressors such as agricultural runoff and industrial pollution.

### Low Adaptive Capacity

This ecosystem exists in many variations within a relatively small proportion of the assessment area, but is extremely altered by habitat destruction, fragmentation, and disconnection of floodplain forests from rivers and streams (e.g., by roads or other infrastructure that impedes the flow of water). The high number of invasive species outcompeting natives has already reduced the adaptive capacity of this ecosystem. Although this ecosystem is highly dependent on disturbance and a regular influx of seeds, nutrients, and water during periodic flooding, increases in flood intensity or more frequent drought may not be tolerated by many species, especially in the early growth stages. Mortality of ash species from emerald ash borer is likely to eliminate this species by mid-century, reducing overall native species diversity. Forests located along river corridors may be buffered from water deficit better than those located farther away on the flood plain, but will be more exposed to flooding effects.

A large stream floodplain forest on the Buckhanon River, West Virginia. Photo by Brian Streets, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A large stream floodplain forest on the Meadow River, West Virginia. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A large stream floodplain forest on the Greenbrier River, West Virginia. Photo by Brian Streets, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## Mixed Mesophytic and Cove Forest

### Moderate Vulnerability (limited-medium evidence, medium agreement)

This relatively sheltered ecosystem may face a suite of amplified disturbances, including wildfire, drought, and invasion by invasive species. Suitable habitat for many species is projected to decline, although there is great potential for the complex topography to provide refugia where disjunct populations may persist.

### Neutral-Negative Potential Impacts

**Drivers:** This ecosystem is adapted to generally wet or mesic sites in the Allegheny Plateau and Allegheny Mountains sections, and is characterized by a high number of tree species. If drought becomes more frequent or widespread in late summer or fall, seedlings and saplings may be at risk of desiccation. Drought would lead to increased risk of wildfire, which this ecosystem would not tolerate well. Increased frequency of extreme weather events (e.g., windstorms and ice storms) may lead to more frequent large-gap disturbances.

**Dominant Species:** Many species are commonly associated with this ecosystem, and individual species responses are expected to differ with ecological sections and expected degree of climate-related changes. Models project that American beech, eastern hemlock (considered a keystone species where it occurs), and sugar maple will remain relatively stable for PCM B1, but will lose suitable habitat, growth potential, and volume in the assessment area for GFDL A1FI (Chapter 5). These species are vulnerable to the direct changes in temperature and precipitation, and are susceptible to moisture stress, beech bark disease, mortality from hemlock woolly adelgid, and other stresses resulting from indirect impacts of climate change. Results are mixed for red maple, tulip tree, black cherry, and white ash, which are projected to lose suitable habitat but maintain potential growth and volume. Although the amount of suitable habitat may contract, models agree that remaining suitable habitat may allow regeneration of these species in the absence of other stressors. Results for northern red oak are highly variable across the assessment area, but suggest positive effects on regeneration where suitable habitat remains. Black oak is projected to remain stable for PCM B1, but for GFDL A1FI suitable habitat is expected to increase while growth potential and trees per acre decrease.

**Stressors:** Increased drought conditions may increase susceptibility of trees in this system to hemlock woolly adelgid, forest tent caterpillar, beech bark disease, and other insect pests and diseases. Eastern hemlock is currently susceptible to widespread mortality from hemlock woolly adelgid, which is expected to dramatically reduce eastern hemlock populations over the next few decades. Japanese stiltgrass, garlic mustard, ailanthus, and bush honeysuckle have already shifted understory species composition, and are expected to increase in response to warmer temperatures. Increases in invasive species could increase fire fuels in this type, leading to potentially more-intense fire when it does occur. Most species are fire-intolerant, although oak species would benefit from an increase in fire.

## Moderate-High Adaptive Capacity

This ecosystem currently has high species diversity, and its sheltered position on concave slopes in complex topography may buffer against climate changes. The ability of coves to collect water and nutrients from higher areas may benefit species by creating refugia from temperature increases, precipitation changes, and wind. Ecosystem response to climate change impacts will vary across the landscape depending on current landscape position, individual species response, and connectivity. In the mountains, species may be able to migrate upwards more easily than northwards to escape warming temperatures. Emerald ash borer infestations have already damaged and killed many ash trees. This forest ecosystem has been diminished by fragmentation and conversion to agriculture, coal mining, and logging. Especially in southeastern Ohio, remaining forest blocks occur in a highly fragmented mosaic of second-growth forests and have reduced biodiversity.

A cove forest in the Allegheny Mountains of West Virginia. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A Southern and Central Appalachian cove forest. Photo by Brian Streets, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## North-Central Interior Beech/Maple Forest

### Moderate Vulnerability (limited-medium evidence, medium agreement)

Although sugar maple and American beech are projected to decline to some degree, many associated species in this ecosystem are projected to do well under a range of future climates. This forest's position on glacial till floodplains, moraines, and plateaus promotes and preserves moist soil conditions, a critical feature which may help buffer the impacts of changing temperature and hydrologic regimes.

### Neutral Potential Impacts

**Drivers:** This forest occurs largely within the lake-effect zone of Lake Erie, where heavy-textured soils and glacial landforms help retain soil moisture. Other instances are found on lowland positions supplied by wetland hydrology. Projected decreases in precipitation in late summer and fall may increase the frequency or extent of drought. This system is intolerant of fire, and is characterized by long disturbance intervals. Increased frequency of extreme weather events is likely to promote canopy gap disturbances of larger size and extent than at present.

**Dominant Species:** Models project that American beech, sugar maple, and eastern hemlock (occurring locally in the glaciated Ohio and eastern portions of the assessment area) will remain relatively stable for PCM B1, but will lose suitable habitat, growth potential, and volume in the assessment area for GFDL A1FI (Chapter 5). These species are vulnerable to the direct changes in temperature and precipitation, and are susceptible to increased moisture stress and other indirect impacts of climate change. Results are mixed for red maple, tulip tree, black cherry, and white ash, which are projected to lose suitable habitat but maintain potential growth and volume. Although the amount of suitable habitat may contract, models agree that remaining suitable habitat may allow regeneration of these species in the absence of other stressors. Results for northern red oak are highly variable across the assessment area, but suggest positive effects on regeneration where suitable habitat remains.

**Stressors:** Beech bark disease, emerald ash borer, hemlock woolly adelgid, anthracnose disease, and a variety of other pests and pathogens currently affect this ecosystem. Certain insects, such as hemlock woolly adelgid, may benefit from warmer winter temperatures, creating additional stress for these forests. The emerald ash borer has already reduced the white ash component in parts of the assessment area. Invasive plants such as princesstree, silktree, ailanthus, and glossy buckthorn compete directly with understory plants and native tree regeneration and these invasives are likely to take advantage of increased temperatures and disturbance.

### Moderate Adaptive Capacity

This ecosystem supports relatively high species diversity. Its position on moist soils in glacial topography, and its proximity to lake-effect precipitation, helps to maintain soil moisture, which may buffer against drought and discourage conditions that promote wildfire. However, these benefits decrease with increasing distance from Lake Erie. Many of the dominant tree species are not tolerant of drought or fire. Drought-stressed trees may be more susceptible to invasives or disease complexes, resulting in decreased productivity or mortality. An increase in wildfire could promote transition to primarily fire-adapted species (e.g., oaks), changing the identity of this ecosystem. Heavy deer browsing is also limiting seedling establishment and growth, and protection from herbivory will be critical in establishing regeneration, now and under future climate conditions.

Sugar maple and beech canopy in an Ohio beech/maple forest. Photo by David M. Hix, Ohio State University, used with permission.

A north-central interior beech/maple forest at Crall Woods, Ohio. Photo by David M. Hix, Ohio State University, used with permission.

## Small Stream Riparian Forest

### Moderate-High Vulnerability (medium evidence, medium agreement)

This ecosystem is adapted to natural disturbance, but is threatened by amplification of the disturbance regime, and by invasive plants, insects, and pathogens. Many species are projected to remain stable or increase under a range of future climate conditions, but a keystone species, hemlock, is likely to disappear in many areas.

### Negative Potential Impacts

**Drivers:** Changes to the timing and intensity of precipitation events may lead to increased flashiness and more frequent high water events in spring. Spring flooding and inundation have the potential for increased erosion, silt loads, and sedimentation. Summer and fall moisture deficits have the potential to create dry vegetation conditions, stressing hydrophilic seedlings and supporting wildfire conditions. Mortality and damage from drought or storms may result in increased coarse woody debris, contributing to wildfire fuels.

**Dominant Species:** Many riverine species in this forest type were modeled only by the Tree Atlas, so evidence is somewhat limited regarding dominant species (Chapter 5). Additionally, some of these species are not common on the landscape, and are therefore difficult to model. Suitable habitat is projected to remain stable or increase for sycamore, river birch, black walnut, and boxelder. Silver maple and cottonwood are projected to decrease for PCM B1 and increase for GFDL A1FI. Hemlock and red maple were modeled by all three models. Eastern hemlock is projected to remain stable or decrease in suitable habitat and potential growth; basal area and trees per acre are projected to decrease due to succession, and to a lesser extent due to climate. Red maple had mixed results for suitable habitat and potential growth, and basal area and trees per acre are projected to increase due to succession and climate change. Many of these species, except red maple, are tightly linked to moisture availability.

**Stressors:** Invasive plants are very problematic in this ecosystem, with greater impacts generally occurring downstream. Increased flashiness followed by dry periods could cause amplification of the current hydrologic cycle, potentially increasing the spread and establishment of current and newly introduced invasive species. Drought-stressed trees may be more susceptible to diseases such as thousand cankers and elm yellows, and insect pests such as hemlock woolly adelgid. Increases in storm frequency and flood intensity have the potential to increase soil erosion and sedimentation, and compound anthropogenic stressors such as agricultural runoff and industrial pollution.

### Moderate Adaptive Capacity

This ecosystem exists in many variations or settings across the landscape with various assemblages of a fairly diverse set of species, many of which are projected to remain stable or even increase under climate change. Further, this ecosystem type is adapted to cope with a high level of variability and natural disturbance, and may be able to handle many impacts of temperature and precipitation changes except for extreme drought or severe flooding. Cold air pooling in valleys and shelters may also provide refugia that are buffered from temperature increases. In the cooler and moister sites, hemlock is a keystone species that has been declining and is projected to decline further. For these forests, the loss of hemlock is likely to change the species assemblage dramatically, with fast-growing generalists like red maple or a variety of invasive species likely to overtake the newly vacated niche.

A small stream riparian forest with a large herbaceous component. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

A small stream riparian forest. Photo by Jim Vanderhorst, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

Cottonwood and other hardwoods along a stream at Alum Creek, Ohio. Photo by David M. Hix, Ohio State University, used with permission.

## Spruce/Fir Forest

### High Vulnerability (limited-medium evidence, medium agreement)

This ecosystem is dependent on very moist conditions, and persists only in the coolest, wettest, and highest elevation sites in mountainous sections. Projected increases in temperature and decreases in summer and fall precipitation may exceed the ecological tolerances of this ecosystem's defining species. Complex topography may provide cool pockets of habitat where these species would be likely to persist.

### Negative Potential Impacts

**Drivers:** This ecosystem type is adapted to cool temperatures and abundant moisture in the form of rain, snow, and fog drip. Projected increases in temperature and potential decreases in precipitation later in the growing season may decrease the amount of atmospheric moisture that could develop into fog in summer or snow in winter. If soils in this ecosystem dry out, the entire ecosystem would be affected. Drier conditions could also increase the risk of duff fire, previously not a threat except after extreme anthropogenic disturbances. Changes in winter processes could affect this high-elevation ecosystem more than others; interacting effects of reduced snow cover (warm temperatures) or increased snow cover (lake effect) may alter soil freezing conditions.

**Dominant Species:** Red spruce and balsam fir (the two keystone species in this ecosystem) are limited to the Allegheny Mountains and the Northern Ridge and Valley sections, and models project suitable habitat and growth potential to decline dramatically for both species under both climate scenarios (Chapter 5). Models also project suitable habitat, growth potential, and trees per acre to decline for eastern hemlock and eastern white pine, but only for GFDL A1FI. Results are mixed for red maple, tulip tree, black cherry, and white ash, which are projected to lose suitable habitat but maintain potential growth and volume. Although the amount of suitable habitat may contract, models agree that remaining suitable habitat may allow regeneration of these species in the absence of other stressors. Other common species were modeled only by the Tree Atlas: cucumbertree, yellow birch, and sweet birch are also projected to lose suitable habitat in the sections occupied by this ecosystem.

**Stressors:** Insect pests such as the hemlock and balsam woolly adelgids currently affect this ecosystem and have the potential to increase when winter temperatures no longer limit populations. There is also potential for new invasive plants, although they may be limited by acidic soils. If deer populations benefit from warmer temperatures, herbivory on hemlock and balsam fir could increase, but red spruce would benefit because it is not a preferred browse species. Acid deposition damages ecosystem health, and it is unclear how climate change may affect the ability of ecosystems to cope with acid deposition in the future.

### Moderate Adaptive Capacity

This forest ecosystem is currently stable and expanding on the landscape to reoccupy available suitable habitat. Red spruce, projected to decline for GFDL A1FI at the end of the century, influences the soil to create positive edaphic conditions that are favorable to its own regeneration. Red spruce has been negatively affected by acid deposition, which may decrease its natural resistance to changes (McLaughlin and Kohut 1992, McLaughlin et al. 1990, Schuler and Collins 2002). Balsam fir has the lowest adaptive capacity of all the species in this ecosystem, largely due to its fire- and drought-intolerance and susceptibility to balsam woolly adelgid and other insect pests. Eastern hemlock is currently susceptible to widespread mortality from hemlock woolly adelgid, which is expected to dramatically reduce eastern hemlock populations over the next few decades. The potential for drought may be buffered by high rainfall and fog generated at higher elevations. Suitable habitat for this ecosystem is already limited to the highest elevations in the Central Appalachians and the range of this ecosystem may contract as climate change forces species upward. Cold air pooling in valleys and shelters may provide areas of refugia buffered from temperature increases. Red spruce is currently expanding on the landscape, and may persist where cool, wet conditions provide refugia.

A high-elevation spruce/fir forest in West Virginia. Photo by Elizabeth Byers, West Virginia Division of Natural Resources, Natural Heritage Program, used with permission.

## CHAPTER SUMMARY

Forest ecosystems across the assessment area will be affected by climate change, although these ecosystems and individual tree species will respond to these changes differently. The synthesis statements in the first half of this chapter can be applied as general principles when specific information about expected climate change impacts is lacking. Overall, we expect that forest ecosystems will be most severely affected by projected decreases in late season precipitation; decreases are projected for summer for GFDL A1FI and for fall for PCM B1. Forest ecosystems that are adapted to dry conditions and frequent disturbances are expected to be less vulnerable to the range of future climates. Forest ecosystems that are adapted to tolerate a wide range of conditions and disturbances, and have higher mobility on the landscape, are also expected to be better able to persist under a range of plausible climates.

The vulnerability determinations for individual forest ecosystems are best interpreted as broad trends and expectations across the assessment area. For some species, climate-related changes over the next century may be a continuation of current trends. For other species, it may take more than 100 years before such changes become apparent. For long-lived species especially, substantial changes on the landscape within this century will likely be the result of succession, management, and disturbance. Vulnerability to anthropogenic stressors such as fragmentation, urban development, and arson impinges on an ecosystem's adaptive capacity, and may be much more influential on ecosystems than climate change, especially over the first half of this century. This assessment uses the most up-to-date information from the scientific literature, a coordinated set of ecosystem modeling results and climate projections, and the input of a large team of local experts. Even so, there are limitations and unknowns that make these determinations imperfect. As new information continues to be generated on the potential impacts of climate change on forests in this region, this assessment should be supplemented with additional resources and stand-level information.

The high diversity in landforms, microclimates, hydrology, and species assemblages across the assessment area greatly complicates model projections and interpretation. In this assessment, forest ecosystems were combined and generalized based on NatureServe's ecological systems, which are themselves made up of hundreds of unique "associations" (Chapter 1). Forest ecosystems have the potential to manifest themselves in very different ways across the assessment area (e.g., varying in species associations and landscape position), and it is important to have a good working knowledge of forest ecosystems at the local level in each section. It is essential to consider local characteristics such as past management history, soils, topographic features, species composition, forest health issues, and recent disturbances when interpreting these general vulnerabilities at local scales. Some site-level factors may amplify these expected vulnerabilities, yet others may buffer the effects of climate change. Developing a clear understanding of potential vulnerabilities across relevant scales will then enable forest managers, landowners, planners, and other resource specialists to consider appropriate adaptation responses. This is true whether the task is to manage a single stand over a few years, or to design a long-term management plan for a large tract of land.

In the following chapter, we extend the discussion to consider the implications of climate trends and forest ecosystem vulnerabilities for other ecosystem services and resource areas that are often important to forest managers.

# CHAPTER 7: MANAGEMENT IMPLICATIONS

The previous chapters of this assessment have described observed and anticipated climate trends, potential impacts to forest ecosystems, and the climate-related vulnerability of nine forest ecosystems in the assessment area. This chapter takes one additional step and summarizes some implications of these climate change impacts and vulnerabilities for a variety of topics important to forest managers. Changes in climate, impacts on forest ecosystems, and ecosystem vulnerability will combine to create both challenges and opportunities in forest management.

Topics were selected to encompass major resource areas that are priorities for public and private land managers. These topics, and the descriptions of climate change implications, are not comprehensive. Some topics have received less scientific attention or contain greater uncertainty. For some topics we relied on input from subject-area experts to discuss climate change implications. Our goal is to provide a springboard for thinking about management implications of climate change and to connect managers to other relevant resources. When available, the "more information" sections provide links to key resources for managers to find more information about the impacts of climate change on that particular topic. The topics addressed are: wildlife, threatened and endangered plant species, nonnative invasive plant species, fire and fuels, infrastructure, air and water quality, forest products, nontimber forest products, forest carbon, recreation, wilderness, cultural resources, urban forests, forest-associated towns and cities, and planning for conservation and natural resource management.

This chapter does not make recommendations as to how management should be adjusted to cope with climate impacts. We recognize that the implications of climate change will vary by ecosystem, ownership, and management objective. Therefore, we provide broad summaries rather than focusing on particular management issues. A separate document, *Forest Adaptation Resources*, has been developed to assist land managers in a decisionmaking process to adapt their land management to projected impacts (Swanston and Janowiak 2012).

## WILDLIFE

Climate change is likely to have both short- and long-term effects on individual organisms, populations, species, and wildlife communities in the Central Appalachians region. These effects may range from direct habitat loss to complex indirect impacts on wildlife populations and their habitats. Changes to habitats discussed in Chapter 6 will likely result in range expansion for some species and the reduction or complete loss of available suitable habitat for others. Wildlife populations may respond by adapting to new conditions or migrating to follow shifts in suitable habitat; species that are unable to adapt or have limited dispersal ability, particularly those that are already rare, may face substantial challenges in a changing climate. Managing wildlife species may require adjustments to accommodate shifting ranges or to provide supplemental food sources during critical periods. Climate change vulnerability assessments have been conducted for many individual species within West Virginia (Byers and Norris 2011), and the broader Central

Appalachians region (Furedi et al. 2011, Schlesinger et al. 2011). These assessments are generally focused on state-listed sensitive species for which climate change is only one of a multitude of stressors which have already affected population ranges or viability. The Climate Change Bird Atlas uses forest inventory data and species-specific habitat requirements to examine the potential for climate change to alter the distribution of 147 bird species across the eastern United States (Landscape Change Research Group 2014).

Birds appear to be less vulnerable to climate change impacts than other taxonomic groups because they tend to have less habitat specificity, are able to disperse long distances, and are not as hindered by natural and anthropogenic obstacles on the landscape. However, bird species that are dependent on specific habitat types (e.g., high-elevation conifer forest) may be unable to meet their habitat requirements in a new location, or habitat shifts may introduce new competitors and predators (Matthews et al. 2011a). Other potential climate change impacts include changes in the timing of migration for some birds, or the resources (e.g., flowers, seeds, larvae) upon which they depend. Many short-distance migrants have been observed to respond to local changes by adjusting their arrival or departure dates, but long-distance (e.g., transcontinental) migrants respond to cues at their origin, and are unable to predict conditions at their summer grounds (Hurlbert and Liang 2012). Birds arriving either too early or too late could face suboptimal conditions (e.g., limited food resources or difficulty finding mates), resulting in adverse impacts to fitness and survival (Fraser et al. 2013).

A young bird amid rhododendron and hemlock. Photo by Patricia Butler, Northern Institute of Applied Climate Science (NIACS) and Michigan Tech, used with permission.

Bat species that rely on insects for food after emerging from hibernation may face similar challenges; shifts in insect populations can influence bats' ability to regain weight lost during hibernation and to reproduce successfully. Bats may be particularly sensitive to climate change because many aspects of their ecology and life history are closely tied to temperature and precipitation, and many species in the assessment area have already suffered catastrophic declines as a result of white-nose syndrome. Modeling of Indiana bat habitat used maternity habitat requirements of less than 82 °F and projected the summer range to contract to climatic refugia in the northeastern United States and Appalachian Mountains (Loeb and Winters 2013).

Other mobile mammal species found in the assessment area may face similar range reductions, particularly species that are adapted to cool, moist habitats. However, species that are dependent on a narrow range of conditions or have limited mobility may not be able to shift to alternate locations as climate and habitat conditions change. For example, the West Virginia northern flying squirrel is closely tied to high-elevation spruce/northern hardwood forests and is restricted in its ability to exploit alternative habitats because of competition with the southern flying squirrel. In addition, as the habitat and range of the southern flying squirrel expands in response to climate change, the potential for hybridization (and loss of genetic integrity) with northern flying squirrels increases (Garroway et al. 2010). Squirrels and other wildlife species that depend on mast trees may benefit from increases in those tree species projected to do well, such as post and white oaks and pignut hickory.

Most regional amphibians and fish are poor dispersers and less able to shift to alternate locations in response to adverse changes in local habitat conditions. In addition, many of these species are aquatic or closely associated with specific aquatic and wetland habitats. As a result, these taxonomic groups make up the majority of species considered to be extremely or highly vulnerable in the state vulnerability assessments noted above. The exceptions are cave-obligate species, because caves and associated groundwater-fed aquatic systems appear to be largely buffered from climatic changes. Vulnerable amphibians include the Cheat Mountain and green salamanders, which are constrained by narrow habitat niches; the Jefferson salamander, which is dependent on ephemeral wetlands; and the eastern hellbender and eastern spadefoot toad, which require specific aquatic and riparian habitat features. Mollusk and fish species are threatened by natural and anthropogenic barriers to movement, and physical habitat specificity contributes to their vulnerability to changes in water temperature and precipitation patterns (Byers and Norris 2011). As a group, mollusks are especially vulnerable to negative impacts associated with climate change because of their limited dispersal ability and dependence on a few fish species to serve as larval hosts. Cold- and cool-water fish species, such as brook trout, sculpin species, and redside dace are highly vulnerable to climate change impacts, particularly populations inhabiting small, high-elevation streams that may experience drying of stream beds or elevated water temperatures.

Some reptiles and invertebrates are also likely to be affected by climate change. Reptiles rely on ambient environmental temperature to maintain their physiological processes and are uniquely sensitive to changes in temperature. The sex of offspring of many turtle species is determined by ambient temperature; thus, concerns for already sensitive species such as the spotted turtle and bog turtle include physiological impacts that may affect long-term fitness of a population regardless of vegetative habitat changes. Although some research has been conducted on how climate change might affect insects, most of that work is focused on European butterflies and insects of economic and environmental concern in forestry and agriculture

Eastern garter snake. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

(Andrew et al. 2013). Within the assessment area, climate-related changes in hydrology and declines in stream quality are expected to adversely affect several dragonflies, such as the crimson-ringed whiteface, rapids clubtail, and green-faced clubtail (Furedi et al. 2011).

The topic of climate change impacts to fish and wildlife is an area of very active research, with new insights into species' adaptations and management ideas to help populations meet these challenges emerging constantly. In addition to research publications, several tools are available online to assist land managers in evaluating species vulnerabilities and potential changes to fish and wildlife resources. A few of these resources follow:

## More Information

- The U.S. Forest Service's Climate Change Resource Center provides information related to climate change impacts to wildlife and species' responses: www.fs.fed.us/ccrc/topics/wildlife/. Please note that Web addresses are current as of the publication date of this assessment but are subject to change.
- NatureServe's Climate Change Vulnerability Index (CCVI) tool uses readily available information about a species' natural history and distribution and about the landscape to predict whether it will likely suffer a range contraction and population reductions due to climate change: https://connect.natureserve.org/science/climate-change/ccvi

- The Climate Change Bird Atlas is a companion to the Climate Change Tree Atlas and uses information about the direct climate effects as well as changes in habitat to project changes in bird species distributions: www.nrs.fs.fed.us/atlas/bird/
- The Appalachian Landscape Conservation Cooperative (LCC) Web site provides links to resources, documents, papers, webinar series announcements, and other information about drivers and impacts of climate change (including those affecting wildlife and fish), particularly in relation to the Appalachian landscape: http://applcc.org/resources/climate-change
- Many states are working to incorporate climate change information into their state wildlife action plans. Voluntary guidance has been provided by the Association of Fish and Wildlife Agencies: www.fishwildlife.org/files/AFWA-Voluntary-Guidance-Incorporating-Climate-Change_SWAP.pdf
- West Virginia's Climate Change Vulnerability Assessment for Species of Concern provides evaluations of climate change impacts for many plants and animals in the assessment area based on NatureServe's CCVI: http://wvdnr.gov/publications/PDFFiles/ClimateChangeVulnerability.pdf
- The Ohio Department of Natural Resources (ODNR) provides a Web page with a variety of links to vulnerability assessment resources: http://www.dnr.state.oh.us/Home/ExperienceWildlifeSubHomePage/where_to_viewwildlifelandingpage/OldWomanCreekDefault/ClimateandWildlife/climate_wlvulnerability/tabid/23672/Default.aspx

## THREATENED AND ENDANGERED PLANT SPECIES

The Central Appalachians region contains a great diversity of threatened, endangered, and rare plants. Within the assessment area, the U.S. Fish and Wildlife Service (USFWS) lists eight plant species as threatened or endangered (T&E): running buffalo clover, northern wild monkshood, eastern prairie fringed orchid, Virginia spiraea, small whorled pogonia, northeastern bulrush, harperella, and shale barren rockcress (USFWS 2014). These species occur in habitats that include wetlands, riparian areas, deciduous forests, grasslands, and small patch habitats such as shale barrens. In addition, the U.S. Forest Service lists 81 plant species as Regional Forester's Sensitive Species due to their rarity on the Monongahela and Wayne National Forests. State Natural Heritage Programs track many more rare plant species, including well over 400 species in West Virginia alone, with additional species tracked in the Appalachian portions of Ohio and Maryland. Thus, rare plants can be found in all of the forest ecosystems that are included in this assessment.

Given the numerous habitats in which rare plants are found, the effects of climate change on rare plants are likely to vary widely. In general, species with limited distributions are believed to be disproportionately vulnerable to the negative impacts of climate change because suitable habitat may not be available, or because they have no way of migrating to suitable habitat that may become available (Schwartz et al. 2006b). However, predicting impacts on individual species can be difficult because many rare species may be limited by narrow ecological tolerances that are not related to climate sensitivity (Schwartz et al. 2006b).

The West Virginia Natural Heritage Program applied NatureServe's Climate Change Vulnerability Index to 18 rare plant species and predicted that 7 of them would be highly vulnerable or extremely vulnerable to negative impacts, including 4 T&E species (northeastern bulrush, harperella, small whorled pogonia, and shale barren rockcress). Eight rare species were predicted to be moderately vulnerable, including two T&E species (Virginia spiraea and running buffalo clover). Only four (non-T&E) rare plant species were predicted to remain stable under a changing climate (Bentley's coralroot, Torrey's mountainmint, Tennessee pondweed, and lillydale onion). Increased fire may benefit some threatened and endangered plants by maintaining habitat or promoting flowering, as evidence suggests for running buffalo clover and eastern prairie fringed orchid (Hessl and Spackman 1995).

## More Information

- U.S. Fish and Wildlife Service Endangered Species Database: http://www.fws.gov/endangered/
- NatureServe's Climate Change Vulnerability Index: https://connect.natureserve.org/science/climate-change/ccvi
- Ohio Natural Heritage Database and Ohio Rare Plant List: http://www.dnr.state.oh.us/Home/wild_resourcessubhomepage/ResearchandSurveys/OhioBiodiversityDatabase/tabid/23652/Default.aspx
- Maryland Natural Heritage Program Rare, Threatened, and Endangered Plants: http://dnr.maryland.gov/wildlife/Plants_Wildlife/rte/rteplants.asp
- West Virginia Natural Heritage Program Rare, Threatened, and Endangered Species: http://www.wvdnr.gov/Wildlife/Endangered.shtm
- Climate Change Vulnerability Assessment of Species of Concern in West Virginia (Byers and Norris 2011): http://wvdnr.gov/publications/PDFFiles/ClimateChangeVulnerability.pdf

Wildflowers of West Virginia. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

## NONNATIVE INVASIVE PLANT SPECIES

Various researchers and predictive models suggest that climate change will likely increase the ability of many invasive plants to invade and spread (Alpert et al. 2000, Dukes et al. 2009, Hellmann et al. 2008). However, the overall impact of invasive plants will vary based on individual species responses, and in some cases the distributions of invasive plants may decrease (Bradley et al. 2009). In general, increased invasions of warm climate species and decreased invasions of cold climate species might be expected in the assessment area. Projected increases in fire activity and disturbances related to extreme weather may favor the expansion of disturbance-adapted invasive species, especially southern climate species like cogongrass and kudzu. Cogongrass in the southeastern United States has contributed to altered fire regimes and is expected to advance northward with warmer temperatures (Lippincott 2000).

In addition, a changing climate has the potential to affect the life cycle of invasive species that are already established in the assessment area. The phenology of temperate plants, such as flowering and leaf-out dates, has been well documented and is known to be especially sensitive to temperature (Cleland et al. 2007b, Parmesan and Yohe 2003). Species that are most responsive to temperature in terms of their flowering date—that is, species that flower earlier in warm years and later in cold years—are the ones that will likely increase in abundance in the face of climate change. Research has shown that many nonnative invasive plants have more flexible flowering dates and have shifted these dates to earlier in the spring than native plants or even nonnative plants that are not invasive (Primack and Miller-Rushing 2012, Willis et al. 2010). For example, the invasive plant purple loosestrife was found to bloom several weeks earlier than it did a century ago, whereas the flowering dates of many other species, such as most native lilies and orchids, did not shift (Primack and Miller-Rushing 2012).

As invasive plant invasions become more widespread, forest managers may need to invest more resources to control invasive plant populations and minimize impacts to forests (e.g., prescribed burns and timber harvest). For example, ailanthus is a particularly problematic invasive species that has already been increasing in the assessment area and may benefit from climate change. Data from the Wayne National Forest show ailanthus trees >5 inches in diameter have increased from 0.7 percent of cover to 1.6 percent in a little over a decade; without action this species is likely to increase exponentially. The Wayne National Forest is working with ODNR, the Appalachian Ohio Weed Control Partnership, and the U.S. Forest Service's Northern Research Station and Northeastern Area State & Private Forestry to aerially map and strategically treat 500,000 acres of ailanthus across all ownerships in southeastern Ohio. These collaborators are able to identify pockets of heavy infestations that can be treated with standard herbicide treatments and future experimental control with a biological agent.

### More Information

- Appalachian Ohio Weed Control Partnership: http://appalachianohioweeds.org/
- Huebner and partners at the USFS Northern Research Station, West Virginia University, and Ohio State University are currently finishing a 4-year study that looks at the impacts of timber harvesting and prescribed fire on three invasive species (garlic mustard, Japanese stiltgrass, and ailanthus) in comparison to red oak. This study may shed more light on the likelihood of increased invasions due to climate change-related increases in disturbance: Huebner, C.D.; McGill, D.; Matlock, G.; Minocha, R.; Dickinson, M.; Miller, G. (unpublished work). Defining an effective forest management strategy that deters invasion by exotic plants: invasive plant response to five forest management regimes. For more information, visit http://nrs.fs.fed.us/people/chuebner.

## FIRE AND FUELS

Potential climate change impacts include an increase in wildfire risk, especially during summer and fall. As mentioned in Chapter 5, invasive shrub and herbaceous cover can increase fuel abundance, as can mortality of native plants. Increased levels of downed woody debris resulting from winter storm and wind events can also contribute to dry fuel loads.

There are three fire seasons in the assessment area: spring, late summer, and fall. The spring season generally lasts from March through late April before leaf-out, and provides the longest burn window when fuels are dry. By the end of May or early June, green-up of understory vegetation raises fuel moisture and tree leaf-out prevents adequate daytime drying of fuels. The late summer season generally lasts from late August through September, when leaves and ground fuels begin to dry out. Droughty weather or at least 7 to 10 rain-free days are necessary for fuel moisture to be low enough to burn. The fall season typically begins in mid- to late October after the first hard frost (and the start of leaf fall) and runs through November. This burn window is extremely variable and fire behavior can be more extreme in fall due to the presence of dry leaf litter, especially oak, that has not yet been compressed by rain or snow.

Projected changes in climate could affect the ability to apply prescribed fire in the assessment area. In spring, increased rainfall could make it difficult to conduct prescribed burns. Throughout the spring and summer, changing precipitation patterns, such as intense rain events followed by longer dry periods, could result in longer periods of drier burn conditions. Burning under drier conditions may result in more intense and hotter fires, including fires that use ladder fuels to move into the forest canopy. As the growing season is extended later into the fall, there is even more potential for increased fuels accumulation. On an interannual level, drought increases wildfire risk during all fire seasons (Lafon et al. 2005) and is likely to play a critical role in future shifts in fire windows and behavior.

Shifts in climate that result in a longer fire season or extension of critical fire weather days would, in turn, increase the potential risk of wildland fire. Change in fire risk across the assessment area and its impacts at local scales will depend on both land use and management decisions. Potential management responses might include rescheduling prescribed burns as optimal burn windows shift toward summer and fall. Fuel models may also need to adjust to climate-related vegetation changes such as increased density of invasive plants, or shifts in species composition that affect fuels on the forest floor (e.g., from maple to oak). Policy and funding decisions and public attitude will ultimately define the response that makes the most sense, and responses may differ between landowners, land managers, and organizations.

### More Information

- The U.S. Forest Service's Climate Change Resource Center: Wildfire and Climate Change: www.fs.fed.us\ccrc\topics\wildfire\
- The Consortium of Appalachian Fire Managers and Scientists (CAFMS): www.cafms.org

## INFRASTRUCTURE

Many landowners and agencies are responsible for managing infrastructure on the forested landscape, such as roads, power lines, sewer lines, dams, drainage ditches, and culverts. Specifications for water infrastructure are based on past climate patterns, and the current trend of intensifying precipitation has placed additional strain on outdated infrastructure. Storms, extreme temperatures, longer growing seasons, and warmer winters can pose particular challenges for infrastructure. Extreme heat and longer growing seasons can result in rising costs associated with roadside and power line vegetation management. Extreme cold and freeze-thaw cycles can accelerate road deterioration. Intense rainfall could increase the potential for erosion on dirt and gravel roads common in forest landscapes, logging projects, gas development, and rural areas. Water resource infrastructure such as bridges, sewers, major culverts, low-water crossings, and dams may have to be redesigned and rebuilt to accommodate flows of increased duration and intensity. Improved stream bank stabilization may have to be incorporated to prevent scouring. Costs associated with debris removal in waterways could also rise.

Projected increases in average temperature, summer heat waves, and summer storms are expected to place additional strain on electrical infrastructure.

An old culvert. Land managers are beginning to replace culverts like this one with larger culverts designed to accommodate larger peak flows and allow the passage of aquatic organisms. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

Although not directly attributed to climate change, an extreme weather event can serve to illustrate the impacts of such events on electrical systems. On June 29, 2012, a derecho with sustained winds of 60 miles per hour gusting to 100 miles per hour ravaged a 600-mile swath across 11 states including Ohio, West Virginia, and Maryland. Across the region, 4.2 million electrical customers lost service. West Virginia, a rural state with sparse populations and mountainous topography, was particularly devastated; more than 600,000 customers lost power for 10 days or more (U.S. Department of Energy 2012). According to an analysis by the U.S. Department of Energy, extensive debris, downed-tree removal operations, additional storms, and unusually high heat hindered the restoration of power (U.S. Department of Energy 2012). The derecho made the National Oceanic and Atmospheric Administration's (NOAA's) list of billion-dollar weather events ($2.8 billion) and resulted in the death of 28 people (NOAA 2014a). Dominion Power reported the derecho to be the most severe weather event in the company's 100-year history after Hurricanes Irene and Isabel (Knight 2012). Following the derecho, the region experienced record high temperatures, which complicated efforts to restore power. Although millions of residents had to go without air conditioning during this particular storm, heat waves are expected to increase in frequency and duration, and are likely to put great demand on electricity supply.

## More Information

- American Society of Civil Engineers 2013 Report Card for America's Infrastructure: http://www.infrastructurereportcard.org/a/#p/home
- The U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather: http://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf

## AIR QUALITY

The direct and indirect effects of a changing climate have important implications for air quality and its management. Although future changes in pollutant emissions can be estimated, air quality impacts will continue to be strongly influenced by climate and weather variables, such as temperature, humidity, and air flow (Mickley et al. 2004). Because mercury, nitrogen, and sulfur are deposited onto the landscape through rain and snow, projected increases in precipitation may increase atmospheric deposition, thus increasing mercury contamination and the acidification of soils and surface waters (Driscoll et al. 2007). Tropospheric ozone in the Central Appalachians is projected to increase as a result of higher temperatures and decreased ventilation resulting from changes in air flow (Wu et al. 2008). Because heat waves and air stagnation retain ozone levels for extended periods, these climate changes affect ozone pollution episodes more than mean ozone levels, and are projected to offset and surpass decreases in ozone brought about by regulation (Wu et al. 2008). There is evidence that warmer temperatures and the burning of vegetation can result in increased volatilization of mercury soil reservoirs, potentially releasing mercury into the atmosphere and transferring it between ecosystems, with deposition occurring in a more mobile and toxic form (Jacob and Winner 2009). Particulate matter may also be affected by changes in climate, although changes are less predictable than for ozone. Because particulate matter is cleaned from the air by rainfall, increases in precipitation frequency due to climate change could have a beneficial effect. However, other climate-related changes in stagnant air episodes, wind patterns, emissions from vegetation, wildfire, and the chemistry of atmospheric pollutants will also influence particulate matter levels in different ways. Air quality regulations are important in controlling emissions, but when climate change impacts are taken into consideration, the current thresholds may not be adequate to meet air quality targets.

### More Information

- Integrating Knowledge to Inform Mercury Policy: www.mercurynetwork.org.uk/policylinks/mercury-and-climate-change/
- The Monongahela National Forest monitors wet deposition, dry deposition, ozone, and particulate matter using the National Atmospheric Deposition Program National Trends Network (NADP/NTN), Clean Air Status and Trends Network (CASTNET), and Interagency Monitoring of Protected Visual Environments (IMPROVE): www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm9_011356.pdf
- Researchers at Penn State are investigating the effects of soil acidification on sugar maple decline on the Allegheny National Forest: http://ecosystems.psu.edu/directory/wes

## WATER QUALITY

It is widely accepted that streamflow is primarily governed by climate, watershed morphology, and land cover, and that hydrology largely controls sediment and nutrient export. Any change in state variables that alters watershed hydrology also influences water quality dynamics (Likens and Bormann 1995). Climate change is already creating challenges in water management by affecting water availability (Georgakakos et al. 2014). Projected increases in total precipitation in spring, intense precipitation events, and storm frequency are expected to lead to more runoff at that time of year, and a subsequent reduction in water quality arising from increased erosion and sedimentation (Liu et al. 2008, U.S. Environmental Protection Agency [EPA] 1998). Increased runoff also promotes flushing of nutrients (e.g., nitrogen and phosphorus) that build up in natural and disturbed ecosystems, thereby increasing the potential for downstream eutrophication and hypoxia (Peterjohn et al. 1996, Vitousek et al. 2010). Additional factors such as fire and insect defoliation exacerbated by climate change are also expected to increase runoff, erosion, and

The steep ridges and valleys in the Allegheny Mountains. These landforms are at greater risk of high-velocity runoff and erosion. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

sedimentation. Late summer soil moisture deficits combined with a longer growing season have the potential to decrease runoff in the latter half of the year, thereby decreasing the capacity of a stream system to dilute larger loads of nutrients (Delpla et al. 2009).

Anthropogenic activities have already damaged aquatic ecosystems by increasing soil erosion and stream sedimentation rates, fragmenting aquatic habitats, reducing channel and floodplain functions, degrading habitats, acidifying and burying streams, and otherwise altering watershed hydrology. Under the range of projected climate changes, aquatic ecosystems would tend to have more varied and more extreme environmental conditions. Changes of this nature tend to place additional hardship on these systems and can further compromise various aquatic resource conditions such as habitat suitability. Aquatic ecosystems that were once intact and naturally functioning can be repaired to various degrees under accelerated timeframes through restoration actions. Accelerating the rate of recovery back toward their inherent state can increase the resiliency of these systems to stressors and disturbances. Water resource managers may minimize risks and impacts by accommodating expanding floodplains, redesigning stormwater and sewer systems, restoring and managing wetlands for stormwater management, and developing novel ways to buffer intense runoff, such as through green roofs and other infrastructure (U.S. EPA 2008).

## More Information

- National Climate Assessment: Water Resources: http://nca2014.globalchange.gov/report/sectors/water
- National Water Program 2008 Strategy: Response to Climate Change: http://water.epa.gov/scitech/climatechange/upload/2008-National-Water-Program-Strategy-Response-to-Climate-Change.pdf

## FOREST PRODUCTS

The forest products industry is important to the economies of the assessment area (Chapter 1). Tree species and forest composition are projected to change over the 21st century (Chapters 5 and 6). Changes in forest composition across the landscape will be influenced by forest management, and will in turn influence forest management and the forest products industry. Several commercially important species, such as black cherry and sugar maple, are projected to decline significantly under a range of possible climate futures during the next century. Conversely, post oak, white oak, and shortleaf pine are projected to increase in the assessment area. Large potential shifts in commercial species availability may pose risks for the forest products sector if the shifts are rapid and the industry is unprepared. The forest products industry may benefit from awareness of anticipated climate trends and shifts in forest species. In many cases, forest managers can take actions to reduce potential risks associated with climate change or proactively encourage species and forest types anticipated to fare better under future conditions (Swanston and Janowiak 2012). There may be regional differences in forest responses, as well as potential opportunities for new merchantable species to gain suitable habitat in the assessment area.

Overall, the effects of climate change on the forest products industry depend not only on ecological responses to the changing climate, but also on socioeconomic factors that will continue to change over the coming century. Major socioeconomic factors include national and regional economic policies, demand for wood products, and competing values for forests (Irland et al. 2001). Large uncertainties are associated with each of these factors. The forest products industry has adjusted to substantial changes over the past 100 years, and continued responsiveness can help the sector remain viable.

### More Information

- The U.S. Forest Service 2010 Resources Planning Act Assessment includes future projections for forest products and other resources through the year 2060 and examines social, economic, land-use, and climate change influences: www.fs.fed.us/research/rpa/
- The Climate Change Tree Atlas provides information on the projected suitable habitat for tree species under climate change: www.nrs.fs.fed.us/atlas/bird/

## NONTIMBER FOREST PRODUCTS

Hundreds of nontimber forest products are used for food, medicine, craft materials, and other purposes in the assessment area (Chamberlain et al. 2009). Changes in climate will have implications for these products in the assessment area and throughout the broader region. Many of these products will be affected by changes in temperature, hydrology, and species assemblages. As illustrations, effects of climate change on two nontimber forest products with broad cultural and economic importance are discussed briefly here: American ginseng and mushrooms.

American ginseng is a perennial herbaceous plant indigenous to the eastern United States that has been traded internationally since the 1700s (Taylor 2006). Concerns over the sustainability of wild American ginseng under heavy harvest pressure in Canada, China, and the United States resulted in international protection under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The USFWS monitors exports in order to examine trends in wild ginseng harvest and set harvest guidelines and restrictions. Individual states also monitor the harvest and export of ginseng and regulate harvesting.

Recent research has examined the potential response of wild ginseng to temperature variations in the assessment area. Findings suggest that genetics of populations at individual locations play a large role in population growth rate responses to temperature. Thus, models that predict responses based on northern and southern boundaries of this species likely underestimate the negative impacts of temperature increases at specific locations (Souther and McGraw 2011). Precipitation may also constrain the overall distribution of ginseng (Souther and McGraw 2011). Neither factor showed a positive population growth response to predicted changes. The combination of harvest pressure and climate change raises concerns about the long-term stability of the American ginseng population in the assessment area.

Hunting morels and other mushrooms is a passion for many people throughout the assessment area for their commercial value, medicinal properties, and culinary applications (Emery and Barron 2010). An analysis of fungal fruiting patterns from southern England over a 65-year-period showed a lengthened fruiting period from 33.2 days in the 1950s to 74.8 days in the current decade (Gange et al. 2007). This change corresponded to increased temperatures in August through October. Another study of 83 species in Norway found an average delay in fruiting of nearly 13 days since 1980, coinciding with warming temperatures and a longer growing season (Kauserud et al. 2008). Although longer growing seasons have lengthened the fruiting season of some fungal species, and shifted the timing of fruiting later in the spring and fall, future responses to changes in temperature and precipitation may be tightly linked to local conditions rather than broad geographic trends. Management of nontimber forest products may require increased monitoring of habitats to ensure viable populations under changing conditions.

## More Information

- Forest Farming: www.extension.org/forest_farming
- Connecting Non-timber Forest Products Stakeholders to Information and Knowledge: A Case Study of an Intranet Web Site: www.srs.fs.usda.gov/pubs/gtr/gtr_srs116/gtr_srs116-04.pdf
- Using Local Ecological Knowledge to Assess Morel Decline in the U.S. Mid-Atlantic Region: www.nrs.fs.fed.us/pubs/jrnl/2010/nrs_2010_emery_001.pdf

## FOREST CARBON

Forest carbon sequestration can mitigate greenhouse gas emissions in the atmosphere. However, climate change and indirect impacts to forest ecosystems may change the ability of forests in the Central Appalachians to store carbon. In this assessment, carbon dioxide fertilization effects on forest ecosystems were not directly modeled or assessed, but are considered an important implication for forest management. Within the assessment area, climate change is projected to lead to longer growing seasons and warmer temperatures, which potentially could support increased forest productivity and carbon storage, as long as water and nutrients are available for photosynthesis. This increase could be offset by climate-related disturbances, such as more insect pests or disease, leading to increases in carbon storage in some areas and decreases in others (Hicke et al. 2012, Knicker 2007). Increases in ozone would reduce photosynthesis and carbon sequestration (Felzer et al. 2003).

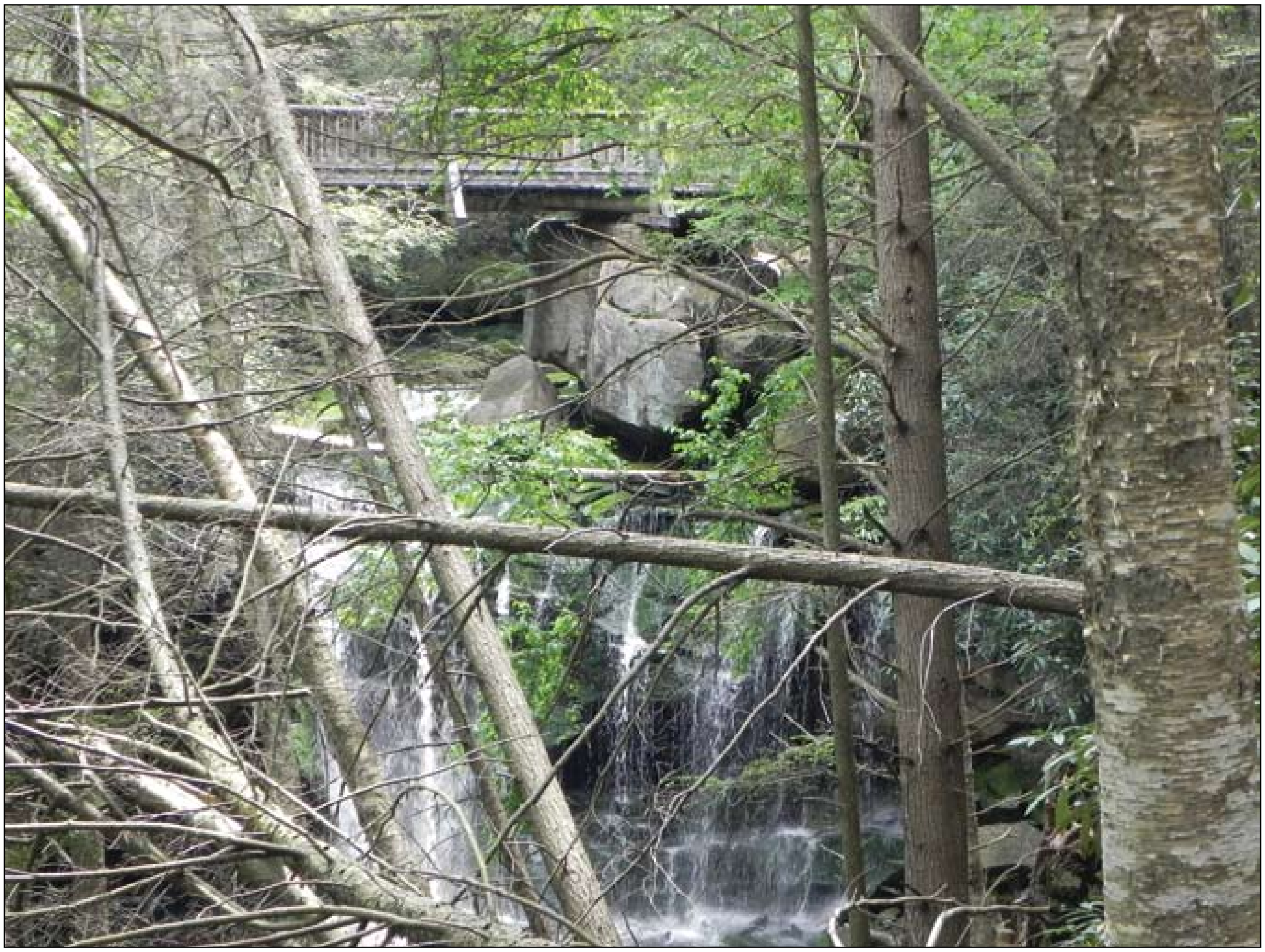
The greatest impacts on forest carbon storage will likely occur through changes in species composition. Habitat suitability models forecast shifts in tree species' geographic ranges in response to climate changes (Chapter 5). Within the assessment area, the oak/gum/cypress and spruce/fir forests store the most carbon per acre, followed by maple/beech/birch and elm/ash/cottonwood forests (Chapter 1). Oak/hickory and oak/pine forests contain considerably less carbon per acre, but are projected to be more resilient to or even benefit from climate change. Not all forests store carbon in the same pools; for example, oak/hickory forests store more carbon aboveground than in the soil and the spruce/fir group stores more carbon in the soil. Thus, shifts in species or assemblages of species on the landscape may result in shifts in carbon storage. Invasive plant species also have the potential to alter species composition and ecosystem functioning. The invasive tree ailanthus can increase carbon cycling rates and alter soil chemistry to favor rapid growth and subsequent forest colonization by new ailanthus seedlings (Gómez-Aparicio et al. 2008).

Soil from federal lands. These public lands contain the highest density of carbon in the Central Appalachians. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

Carbon management and conservation of carbon stocks will require managing species composition and maintaining forest cover on the landscape. The biggest loss of forest carbon in the assessment area has already occurred as a result of historic logging, loss of soil from erosion and volatilization from fire, and decades of land conversion from forests to agriculture and urbanization. The ability of existing ecosystems to sequester carbon may be further hindered by increased disturbances and stresses brought on by climate change. Carbon management can benefit future landscape-scale restoration projects. Riparian restoration and wetland restoration have the potential to help landscapes slow the export of nutrients or even capture and store soil carbon that would otherwise leave the watershed. Replanting riparian areas and encouraging the regrowth of these areas can help to address the historic forest carbon loss for several of the ecosystems analyzed in the assessment. Opportunities to focus restoration management on stabilizing soils, planting trees, and addressing historic land degradation are numerous.

## More Information

- The U.S. Forest Service's Climate Change Resource Center: Forests and Carbon Storage: www.fs.fed.us/ccrc/topics/forests-carbon/
- A Synthesis of the Science on Forests and Carbon for U.S. Forests: www.fs.fed.us/rm/pubs_other/rmrs_2010_ryan_m002.pdf



The Blackwater Falls in the Canaan Valley, West Virginia, a popular recreation area. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

## RECREATION

Opportunities for outdoor recreation depend on the natural resource (e.g., spelunking in caves versus hiking mountain trails) and the weather on any given day. Projected increases in temperature and precipitation, especially heat waves and intense precipitation events (Chapter 4), are expected to change recreation patterns. Warmer spring and fall weather may increase the length of the recreation season, which could require a shift in the open season for recreation areas, requiring more staff hours and potentially more infrastructure. Regional increases in average temperatures and heat waves during summer months could shift visitor behavior, depending on the magnitude of changes. Many visitors to the Monongahela National Forest arrive during the summer to escape the heat at lower elevations or in urban areas, and temperature increases could result in higher visitation rates (Loomis and Crespi 1999, Mendelsohn and Neumann 2004, Richardson and Loomis 2004). If temperatures become too hot for outdoor recreation, however, visitation and outdoor recreation and tourism could decrease (Nicholls 2012). Specific activities such as fishing or skiing may also be limited by warmer temperatures (Morris and Walls 2009).

Projected increases in intense precipitation and strong storm events could lead to more frequent closings of public recreation areas. The same derecho of 2012 that knocked out power to several states also blew down thousands of trees across the region, and caused many public places to close, such as Lake Sherwood Recreation Area in West Virginia. In 2013, effects of Hurricane Sandy closed a large part of the Monongahela National Forest for several months because of such hazards as broken, hanging, and down trees, which damaged facilities, and closed roads and trails. Many recreation areas are located near rivers and streams, which are regularly subject to flood events. To properly protect recreation visitors, short- and long-term closings may be needed to repair damage caused by intense precipitation and strong storm events.

Warmer winter temperatures could also affect winter recreation. Warmer temperatures that prevent Lake Erie from freezing may allow more moisture to evaporate from the lake and fall as snow on land. However, warmer average temperatures may also increase the probability that precipitation will fall as rain rather than snow. A particular economic concern is the decreased viability of downhill skiing during the holiday season, which can generate as much as one-third of a ski resort's annual revenue (Dunnington 2011). Although downhill ski areas can generate artificial snow, few options exist for adapting cross-country skiing, sledding, snowshoeing, and other snow-dependent winter sports to warmer temperatures (Morris and Walls 2009). These winter activities may be replaced by hiking and other activities not dependent on snow, requiring adjustments in how recreation areas are managed. The degree of climate change will ultimately influence the severity of impacts on recreation activities, but there are many opportunities for visitors and managers to adapt their activities by changing the timing or location (Morris and Walls 2009).

### More Information

- National Climate Assessment Midwest Technical Input Report: Recreation and Tourism Sector: glisa.msu.edu/docs/NCA/MTIT_RecTourism.pdf
- Climate Change and Outdoor Recreation Resources: www.rff.org/RFF/Documents/RFF-BCK-ORRG_ClimateChange.pdf

## WILDERNESS

The Wilderness Act of 1964 was established to protect areas in their natural condition and to assure that an increasing human population, accompanied by expanding settlement and growing mechanization, does not modify all areas within the United States (Wilderness Act of 1964). U.S. Forest Service policy directs the agency to "manage the wilderness resource to ensure its character and values are dominant and enduring" (U.S. Forest Service 2007). According to the Monongahela National Forest Land and Management Plan, management emphasis for its eight wilderness areas on the Forest is to "preserve wilderness attributes and the natural environment for future generations" (U.S. Forest Service 2006a).

It has been argued that climate change would have the greatest impacts on species that are confined to protected areas, largely because populations would not be able to migrate with changing range limits for species (Peters and Darling 1985). Additionally, species within protected areas would potentially face new competitors, predators, or diseases as many native and nonnative species move around on the landscape. Models of climate change impacts on ecosystems project that more than 40 percent of Canada's protected areas will undergo a major change in vegetation (Lemieux and Scott 2005). Management of wilderness areas may need to address difficult questions about whether to protect current species assemblages, or to allow new species assemblages to form, and if the latter, to what extent.

An increase in intense precipitation and strong storm events would cause muddy conditions on trails, erosion of trail tread, and down trees across trails. Mechanized equipment is not allowed in wilderness areas; the additional physical labor to complete trail maintenance is expensive and time consuming. For example, after Hurricane Sandy in 2013, trails within Otter Creek Wilderness and Cranberry Wilderness areas were closed for several months until specialized crews were funded to clear the trails with crosscut saws and axes. Responding to increased disturbances may require additional resources to manage wilderness areas.

## More Information

- Climate Change Toolbox: Effect of Climate Change on Wilderness and Protected Areas: www.wilderness.net/climate
- The U.S. Forest Service's Climate Change Resource Center: Wilderness and Climate Change: www.fs.fed.us/ccrc/topics/wilderness/

Private lands juxtaposed with the Shawnee State Forest, Ohio. Photo by the Ohio Department of Natural Resources, used with permission.

# CULTURAL RESOURCES

The remnants of past human activity, such as paintings, sculptures, and objects for everyday life, are present within the assessment area. These resources date to both prehistoric and historic time periods, and exist both above and below the ground surface. Climate change impacts on the physical environment have the potential to affect the nature, character, and condition of these cultural resources.

Increases in extreme precipitation events, in combination with a more episodic regime, are expected to intensify erosion and weathering of cultural resources. Consequently, the physical integrity of historic structures could be undermined and subsurface resources threatened if the soil covering them is washed away. As precipitation increases, the risk of flooding also escalates; flooding would hasten the erosion process of sites on ridge tops and on flood terraces. Floodwaters can further threaten the integrity of historic structures in low-lying areas by eroding the foundation, or adding moisture. The increased moisture can promote mold and fungus growth, thereby hastening deterioration of wooden and other constructed features (Schiffer 1996). Erosion of rock shelters has already been witnessed within the assessment area on sites composed largely of erodible sandstone that are more frequently being inundated with water. Artifacts and other cultural materials located in these shelters have been transported by water to nearby creeks. Increased moisture levels and damage from freeze/thaw cycles and subsequent erosion have resulted in roof collapse within these rock shelters as well. Projected increases in freeze/thaw events and deep soil frost would exacerbate these effects.

Longer growing seasons and range shifts in native and invasive plants expand the potential for these taxa to damage historic structures as these plants tend to cling to structures at points of weakness, accelerating structural degradation (Schiffer 1996). An altered fire regime could become an increasing source of disturbance if climate shifts encourage more frequent or intense fire behavior. Fire and firefighting activities can destroy historic structures and threaten all types of cultural resources (Buenger 2003). Managing cultural resources will become more challenging as a result of the direct and indirect impacts of climate change. Identifying and documenting existing cultural resources now will be critical in conserving these important artifacts and historical information.

## More Information

- Climate Change and World Heritage: whc.unesco.org/documents/publi_wh_papers_22_en.pdf
- National Park Service Climate Change Response Strategy: http://www.nps.gov/orgs/ccrp/upload/NPS_CCRS.pdf

# URBAN FORESTS

Climate change will likely affect urban forests in the assessment area as well. Urban environments can pose additional stresses to trees not encountered in natural environments, such as pollution from vehicle exhaust, confined root environments, and road salts. Urban environments also cause a “heat island effect,” and thus warming in cities will likely be even greater than that experienced in natural communities. Impervious surfaces can make urban environments more susceptible to flash floods, placing flood-intolerant species at risk. All of these abiotic stressors can make urban forests more susceptible to nonnative species invasion, and insect and pathogen attack, especially because only a limited range of species and genotypes is typically planted in urban areas. Urban settings are also the most likely places for exotic insect pests to be introduced.

Projected changes in climate can pose both challenges and opportunities for the management of urban forests. Shifts in temperature and changes in extreme events may have effects on species selection for planting. Native species projected to decline under climate change will likely not tolerate even more extreme conditions presented by urban settings. Conversely, urban environments may favor heat-tolerant or drought-tolerant native species or new migrants (Chapter 5). Determining appropriate species for planting may be a challenge, but community foresters are already familiar with the practice of planting species novel to an area. Because of urban effects on climate, many community forests already contain species that are from planting zones south of the area or cultivars that tolerate a wide range of climate conditions.

Large disturbance events may also become more frequent or intense in the future, necessitating informed decisions in response. For example, wind events or pest outbreaks may be more damaging to already stressed trees. If leaf-out dates advance earlier in the spring due to climate change, community forests may be increasingly susceptible to early-season frosts or snowstorms. More people and larger budgets may be required to handle an increase in the frequency or intensity of these events, which may become more difficult in the face of reduced municipal budgets and staffing.

### More Information

- The U.S. Forest Service's Climate Change Resource Center: Urban Forests and Climate Change: www.fs.fed.us/ccrc/topics/urban-forests/
- Urban Forests: Climate Adaptation Guide: www.toolkit.bc.ca/Resource/Urban-Forests-Climate-Adaptation-Guide
- Climate Change Adaptation Options for Toronto's Urban Forest: www.cleanairpartnership.org/pdf/climate_change_adaptation.pdf

## FOREST-ASSOCIATED TOWNS AND CITIES

The forests of the Central Appalachians are deeply and intimately linked to human communities. Conversely, these communities are tied to the health and functioning of surrounding forests, whether for economic, cultural, recreational, or other reasons. Climate change impacts on forest ecosystems are likely to affect the human communities that use these resources and to change or challenge how those communities use and relate to these forests. These complex feedbacks could very well pose a challenge to current forest management goals and activities. Consequently, it is important to address potential climate change impacts on forest-associated towns, cities, and other communities, and the implications for managing healthy ecosystems.

Although impact models can predict species or community responses to climate change, considerably less is known about the potential social and cultural impacts of climate or forest change and how human communities might best respond. Community vulnerability to climate change is a function of the community's exposure to change, such as being situated within a flood plain projected to receive increased precipitation, and its relative sensitivity to such changes, such as being constrained by reduced funding from the Federal Emergency Management Act (FEMA) due to budget cuts or other national priorities. Community adaptive capacity is a function of the community's ability to act in an adaptive way and includes both material (i.e., capital) and nonmaterial (i.e., leadership) resources that can be leveraged by the community to monitor, anticipate, and proactively manage hazards, stressors, and disturbances.

These concepts help frame the issue of climate change from a community perspective, but it is important to keep in mind that every forest-

Multiple land uses in West Virginia. Agriculture and development dominate the flat valleys. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

associated community has particular conditions, capacities, and constraints that might make it more vulnerable or resilient to climate change than other communities. For example, forest users from a city like Huntington, WV, face different sources of vulnerability than forest users from a small town like Glouster, OH. Moreover, the effects of climate change and forest impacts are not evenly distributed geographically or socially. For example, a tourism-dependent community may be more or less exposed to climate change than certain social groups within communities (e.g., individuals working in forest products industries), or they may be equally exposed, but more or less able to adapt.

If resource professionals, community leaders, and local organizations are to help communities mitigate the impacts of climate change and adapt, they must be able to assess community vulnerabilities and capacities to organize and engage various resources (Fischer et al. 2013).

## More Information

- Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners: www.resalliance.org/index.php/resilience_assessment
- Assessing Social Vulnerability to Climate Change in Human Communities near Public Forests and Grasslands: A Framework for Resource Managers and Planners: http://people.oregonstate.edu/~hammerr/SVI/Fischer_etal_JoF_2013.pdf
- Community Vulnerability and Adaptive Capacity Project: http://www.cfc.umt.edu/VAC/default.php
- A study is underway to explore the perceived vulnerability and adaptive capacity of forest-associated human communities in southeastern Ohio. For more information, contact Dr. Daniel Murphy at the University of Cincinnati: http://asweb.artsci.uc.edu/collegedepts/anthro/fac_staff/profile_details.aspx?ePID=MzA0ODcx

## CONSERVATION PLANNING

Climate change has many important implications for land conservation planning in the Central Appalachians. Climate change science can be used to help prioritize land conservation investments and help guide project design. Some of the most useful decision-support tools for conservation planning are site-specific technical assistance through scientific experts to geographic information systems (GIS) mapping tools that allow the user to assess how individual parcels of land relate to variables such as forest carbon and projected “climate-safe” habitat areas.

Conservation in the complex landscapes of the Central Appalachians also requires careful analysis to evaluate the potential contribution of conservation projects to climate adaptation. The region’s forests provide vital ecosystem services to human and natural communities. These services, such as drinking water supplies and cold-water habitats, could be affected by greater extremes of precipitation and other manifestations of climate change. Given the steep slopes in the region, watersheds are naturally prone to flooding and at particular risk from increases in extreme precipitation events. Conservation linked with adaptive management can be directed to the most vulnerable watersheds to help them withstand these impacts.

Further, climate change analysis is nuanced by the region’s globally significant mixture of microhabitats and connecting habitat corridors stretched across rugged landscapes. Planning for conservation of terrestrial habitat “strongholds” from climate change requires a close look at the landscape to identify those corridors and habitats that will be most resilient in the face of projected shifts. As evidence of the unique opportunities in the upper Potomac watershed, the Open Space Institute and Doris Duke Charitable Foundation have targeted a special conservation funding source to this region for conservation of important sites for climate adaptation. The Nature Conservancy’s resilience analysis project identifies sites across the Northeast that have high or low resilience to climate changes based on geophysical characteristics (Anderson et al. 2012). Integrating this kind of information into conservation planning and prioritization can help identify and protect areas that have unique potential for conservation.

Carbon dioxide emissions have directly contributed to ongoing climate change, and it is unclear how emissions levels may change over the course of the century. Identifying forest tracts that have high carbon stocks or potential for high carbon levels through conservation- and carbon-oriented management can help maintain and even increase this important source of carbon mitigation. U.S. forests currently sequester 10 to 20 percent of the nation’s carbon emissions each year (Ryan et al.

2010). Carbon-oriented prioritization is particularly important in the Central Appalachians region, where the region's forests have substantial carbon stores. For example, oak/hickory forests in the region can hold as much as 132 tons of carbon per acre in soils and aboveground biomass.

Land managers can prioritize protection on sites that are strong carbon sinks, or that have potential for resilience under climate change. Designing land conservation projects for climate objectives may require specific long-term ownership and management prescriptions to be attached to a conservation agreement. In some cases, a good conservation strategy may be to leave lands in private ownership, and to develop conservation easement terms that support adaptive management by the landowner to address climate shifts. In other cases, where complex restoration or species-specific management is needed, an appropriate conservation strategy might be to seek a public agency owner that can provide the necessary financial and technical resources. In either instance, the key principle is to use available climate information to assess projected stressors on the property in the future, and then to integrate those considerations into project design. All of the efforts described above will be advanced by new science and data products to guide project selection and design. Private nonprofit organizations, government agencies, landowners, and potential funders will increasingly need spatially explicit information on how climate shifts will play out over the land. This science can enable effective use of funding, staff time, and other resources that are essential to advancing "climate-informed" conservation of forests in the Central Appalachians, and shaping conservation efforts to deliver a more resilient landscape.

### More Information

- The Open Space Institute and Doris Duke Charitable Foundation: www.osiny.org/site/PageServer?pagename=Issues_Habitat
- The Nature Conservancy Northeast Resilience Analysis: www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/ne/Pages/default.aspx

## NATURAL RESOURCE MANAGEMENT PLANNING

Until recently, climate change has not played a large role in natural resource planning. However, many federal and state-level land management agencies are beginning to address the issue. For example, the U.S. Forest Service's 2012 Planning Rule directly addresses the impacts and ramifications of climate change. In fact, climate change was among the stated purposes for revising the rule. Similarly, the state forestry agencies of Ohio, West Virginia, and Maryland began to officially address climate change in the 2010 State Forest Resource Assessment and Strategy.

Private lands make up about 85 percent of forest lands in the Central Appalachians region (Chapter 1). Northeastern Area State & Private Forestry oversees the Forest Stewardship Program to assist private landowners with conservation planning and to provide forest management plans at low cost. This unit is currently funding two examples of forest adaptation to climate change, using the tools in *Forest Adaptation Resources* (Swanston and Janowiak 2012) to identify adaptation actions in Forest Stewardship Plans. Because the goals for private landowners are diverse and can include goals for soil and water conservation, timber production, wildlife, and many more values, each example of adaptation will differ based on landowner needs. The Northeastern Area unit is also working with the Northern Institute of Applied Climate Science to develop an online version of the adaptation workbook presented in *Forest Adaptation Resources* that will be more accessible to natural resource managers.

Management plans for national forests or state agencies are typically written to guide management for a 10- to 15-year period, and it may be difficult to foresee projected shifts in climate within this short planning horizon. If climate change results in more frequent disturbances or unanticipated interactions among major stressors, managers may find it more difficult to adhere to the stated goals, objectives, and priorities in current Forest Plans. Incorporating adaptive management principles and including flexibility to address shifting conditions and priorities may be a strategy to handle the uncertainties of climate change. But building that flexibility into forest plans may pose a challenge both in completing the analysis (with specialists who may be unaccustomed to analyzing adaptive management strategies) and in educating the public about the need for proposed actions. Project-level planning on national forests will face challenges with interdisciplinary teams grappling to understand both the impacts that projects may have on greenhouse gas emissions and carbon sequestration levels and the impacts that climate change may have on projects. Input from the public is expected to increasingly question these relationships and interdisciplinary teams must be able to respond. Draft guidance is available from the Council on Environmental Quality (CEQ) and the U.S. Forest Service on project-level climate change considerations.

### More Information

- Forest Steward Program for private landowners: http://www.na.fs.fed.us/stewardship/index.shtm
- Region 9 Climate Change Guidance: www.fs.fed.us/emc/nepa/climate_change/includes/cc_nepa_guidance.pdf
- Draft National Environmental Policy Act Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions: http://energy.gov/sites/prod/files/CEQ_Draft_Guidance-ClimateChangeandGHGemissions-2.18.10.pdf
- Statewide Forest Action Plans: http://www.forestactionplans.org/regions/northeastern-region
- *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* provides concepts and tools for integrating climate change considerations into natural resource planning and management: www.nrs.fs.fed.us/pubs/40543

## CHAPTER SUMMARY

The breadth of the topics above highlights the wide range of effects that climate change may have on forest management in the Central Appalachians region. It is not the role of this assessment to identify adaptation actions that should be taken to address these climate-related risks and vulnerabilities, nor would it be feasible to prescribe suitable responses for all future circumstances. Decisions to address climate-related risks for forest ecosystems will be affected by economic, political, ecological, and societal factors. These factors will be specific to each land owner and agency, and are highly unpredictable.

Confronting the challenge of climate change presents opportunities for managers and other decision-makers to plan ahead, build resilient landscapes, and ensure that the benefits that forests provide are sustained into the future. Resources are available to help forest managers and planners incorporate climate change considerations into existing decisionmaking processes (Swanston and Janowiak 2012) (www.forestadaptation.org). This assessment will be a useful foundation for land managers in that process, to be further enriched by local knowledge and site-specific information.

# GLOSSARY

**aerosol**

a suspension of fine solid particles or liquid droplets in a gas, such as smoke, oceanic haze, air pollution, and smog. Aerosols may influence climate by either scattering and absorbing radiation, or by acting as condensation nuclei for cloud formation or modifying the properties and lifetime of clouds.

**asynchronous quantile regression**

a type of regression used in statistical downscaling. Quantile regression models the relation between a set of predictor variables and specific percentiles (or quantiles) of the response variable.

**bagging trees**

This statistical technique begins with a “regression tree” approach, but recognizes that part of the output error in using a single regression tree comes from the specific selection of an original data set. The bagging trees method uses another statistical technique called “bootstrapping” to create several similar data sets. Regression trees are then produced from these new data sets and results are averaged.

**barrens**

plant communities that occur on sandy soils and that are dominated by grasses, low shrubs, small trees, and scattered large trees.

**baseflow**

the condition in which groundwater provides the entire flow of a stream. (During most of the year, streamflow is composed of both groundwater discharge and land surface runoff.)

**biomass**

the mass of living organic matter (plant and animal) in an ecosystem; biomass also refers to organic matter (living and dead) available on a renewable basis for use as a fuel; biomass includes trees and plants (both terrestrial and aquatic), agricultural crops and wastes, wood and wood wastes, forest and mill residues, animal wastes, livestock operation residues, and some municipal and industrial wastes.

**boreal**

a zone between 50 and 55° and 65 and 70° latitude in the Northern Hemisphere characterized by cool northern temperatures and low rainfall (<20 inches).

**carbon dioxide ($CO_2$) fertilization**

increased plant uptake of $CO_2$ through photosynthesis in response to higher concentrations of atmospheric $CO_2$ .

**climate normal**

the arithmetic mean of a climatological element computed over three consecutive decades.

**$CO_2$-equivalent ($CO_2$-eq)**

the concentration of carbon dioxide ($CO_2$ ) that would cause the same amount of radiative forcing as a given mixture of $CO_2$ and other forcing components.

**convective storm**

Convection is a process whereby heat is transported vertically within the atmosphere. Convective storms result from a combination of convection, moisture, and instability. Convective storms can produce thunderstorms, tornadoes, hail, heavy rains, and straight-line winds.

**dendritic drainage**
a stream drainage pattern that resembles the branching pattern of a tree, with tributaries joining larger streams at angles <90°. This type of drainage occurs where the subsurface geology has a uniform resistance to erosion, and therefore little influence on the direction that tributaries take.

**derecho**
widespread and long-lived convective windstorm that is associated with a band of rapidly moving showers or thunderstorms characterized by wind gusts that are greater than 57 miles per hour and that may exceed 100 miles per hour (National Oceanic and Atmospheric Administration 2012).

**disturbance**
stresses and destructive agents such as invasive species, diseases, and fire; changes in climate and serious weather events such as hurricanes and ice storms; pollution of the air, water, and soil; real estate development of forest lands; and timber harvest. Some of these are caused by humans, in part or entirely; others are not.

**downscaling**
a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution general circulation models (GCMs); involves examining the statistical relationship between past climate data and on-the-ground measurements.

**driver**
any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

**dynamical downscaling**
a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution general circulation models (GCMs) using a limited-area, high-resolution model (a regional climate model, or RCM) driven by boundary conditions from a GCM to derive smaller-scale information.

**eastern deciduous forest**
a forest dominated by trees such as oaks, maples, beech, hickories, and birches that drop their leaves. Evergreen conifers do live in this forest, but are rarely dominant. This forest develops under cold winters (but not as cold as the boreal region to the north), and annual rainfall is higher in this forest than anywhere else in North America except for the subtropical and tropical areas to the south.

**ecological processes**
processes fundamental to the functioning of a healthy and sustainable ecosystem, usually involving the transfer of energy and substances from one medium or trophic level to another.

**ecoregion**
repetitive pattern of ecosystems associated with commonalities in soil and landform that characterize that larger region.

**edaphic**
of or pertaining to soil characteristics.

**emissions scenario**
a plausible representation of the future development of emissions of greenhouse gases and aerosols that are potentially radiatively active, based on certain demographic, technological, or environmental developments (Intergovernmental Panel on Climate Change [IPCC] 2007).

**esker**
a serpentine ridge of glacial drift, originally deposited by a meltwater stream running beneath a glacier.

**evapotranspiration**
the sum of evaporation from the soil and transpiration from plants.

**fluvial**
of, relating to, produced by, or inhabiting a stream or river.

**forest type**
a classification of forest land based on the dominant species present, as well as associate species commonly occurring with the dominant species.

**forest-type group**
based on FIA definitions, a combination of forest types that share closely associated species or site requirements and are generally combined for brevity of reporting.

**fragmentation**
a disruption of ecosystem or habitat connectivity, caused by human or natural disturbance, creating a mosaic of successional and developmental stages within or between forested tracts of varying patch size, isolation (distance between patches), and edge length.

**functional diversity**
the value, range, and relative abundance of functional traits in a given ecosystem.

**fundamental niche**
the total habitat available to a species based on climate, soils, and land cover type in the absence of competitors, diseases, or predators.

**general circulation model (GCM)**
a mathematical model of the general circulation of a planetary atmosphere or ocean and based on the Navier–Stokes equations on a rotating sphere with thermodynamic terms for various energy sources.

**glacial drift (till)**
unsorted and unstratified drift (typically a heterogeneous mix of sand, silt, clay, gravel, and stones) deposited directly by and underneath a glacier without subsequent reworking by meltwater.

**greenhouse effect**
the rise in temperature that the Earth experiences because certain gases in the atmosphere (water vapor, carbon dioxide, nitrous oxide, and methane, for example) absorb and emit energy from the sun.

**growing season**
the period in each year when the weather and temperature are right for plants to grow.

**growing stock**
a classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor. When associated with volume, this includes only trees ≥5.0 inches in diameter at breast height.

**habitat**
those parts of the environment (aquatic, terrestrial, and atmospheric) often typified by a dominant plant form or physical characteristic, on which an organism depends, directly or indirectly, in order to carry out its life processes.

**hardwood**
a dicotyledonous tree, usually broad-leaved and deciduous. Hardwoods can be split into soft hardwoods (red maple, paper birch, quaking aspen, and American elm) and hard hardwoods (sugar maple, yellow birch, black walnut, and oaks).

**impact model**
simulations of impacts on trees, animals, and ecosystems; these models use GCM projections as inputs, and include additional inputs such as tree species, soil types, and life history traits of individual species.

**importance value**
an index of the relative abundance of a species in a given community (0 = least abundant, 50 = most abundant).

**industrially owned forest**
land owned by forest product companies that harvest and market timber.

**intensity**
amount of precipitation falling per unit of time.

**kame**
a short ridge or mound of stratified drift deposited from a retreating glacier.

**karst**
an area of irregular limestone (calcium carbonate) in which erosion has produced fissures, sinkholes, underground streams, and caverns. Most caves are formed below the water table, resulting in stalactites and stalagmites.

**kettle**
a depression left in a mass of glacial drift, formed by the melting of an isolated block of glacial ice.

**Kyoto Protocol**
Adopted at the 1997 Third Session of the Conference of Parties to the UN Framework Convention on Climate Change in Kyoto, Japan, it contains legally binding commitments to reduce anthropogenic greenhouse gas emissions by at least 5 percent below 1990 levels in the period 2008-2012 (IPCC 2007).

**lacustrine**
pertaining to or formed in a lake.

**mass wasting**
movement of water and other materials as controlled by gravity; occurs on slopes under influence of gravitational stress. Gravity pulls on a mass until a critical shear-failure point is reached; thus, the greater the slope, the more mass wasting.

**mesic**
pertaining to sites or habitats characterized by intermediate (moist, but not wet or dry) soil moisture conditions.

**mesophication**
a process "whereby microenvironmental conditions (cool, damp, and shaded conditions; less flammable fuel beds) continually improve for shade-tolerant mesophytic species and deteriorate for shade-intolerant, fire-adapted species" (Nowacki and Abrams 2008: 123).

**model error**
uncertainty caused by a lack of complete understanding of some climate processes, or by the inability of models to pick up small-scale but influential climate processes.

**model reliability score**
for the Tree Atlas: a "tri-model" approach to assess reliability of model predictions for each species, classified as high, medium, or low, depending on the assessment of the stability of the bagged trees and the R2 in RandomForest (Iverson et al. 2008b: 392).

**modifying factor**
environmental variables (e.g., site conditions, interspecies competition, disturbance, dispersal ability) that influence the way a tree may respond to climate change.

**moraine**
an accumulation of boulders, stones, or other debris carried and deposited by a glacier.

**nonindustrial private landowners**
an ownership class of private lands where the owner does not operate wood-using plants.

**northern hardwoods**
forest type with wet-mesic to dry-mesic soils, medium to high soil nutrient level, and supporting tree species such as sugar maple (dominant), basswood, hemlock, yellow birch, ironwood, red maple, and white ash.

**orographic lifting**
the process in which an air mass is forced from a low elevation to a higher elevation. Adiabatic cooling can subsequently raise the relative humidity to 100 percent, resulting in clouds and precipitation.

**parcelization**
the subdivision of a single forest ownership into two or more ownerships. Parcelization may result in fragmentation if habitat is altered under new ownership.

**peak flow**
the maximum instantaneous discharge of a stream or river at a given location.

**phenology**
the timing of natural events such as the date that migrating birds return, the first flower dates for plants, and the date on which a lake freezes in the autumn or opens in the spring. Also refers to the study of this subject.

**process model**
a model that relies on computer simulations based on mathematical representations of physical and biological processes that interact over space and time.

**projection**
a model-derived estimate of future climate, and the pathway leading to it.

**proxy**
a figure or data source that is used as a substitute for another value in a calculation. Ice and sediment cores, tree rings, and pollen fossils are all examples of things that can be analyzed to infer past climate. The size of rings and the isotopic ratios of elements (e.g., oxygen, hydrogen, and carbon) in rings and other substrates allow scientists to infer climate and timing.

**pulpwood**
roundwood, whole-tree chips, or wood residues used for the production of wood pulp for making paper and paperboard products.

**radiative forcing**
the change in net irradiance between different layers of the atmosphere. A positive forcing (more incoming energy) tends to warm the system; a negative forcing (more outgoing energy) tends to cool it. Causes include changes in solar radiation or concentrations of radiatively active gases and aerosols.

**RandomForests**
RandomForests is a statistical technique similar to bagging trees in that it also uses bootstrapping to construct multiple regression trees. The difference is that each tree is produced with a random subset of predictors. Typically, 500 to 2,000 trees are produced and the results are aggregated by averaging. This technique eliminates the possibility of overfitting data.

**Real Estate Investment Trust (REIT)**
Considered private, nonindustrial landowners, REITS own and operate large acreages of timberland.

**realized niche**
the portion of potential habitat that a species occupies; usually it is less than what is available because of predation, disease, and competition with other species.

**recharge**
the natural process of movement of rainwater from land areas or streams through permeable soils into water-holding rocks that provide underground storage (i.e., aquifers).

**refugia**

locations and habitats that support populations of organisms that are limited to small fragments of their previous geographic range.

**resampling**

a method to resize or change the resolution of a data grid in geographic information systems. Resampling should not be confused with downscaling. Resampling is performed only on grids that are larger than the original cell size.

**roundwood**

logs, bolts, and other round timber generated from harvesting trees for industrial or consumer use.

**runoff**

that part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions or storage.

**saw log**

a log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight, and with a minimum diameter inside bark of 6 inches for softwoods and 8 inches for hardwoods, or meeting other combinations of size and defect specified by regional standards.

**sawtimber**

a live tree of commercial species containing at least a 12-foot saw log or two noncontiguous 8-foot or longer saw logs, and meeting specifications for form; softwoods must be at least 9 inches, and hardwoods must be at least 11 inches, respectively, in diameter outside the bark.

**scenario**

a coherent, internally consistent, and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (IPCC 2007).

**senescence**

the process of aging in plants. Leaf senescence causes leaves of deciduous trees to change color in autumn.

**significant trend**

significant trends are least-squares regression p-values of observed climate trends. In this report, significant trends ($p < 0.10$) are shown by stippling on maps of observed climate trends. Where no stippling appears ($p > 0.10$), observed trends have a higher probability of being due to chance alone (Girvetz et al. 2009).

**snowpack**

layers of accumulated snow that usually melts during warmer months.

**softwood**

a coniferous tree, usually evergreen, having needles or scale-like leaves.

**species distribution model**

a model that uses statistical relationships to project future change.

**statistical downscaling**

a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution general circulation models (GCMs) by deriving statistical relationships between observed small-scale (often station level) variables and larger-(GCM-) scale variables. Future values of the large-scale variables obtained from GCM projections of future climate are then used to drive the statistical relationships and so estimate the smaller-scale details of future climate.

**stormflow**

runoff that occurs due to a heavy precipitation event.

**streamflow**

discharge that occurs in a natural surface stream course whether or not it is diverted or regulated.

**threat**

a source of danger or harm.

**Timber Investment Management Organization (TIMO)**

Considered private, nonindustrial landowners, TIMOs act as investment managers for clients who own timberlands as partnership shares.

**topkill**

death of aboveground tree stem and branches.

**transpiration**

liquid water phase change occurring inside plants with the vapor diffusing to the atmosphere.

**uncertainty**

a term used to describe the range of possible values around a best estimate, sometimes expressed in terms of probability or likelihood.

**vulnerability**

susceptibility to a threat.

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# APPENDIX 1. SPECIES LISTS

**Table 24.—Common and scientific names of native plants mentioned in this assessment**

| Common Name | Scientific Name |
|---|---|
| balsam fir | *Abies balsamea* |
| boxelder | *Acer negundo* |
| black maple | *Acer nigrum* |
| striped maple | *Acer pensylvanicum* |
| red maple | *Acer rubrum* |
| silver maple | *Acer saccharinum* |
| sugar maple | *Acer saccharum* |
| mountain maple | *Acer spicatum* |
| northern wild monkshood | *Aconitum noveboracense* |
| yellow buckeye | *Aesculus flava* |
| Ohio buckeye | *Aesculus glabra* |
| lillydale onion | *Allium oxyphilum* |
| speckled alder | *Alnus incana* |
| hazel alder | *Alnus serrulata* |
| serviceberry | *Amelanchier Medik.* |
| shale barren rockcress | *Arabis serotina* |
| pawpaw | *Asimina triloba* |
| yellow birch | *Betula alleghaniensis* |
| sweet birch | *Betula lenta* |
| river birch | *Betula nigra* |
| American hornbeam | *Carpinus caroliniana* |
| mockernut hickory | *Carya alba* |
| bitternut hickory | *Carya cordiformis* |
| pignut hickory | *Carya glabra* |
| shagbark hickory | *Carya ovata* |
| black hickory | *Carya texana* |
| American chestnut | *Castanea dentata* |
| northern catalpa | *Catalpa speciosa* |
| sugarberry | *Celtis laevigata* |
| common hackberry | *Celtis occidentalis* |
| common buttonbush | *Cephalanthus occidentalis* |
| eastern redbud | *Cercis canadensis* |
| Bentley's coralroot | *Corallorhiza bentleyi* |
| silky dogwood | *Cornus amomum* |
| roughleaf dogwood | *Cornus drummondii* |
| flowering dogwood | *Cornus florida* |
| ram's-head lady's-slipper | *Cypripedium arietinum* |
| common persimmon | *Diospyros virginiana* |
| American beech | *Fagus grandifolia* |
| white ash | *Fraxinus americana* |
| black ash | *Fraxinus nigra* |
| green ash | *Fraxinus pennsylvanica* |
| blue ash | *Fraxinus quadrangulata* |
| water locust | *Gleditsia aquatica* |
| honeylocust | *Gleditsia triacanthos* |
| bushy St. Johnswort | *Hypericum densiflorum* |
| American holly | *Ilex opaca* |
| common winterberry | *Ilex verticillata* |
| small whorled pogonia | *Isotria medeoloides* |
| butternut | *Juglans cinerea* |
| black walnut | *Juglans nigra* |
| eastern redcedar | *Juniperus virginiana* |
| mountain laurel | *Kalmia latifolia* |
| tamarack | *Larix laricina* |
| northern spicebush | *Lindera benzoin* |
| sweetgum | *Liquidambar styraciflua* |
| tulip tree | *Liriodendron tulipifera* |
| osage orange | *Maclura pomifera* |
| cucumbertree | *Magnolia acuminata* |
| mountain magnolia | *Magnolia fraseri* |
| southern magnolia | *Magnolia grandiflora* |
| red mulberry | *Morus rubra* |
| blackgum | *Nyssa sylvatica* |
| eastern hophornbeam | *Ostrya virginiana* |
| sourwood | *Oxydendrum arboreum* |
| American ginseng | *Panax quinquefolius* |

**Table 24 (continued).**

| Common Name | Scientific Name |
|---|---|
| black chokeberry | *Photinia melanocarpa* |
| red spruce | *Picea rubens* |
| shortleaf pine | *Pinus echinata* |
| Table Mountain pine | *Pinus pungens* |
| red pine | *Pinus resinosa* |
| pitch pine | *Pinus rigida* |
| eastern white pine | *Pinus strobus* |
| loblolly pine | *Pinus taeda* |
| Virginia pine | *Pinus virginiana* |
| eastern prairie fringed orchid | *Platanthera leucophaea* |
| sycamore | *Platanus occidentalis* |
| eastern cottonwood | *Populus deltoides* |
| bigtooth aspen | *Populus grandidentata* |
| quaking aspen | *Populus tremuloides* |
| Tennessee pondweed | *Potamogeton tennesseensis* |
| pin cherry | *Prunus pensylvanica* |
| black cherry | *Prunus serotina* |
| chokecherry | *Prunus virginiana* |
| harperella | *Ptilimnium nodosum* |
| Torrey's mountainmint | *Pycnanthemum torrei* |
| white oak | *Quercus alba* |
| swamp white oak | *Quercus bicolor* |
| scarlet oak | *Quercus coccinea* |
| northern pin oak | *Quercus ellipsoidalis* |
| southern red oak | *Quercus falcata* |
| bear oak/scrub oak | *Quercus ilicifolia* |
| shingle oak | *Quercus imbricaria* |
| bur oak | *Quercus macrocarpa* |
| blackjack oak | *Quercus marilandica* |

| Common Name | Scientific Name |
|---|---|
| chinkapin oak | *Quercus muehlenbergii* |
| water oak | *Quercus nigra* |
| pin oak | *Quercus palustris* |
| willow oak | *Quercus phellos* |
| chestnut oak | *Quercus prinus* |
| northern red oak | *Quercus rubra* |
| Shumard's oak | *Quercus shumardii* |
| post oak | *Quercus stellata* |
| black oak | *Quercus velutina* |
| great laurel | *Rhododendron maximum* |
| black locust | *Robinia pseudoacacia* |
| coastal plain willow | *Salix caroliniana* |
| black willow | *Salix nigra* |
| sassafras | *Sassafras albidum* |
| northeastern bulrush | *Scirpus ancistrochaetus* |
| American mountain ash | *Sorbus americana* |
| Virginia spiraea | *Spiraea virginiana* |
| northern white-cedar | *Thuja occidentalis* |
| American basswood | *Tilia americana* |
| running buffalo clover | *Trifolium stoloniferum* |
| eastern hemlock | *Tsuga canadensis* |
| winged elm | *Ulmus alata* |
| American elm | *Ulmus americana* |
| cedar elm | *Ulmus crassifolia* |
| slippery elm | *Ulmus rubra* |
| rock elm | *Ulmus thomasii* |
| southern mountain cranberry | *Vaccinium erythrocarpum* |
| velvetleaf huckleberry | *Vaccinium myrtilloides* |
| wild raisin (withe-rod) | *Viburnum nudum* |

**Table 25.—Common and scientific names of pathogens and nonnative plants mentioned in this assessment**

| Common Name | Scientific Name |
|---|---|
| **Pathogens** | |
| armillaria | *Armillaria mellea* |
| Lyme disease | *Borrelia burgdorferi* |
| elm yellows | *Candidatus phytoplasma ulmi* |
| white pine blister rust | *Cronartium ribicola* |
| chestnut blight | *Cryphonectria parasitica* |
| diplodia | *Diplodia pinea* and *D. scrobiculata* |
| West Nile virus | *Flavivirus* spp. |
| scleroderris canker | *Gremmeniella abietina* |
| annosum root disease | *Heterobasidion irregulare* |
| hypoxylon canker | *Hypoxylon mammatum* |
| sudden oak death | *Phytophthora ramorum* |
| phytophthora root rot | *Phytophthora* spp. |
| sirococcus shoot blight | *Sirococcus conigenus* |
| sphaeropsis shoot blight | *Sphaeropsis sapinea* |
| **Nonnative invasive plants** | |
| Norway maple | *Acer platanoides* |
| ailanthus | *Ailanthus altissima* |
| silk tree | *Albizia julibrissin* |
| garlic mustard | *Alliaria petiolata* |
| porcelain berry | *Ampelopsis brevipedunculata* |
| dwarf mistletoe | *Arceuthobium pusillum* |
| Japanese barberry | *Berberis thunbergii* |
| paper mulberry | *Broussonetia papyrifera* |
| Asiatic bittersweet | *Celastrus orbiculatus* |
| spotted knapweed | *Centaurea stoebe* |
| hayscented fern | *Dennstaedtia punctilobula* |
| viper's bugloss | *Echium vulgare* |
| autumn olive | *Elaeagnus umbellata* |
| burning bush | *Euonymus* spp. |
| Japanese knotweed | *Fallopia japonica* |
| buckthorn | *Frangula alnus* |
| creeping charlie | *Glechoma hederacea* |
| English ivy | *Hedera helix* |
| cogongrass | *Imperata cylindrica* |
| sericea lespedeza | *Lespedeza cuneata* |
| privet | *Ligustrum vulgare* |
| Japanese honeysuckle | *Lonicera japonica* |
| bush honeysuckle | *Lonicera mackii* |
| purple loosestrife | *Lythrum salicaria* |
| yellow sweetclover | *Melilotus officinalis* |
| Japanese stiltgrass | *Microstegium vimineum* |
| basket grass | *Oplismenus hirtellus* |
| princess tree | *Paulownia tomentusa* |
| mile-a-minute vine | *Persicaria perfoliata* |
| reed canarygrass | *Phalaris arundinacea* |
| common reed (phragmites) | *Phragmites australis* |
| Canada bluegrass | *Poa compressa* |
| kudzu | *Pueraria lobata* |
| glossy buckthorn | *Rhamnus* spp. |
| multiflora rose | *Rosa multiflora* |
| crown vetch | *Securigera varia* |
| Japanese spiraea | *Spiraea japonica* |

**Table 26.—Common and scientific names of fauna mentioned in this assessment**

| Common Name | Scientific Name |
|---|---|
| hemlock woolly adelgid | *Adelges tsugae* |
| saw-whet owl | *Aegolius acadicus* |
| emerald ash borer | *Agrilus planipennis* |
| Jefferson salamander | *Ambystoma jeffersonianum* |
| spotted salamander | *Ambystoma maculata* |
| tiger salamander | *Ambystoma tigrinum* |
| green salamander | *Aneides aeneus* |
| Asian longhorned beetle | *Anoplophora glabripennis* |
| Dry Fork Valley cave pseudoscorpion | *Apochthonius pauscisinosus* |
| eastern cave-loving funnel web spider | *Calymmaria cavicola* |
| coyote | *Canis latrans* |
| eastern timber wolf | *Canis lupus lycaon* |
| beaver | *Castor canadensis* |
| spruce budworm | *Choristoneura fumiferana* |
| spotted turtle | *Clemmys guttata* |
| redside dace | *Clinostomus elongatus* |
| Virginia big-eared bat | *Corynorhinus townsendii virginianus* |
| sculpin | *Cottus* spp. |
| eastern hellbender | *Cryptobranchus alleganiensis* |
| beech scale | *Cryptococcus fagisuga* |
| earthworms (nonnative) | *Dendrobaena octaedra, Lumbricus rubellus,* and *L. terrestris* |
| southern pine beetle | *Dendroctonus frontalis* |
| blackburnian warbler | *Dendroica fusca* |
| birch leaf miner | *Fenusa pusilla* |
| southern flying squirrel | *Glaucomys volans* |
| bog turtle | *Glyptemys muhlenbergii* |
| rapids clubtail | *Gomphus quadricolor* |
| green-faced clubtail | *Gomphus viridifrons* |
| worm-eating warbler | *Helmitheros vermivorus* |
| wood thrush | *Hylocichla mustelina* |
| bark beetle | *Ips* spp. and *Dendroctonus* spp. |
| spring hemlock looper | *Lambdina fiscellaria fiscellaria* |
| silver-haired bat | *Lasionycteris noctivagans* |
| eastern red bat | *Lasiurus borealis* |
| hoary bat | *Lasiurus cinereus* |
| crimson-ringed whiteface | *Leucorrhinia glacialis* |
| red crossbill | *Loxia curvirostra* |
| gypsy moth | *Lymantria dispar dispar* |
| bobcat | *Lynx rufus* |
| forest tent caterpillar | *Malacosoma disstria* |
| wild turkey | *Meleagris gallopavo* |
| small-footed bat | *Myotis leibii* |
| little brown bat | *Myotis lucifugus* |
| northern bat | *Myotis septentrionalis* |
| Indiana bat | *Myotis sodalis* |
| Carter cave spider | *Nesticus carteri* |
| jumping oak gall wasp | *Neuroterus* sp. |
| red-spotted newt | *Notophthalmus viridescens* |
| white-tailed deer | *Odocoileus virginianus* |
| Kentucky warbler | *Oporornis formosus* |
| tri-colored bat | *Perimyotis subflavus* |
| red-backed salamander | *Plethodon cinereus* |
| Cheat Mountain salamander | *Plethodon nettingi* |
| eastern cougar | *Puma concolor couguar* |
| northern flying squirrel | *Sabrinus glaucomys fuscus* |
| brook trout | *Salvelinus fontinalis* |
| eastern spadefoot toad | *Scaphiopus holbrookii* |
| eastern gray squirrel | *Sciurus carolinensis* |
| cerulean warbler | *Setophaga cerulea* |
| black bear | *Ursus americanus* |
| ambrosia beetle | *Xyloterinus politus* |

# APPENDIX 2: TREND ANALYSIS AND HISTORICAL CLIMATE DATA

We used the ClimateWizard Custom Analysis tool to examine historical averages and trends in precipitation and temperature within the assessment area (Gibson et al. 2002, Girvetz et al. 2009). Data for ClimateWizard are derived from PRISM (Parameter-elevation Regressions on Independent Slopes Model) (Gibson et al. 2002). The PRISM model interpolates historical data from the National Weather Service cooperative stations, the Midwest Climate Data Center, and the Historical Climate Network, among others. Data undergo strict quality control procedures to check for errors in station measurements. The PRISM model finds linear relationships between these station measurements and local elevation by using a digital elevation model (digital gridded version of a topographic map). Temperature and precipitation are then derived for each pixel on a continuous 2.5-mile grid across the conterminous United States. The closer a station is to a grid cell of interest in distance and elevation, and the more similar it is in its proximity to coasts or topographic features, the higher the weight the station will have on the final, predicted value for that cell. More information on PRISM can be found at: www.prism.oregonstate.edu/. Please note that Web addresses are current as of the publication date of this assessment but are subject to change.

A 30-year climate “normal” for the assessment area and each ecological section within the assessment area was calculated from the mean for 1971 through 2000 (Table 27). Linear trend analysis was performed for 1901 through 2011 by using restricted maximum likelihood (REML) estimation (Girvetz et al. 2009). Restricted maximum likelihood methods were used for trend analysis of past climate for the International Panel on Climate Change Working Group 1 Report and are considered an effective way to determine trends in climate data over time (Trenberth et al. 2007). A first-order autoregression was assumed for the residuals, meaning that values one time step away from each other are assumed to be correlated. This method was used to examine trends for every 2.5-mile grid cell. The slope and p-values for the linear trend over time were calculated annually, seasonally, and monthly for each climate variable, and then mapped. An overall trend for an area is based on the trend analysis of the average value for all grid cells within the area over time (Table 28).

The developers of the ClimateWizard tool advise users to interpret the linear trend maps in relation to the respective map of statistical confidence (Figs. 44 and 45). In this case, statistical confidence is described by using p-values from a t-test applied to the linear regression. A p-value can be interpreted as the probability of the slope being different from zero by chance. For this assessment, p-values of less than 0.1 were considered to have sufficient statistical confidence. Areas with low statistical confidence in the rate of change (gray areas on the map) should be interpreted with caution.

Table 27.—Annual and seasonal mean values for selected climate variables from 1971 through 2000 for ecological sections within the assessment area

| Ecological section | Season | Precipitation (inches) | Mean temperature (°F) | Minimum temperature (°F) | Maximum temperature (°F) |
|---|---|---|---|---|---|
| 221E | Annual | 42.3 | 52.1 | 40.7 | 63.5 |
| | Fall | 9.3 | 53.9 | 42.2 | 65.6 |
| | Spring | 11.3 | 51.3 | 38.8 | 63.8 |
| | Summer | 12.7 | 71.3 | 59.6 | 83.0 |
| | Winter | 9.1 | 32.0 | 22.3 | 41.6 |
| 221F | Annual | 39.6 | 49.3 | 39.2 | 59.5 |
| | Fall | 9.6 | 51.8 | 41.6 | 62.0 |
| | Spring | 10.3 | 48.1 | 37.1 | 59.1 |
| | Summer | 12.0 | 69.4 | 58.2 | 80.7 |
| | Winter | 7.7 | 28.0 | 19.8 | 36.2 |
| M221A | Annual | 39.1 | 51.3 | 39.8 | 62.9 |
| | Fall | 9.6 | 53.0 | 41.1 | 64.9 |
| | Spring | 10.5 | 50.3 | 38.0 | 62.6 |
| | Summer | 11.2 | 70.1 | 58.0 | 82.2 |
| | Winter | 7.8 | 31.9 | 21.9 | 41.9 |
| M221B | Annual | 48.5 | 49.0 | 37.8 | 60.2 |
| | Fall | 10.7 | 50.7 | 39.3 | 62.2 |
| | Spring | 13.1 | 48.1 | 36.0 | 60.2 |
| | Summer | 13.7 | 66.8 | 55.5 | 78.1 |
| | Winter | 10.9 | 30.3 | 20.4 | 40.1 |
| M221C | Annual | 47.0 | 52.4 | 41.0 | 63.9 |
| | Fall | 10.0 | 53.9 | 42.3 | 65.5 |
| | Spring | 12.7 | 51.9 | 39.1 | 64.6 |
| | Summer | 13.7 | 70.2 | 58.9 | 81.6 |
| | Winter | 10.5 | 33.8 | 23.8 | 43.8 |

In addition, because maps are developed from weather station observations that have been spatially interpolated, developers of the ClimateWizard tool and PRISM data set recommend that inferences about trends should not be made for single grid cells or even small clusters of grid cells. The number of weather stations has also changed over time, and station data are particularly limited before 1948, meaning grid cells from earlier in the century are based on an interpolation of fewer points than later in the century (Gibson et al. 2002). Therefore, interpretations should be based on many grid cells showing regional patterns of climate change with high statistical confidence. For those interested in understanding trends in climate at a particular location, it is best to refer to weather station data for the closest station in the Global Historical Climatology Network from the National Climatic Data Center (http://www.ncdc.noaa.gov/).

We selected the time period 1901 through 2011 because it was sufficiently long to capture interdecadal and intradecadal variation in climate for the region. We acknowledge that different trends can be inferred by selecting different beginning and end points in the analysis. Therefore, trends should be interpreted based on their relative magnitude and direction, and the slope of any single trend should be interpreted with caution.

**Table 28.—Annual, seasonal, and monthly mean values and linear trend analysis for selected climate variables from 1901 through 2011 for the assessment area.**

| Month or season | Mean precip. (inches) | Precip. change (inches) | Precip. p-value[a] | Mean TMean (°F) | TMean change (°F) | TMean p-value[a] | Mean TMin (°F) | TMin change (°F) | TMin p-value[a] | Mean TMax (°F) | TMax change (°F) | TMax p-value[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 3.3 | -0.7 | 0.14 | 29.7 | -2.4 | 0.24 | 20.4 | -1.6 | 0.41 | 39.1 | -3.1 | 0.14 |
| February | 2.8 | -0.1 | 0.70 | 31.4 | 1.7 | 0.38 | 21.2 | 2.0 | 0.33 | 41.5 | 1.4 | 0.48 |
| March | 3.8 | -0.4 | 0.40 | 40.3 | -0.1 | 0.94 | 29.1 | -0.3 | 0.79 | 51.5 | 0.1 | 0.95 |
| April | 3.7 | 0.2 | 0.51 | 50.5 | **2.4** | **0.00** | 38.0 | **1.6** | **0.02** | 62.9 | **3.2** | **0.00** |
| May | 4.1 | **0.9** | **0.05** | 60.0 | 0.0 | 0.96 | 47.4 | 0.6 | 0.42 | 72.7 | -0.7 | 0.48 |
| June | 4.2 | -0.4 | 0.38 | 68.2 | 0.5 | 0.50 | 56.0 | **1.4** | **0.07** | 80.3 | -0.4 | 0.68 |
| July | 4.5 | 0.3 | 0.33 | 71.9 | 0.0 | 0.97 | 60.1 | **1.3** | **0.06** | 83.7 | **-1.2** | **0.10** |
| Aug | 3.9 | -0.2 | 0.47 | 70.5 | **1.2** | **0.03** | 58.8 | **2.1** | **0.00** | 82.3 | 0.3 | 0.64 |
| Sept | 3.2 | **0.9** | **0.04** | 64.3 | -0.6 | 0.51 | 52.0 | 0.9 | 0.40 | 76.6 | **-2.1** | **0.03** |
| Oct | 2.8 | 0.3 | 0.48 | 53.2 | -0.8 | 0.42 | 40.7 | 0.4 | 0.73 | 65.7 | **-2.0** | **0.07** |
| Nov | 3.0 | **1.2** | **0.01** | 42.2 | **2.3** | **0.01** | 31.6 | **2.8** | **0.00** | 52.8 | **1.8** | **0.08** |
| Dec | 3.2 | -0.1 | 0.70 | 32.6 | 1.5 | 0.25 | 23.6 | 1.7 | 0.19 | 41.6 | 1.2 | 0.37 |
| Winter | 3.1 | -1.0 | 0.14 | 31.2 | 0.3 | 0.81 | 21.7 | 0.7 | 0.58 | 40.7 | -0.1 | 0.91 |
| Spring | 3.9 | 0.7 | 0.29 | 50.3 | 0.8 | 0.19 | 38.2 | 0.6 | 0.24 | 62.4 | 0.9 | 0.20 |
| Summer | 4.2 | -0.3 | 0.64 | 70.2 | 0.6 | 0.22 | 58.3 | **1.6** | **0.00** | 82.1 | -0.4 | 0.46 |
| Fall | 3.0 | **2.3** | **0.00** | 53.2 | 0.3 | 0.57 | 41.4 | **1.4** | **0.04** | 65.0 | -0.7 | 0.27 |
| Annual | 42.4 | 1.7 | 0.26 | 51.2 | 0.5 | 0.29 | 39.9 | **1.1** | **0.03** | 62.6 | -0.1 | 0.87 |

*P-values represent the probability of observing that trend by chance. P-values in boldface indicate a less than 10-percent probability that the trend was due to chance. TMean = mean temperature, TMin = minimum temperature, TMax = maximum temperature.

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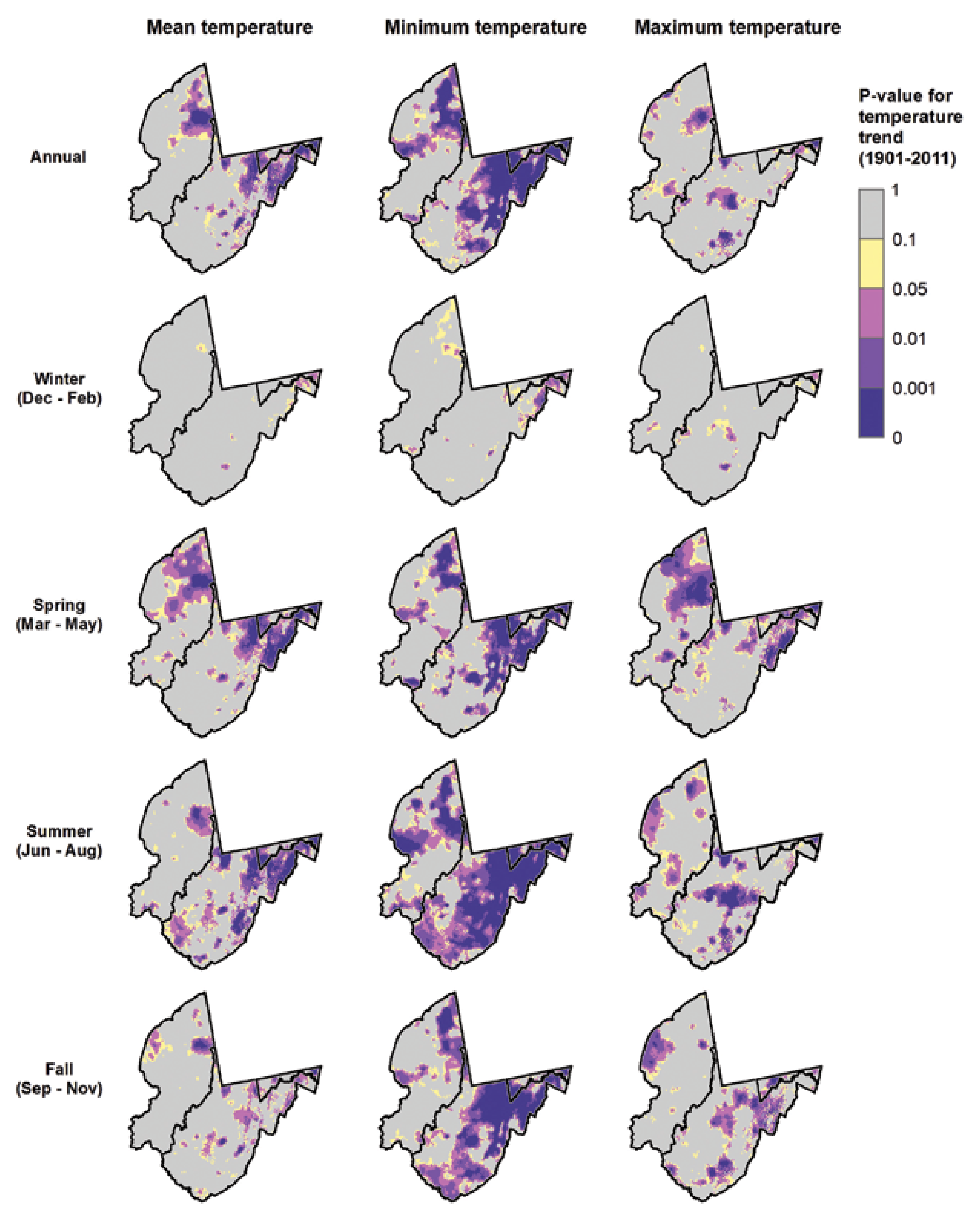

Figure 44.—Statistical confidence (p-values for the linear regression) for trends in temperature from 1901 through 2011. Gray values represent areas of low statistical confidence. Data source: ClimateWizard (2013).

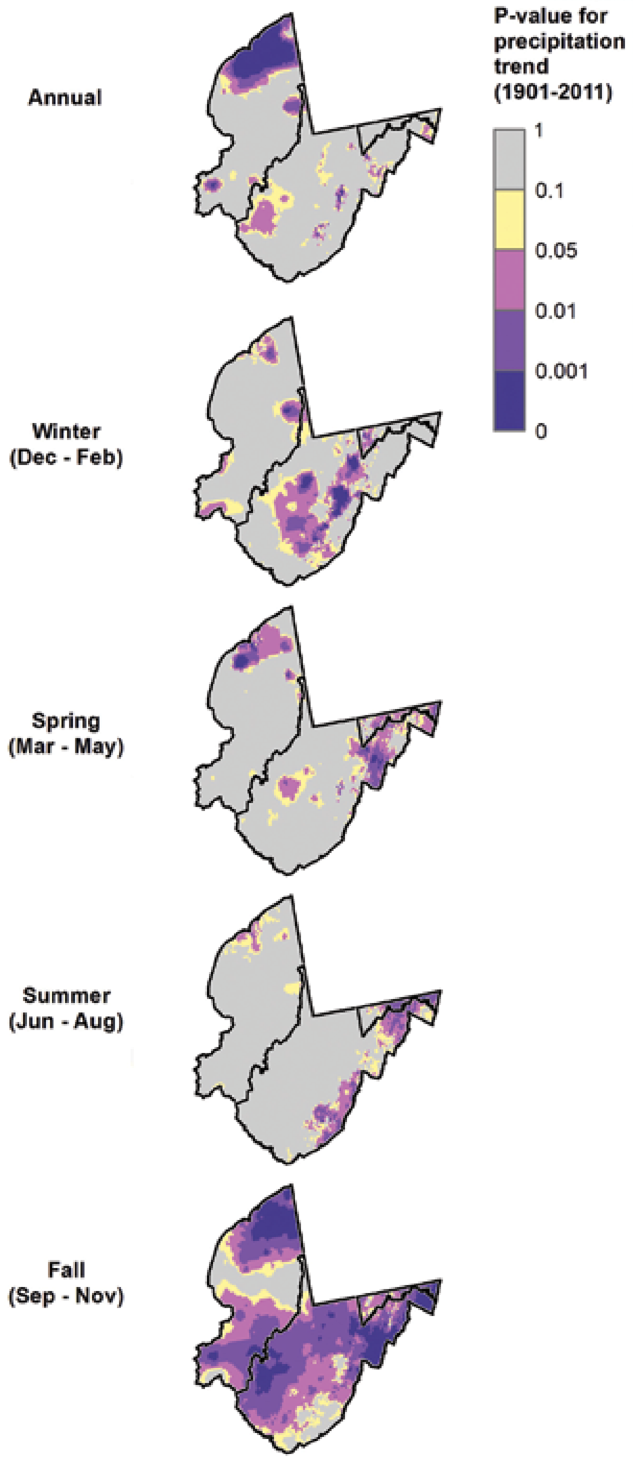

Figure 45.—Statistical confidence (p-values for the linear regression) for trends in precipitation from 1901 through 2011. Gray values represent areas of low statistical confidence. Data source: ClimateWizard (2013).

# APPENDIX 3: ADDITIONAL FUTURE CLIMATE PROJECTIONS

This appendix provides supplementary information to Chapter 4, presented as maps of projected change for early- and mid-century (Figs. 46 through 53) and graphs of early-, mid-, and late-century departures from baseline climate (Figs. 54 through 58).

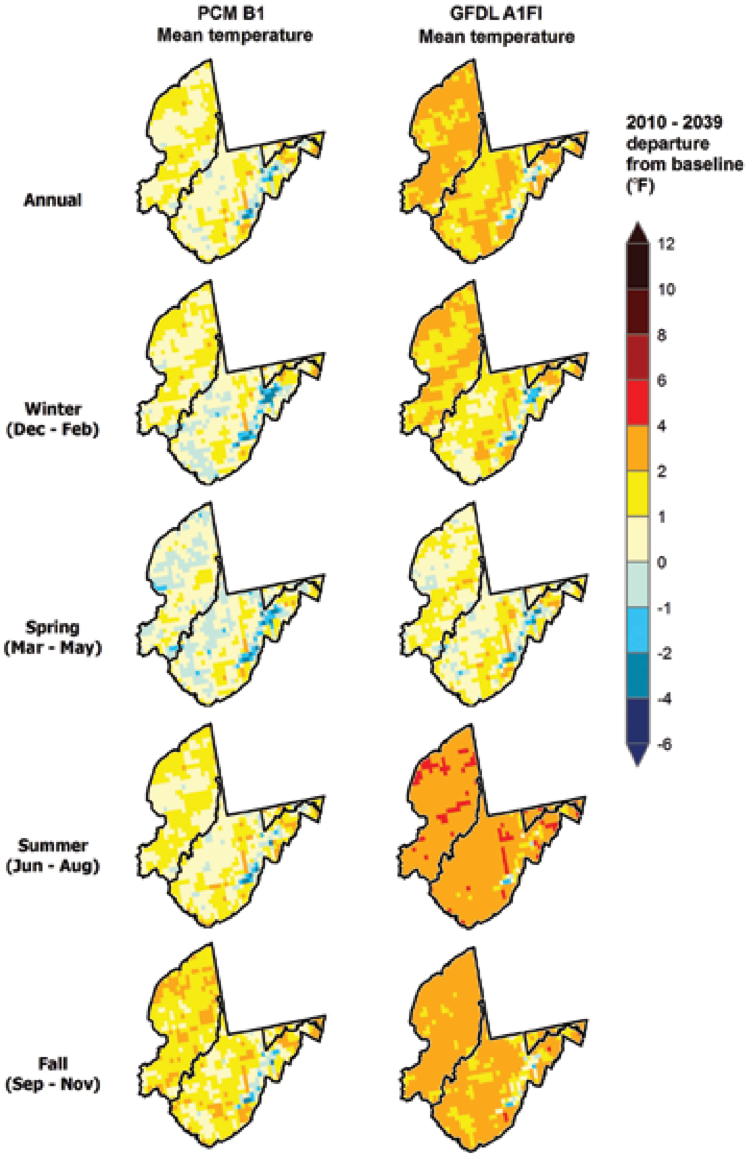

Figure 46.—Projected difference in daily mean temperature at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000) for two climate scenarios.

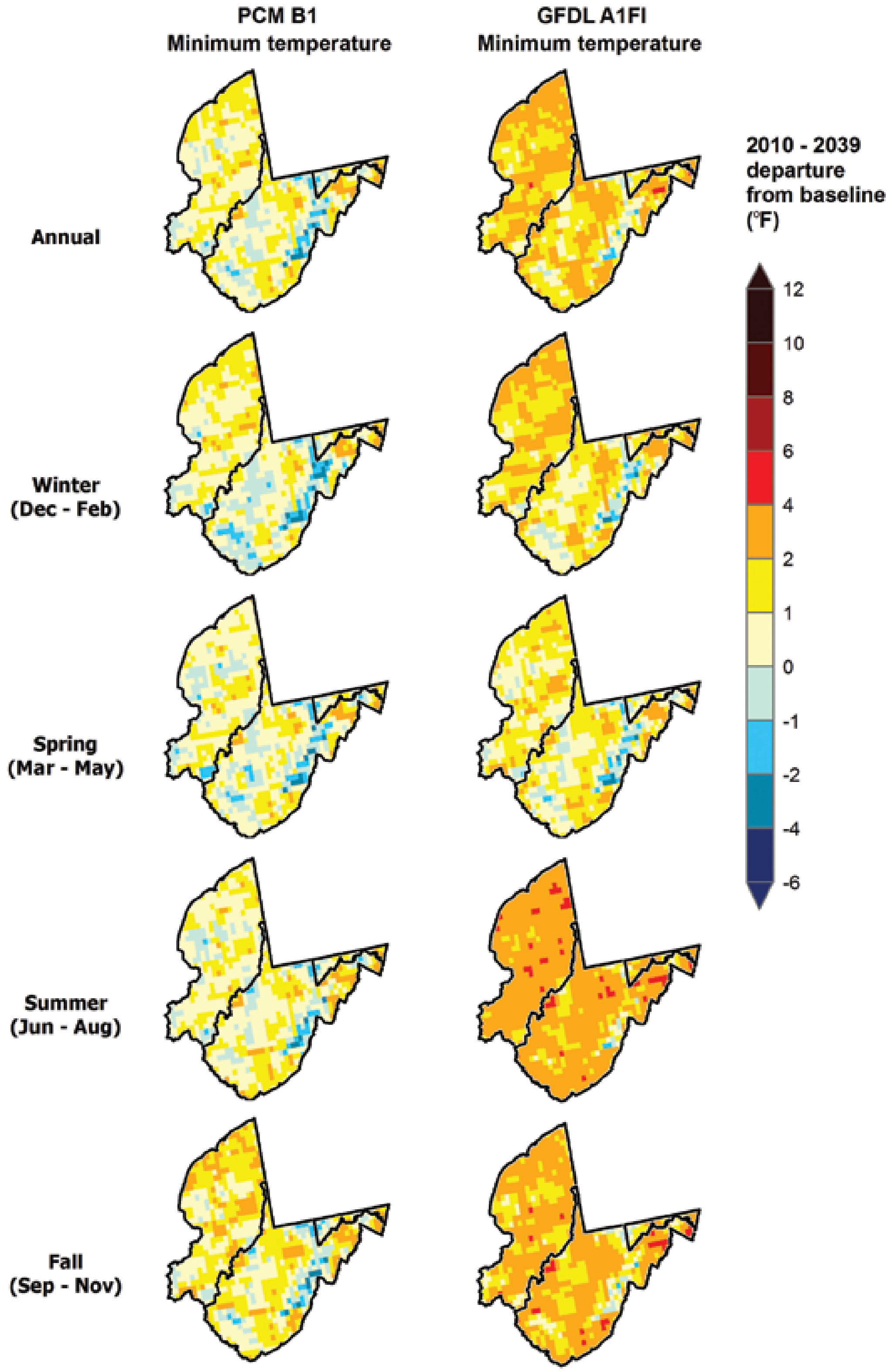

Figure 47.—Projected difference in daily minimum temperature at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000) for two climate scenarios.

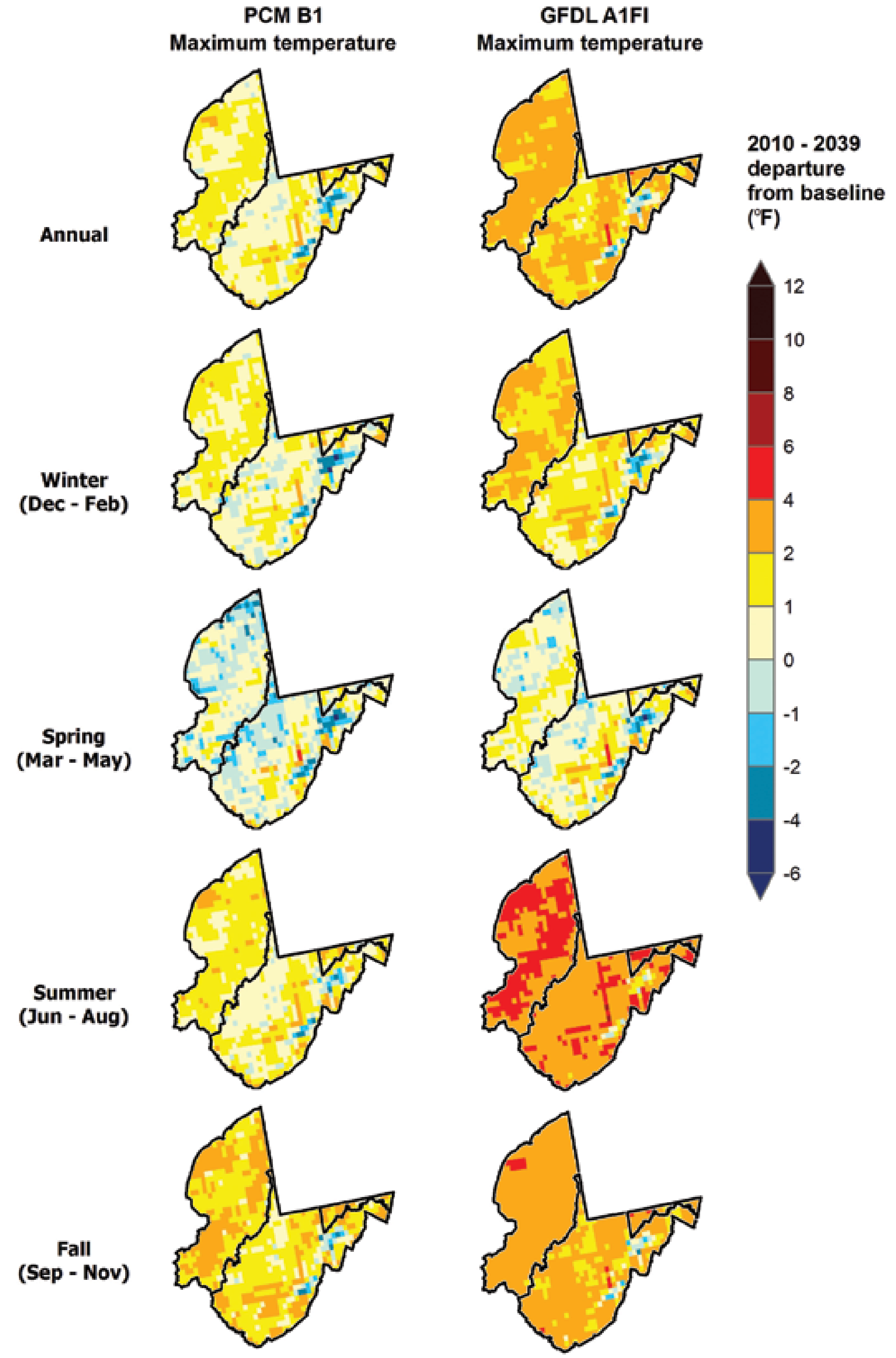

Figure 48.—Projected difference in daily maximum temperature at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000) for two climate scenarios.

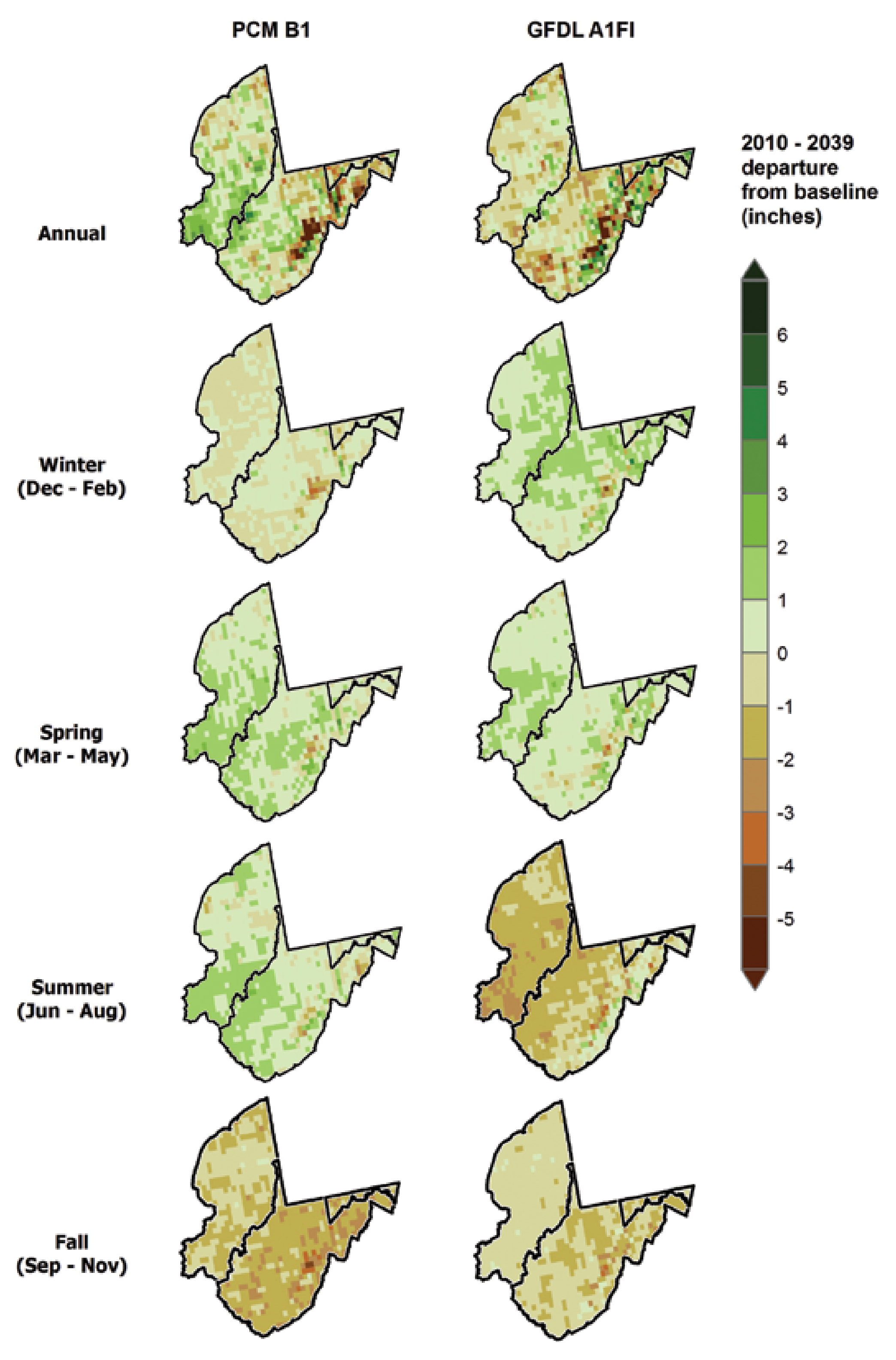

Figure 49.—Projected difference in precipitation at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000) for two climate scenarios.

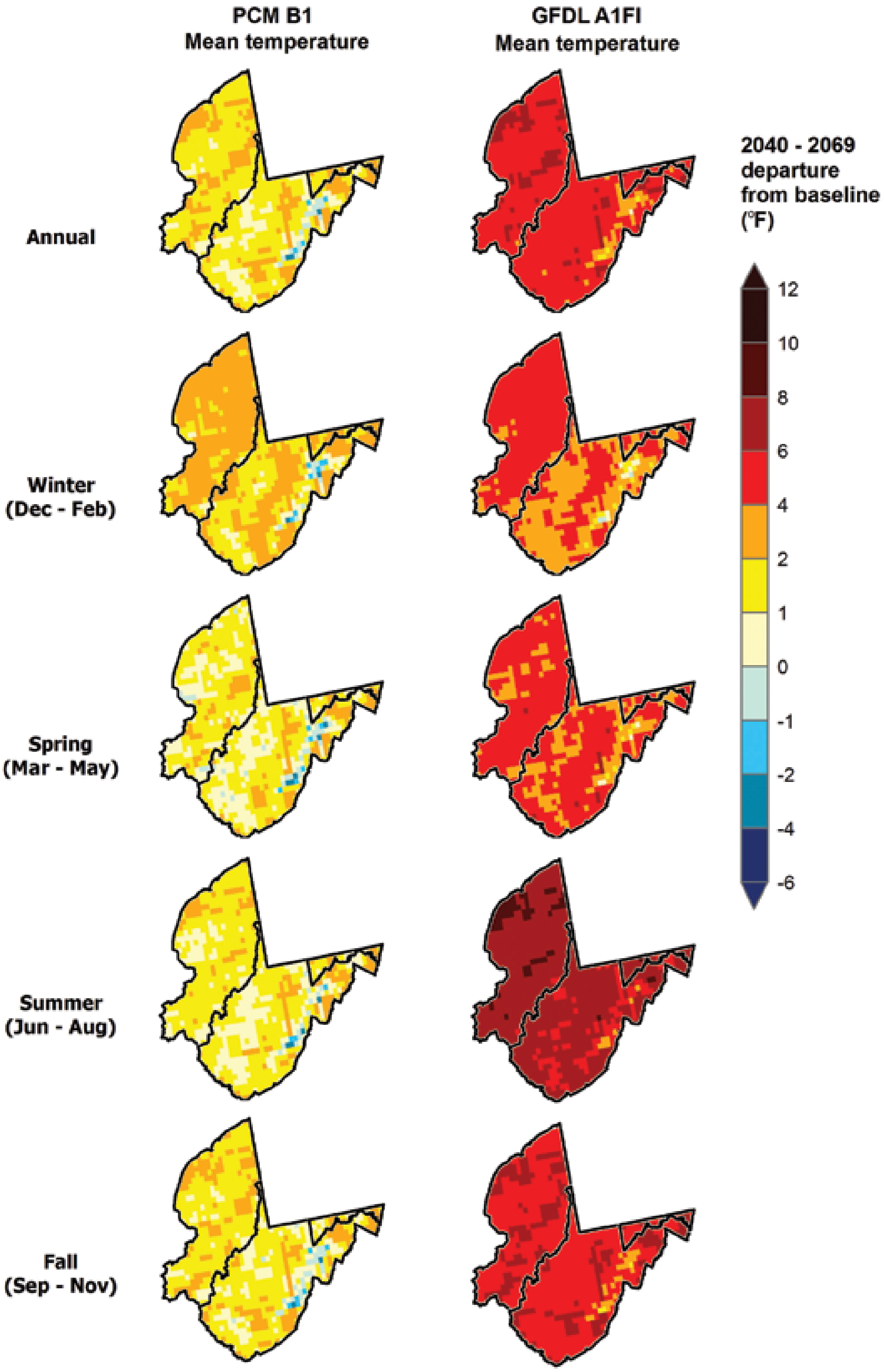

Figure 50.—Projected difference in daily mean temperature for the middle of the century (2040 through 2069) compared to baseline (1971 through 2000) for two climate scenarios.

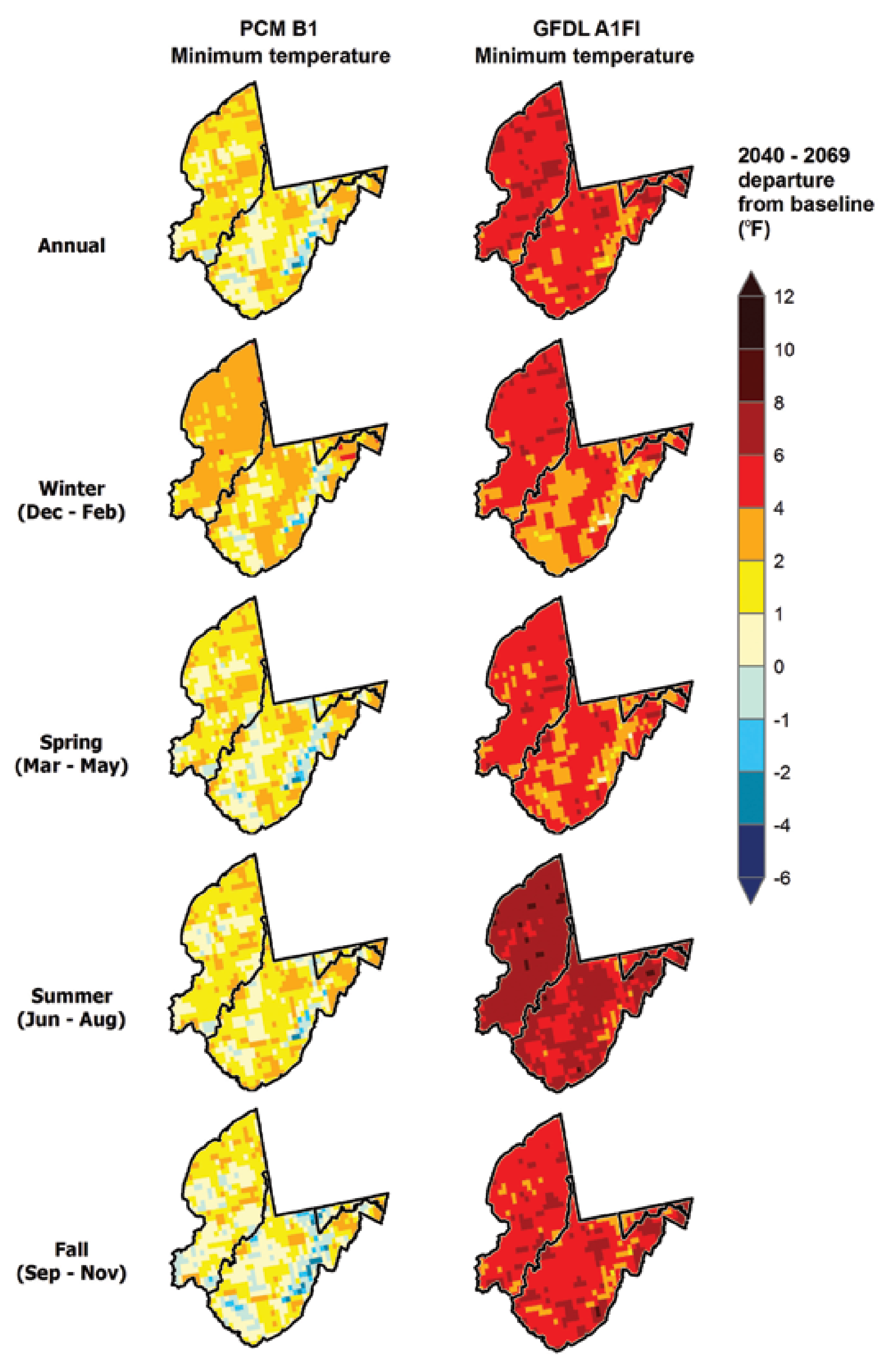

Figure 51.—Projected difference in daily minimum temperature for the middle of the century (2040 through 2069) compared to baseline (1971 through 2000) for two climate scenarios.

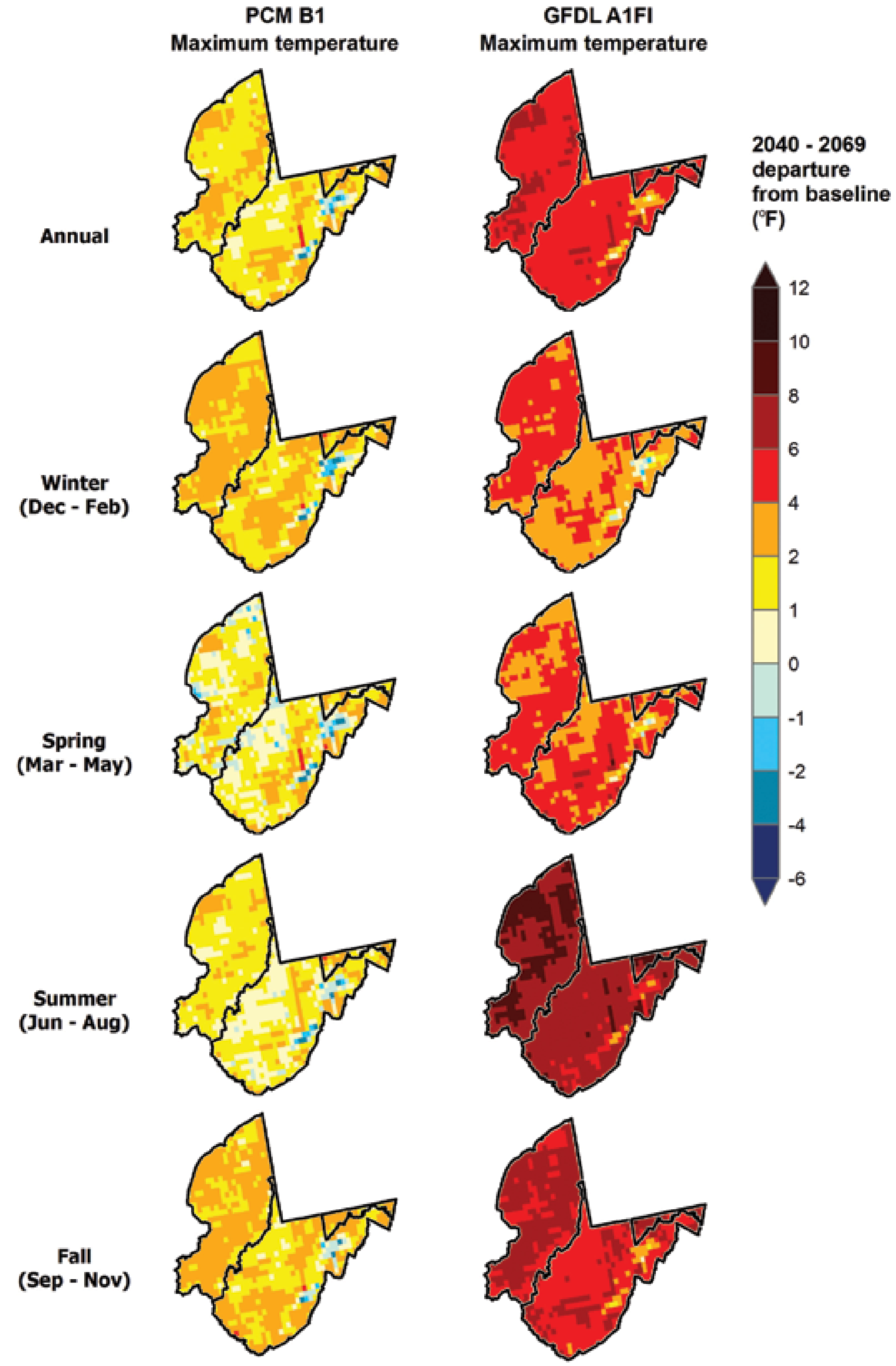

Figure 52.—Projected difference in daily maximum temperature for the middle of the century (2040 through 2069) compared to baseline (1971 through 2000) for two climate scenarios.

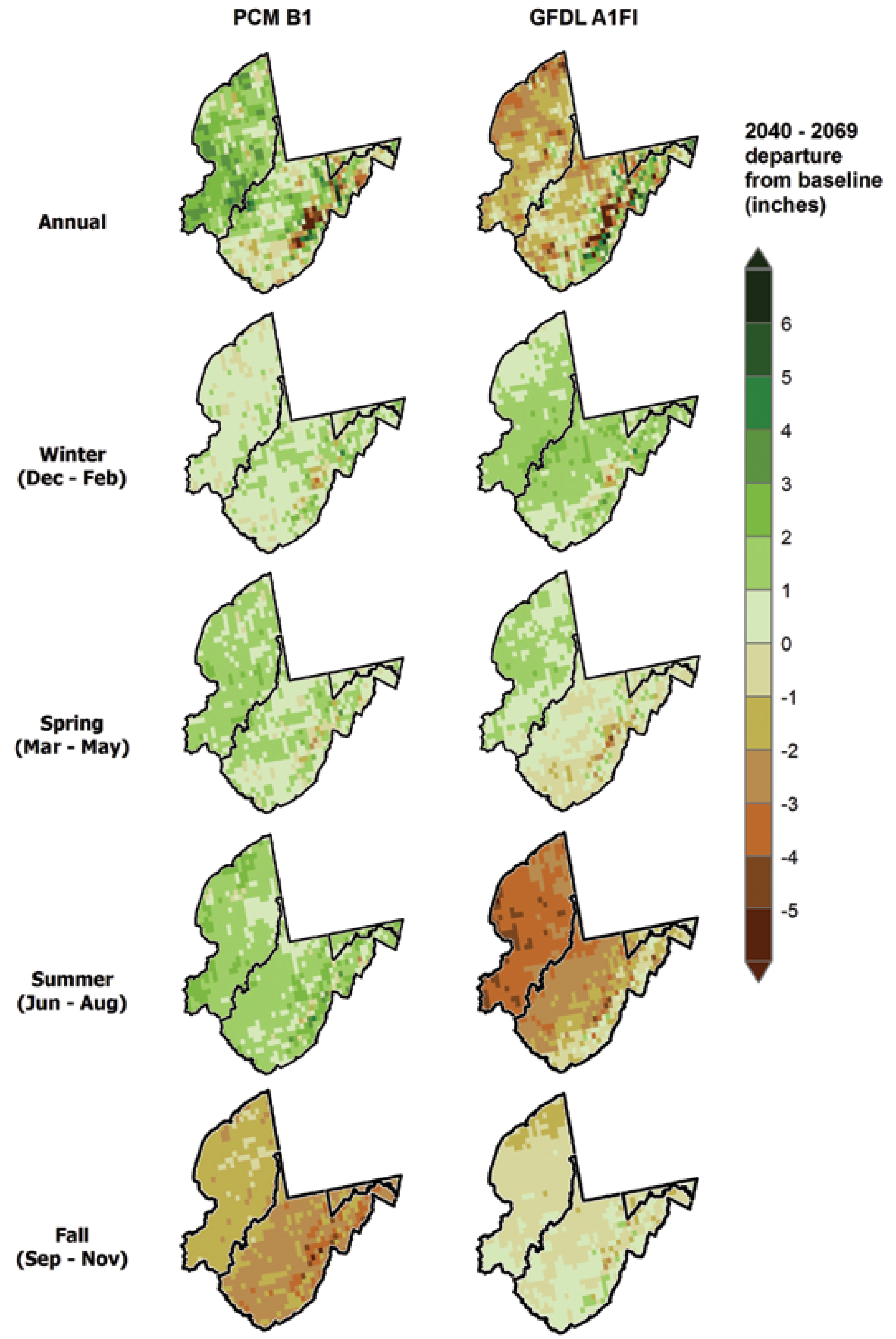

Figure 53.—Projected difference in precipitation for the middle of the century (2040 through 2069) compared to baseline (1971 through 2000) for two climate scenarios.

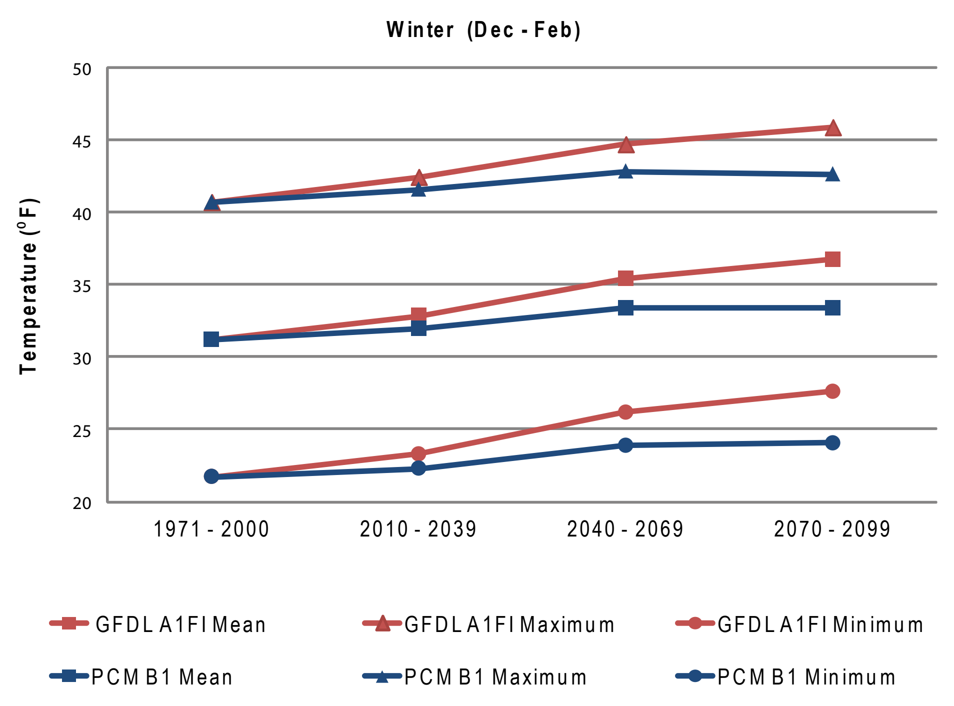

Figure 54.—Projected changes in winter mean, minimum, and maximum temperatures across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations.

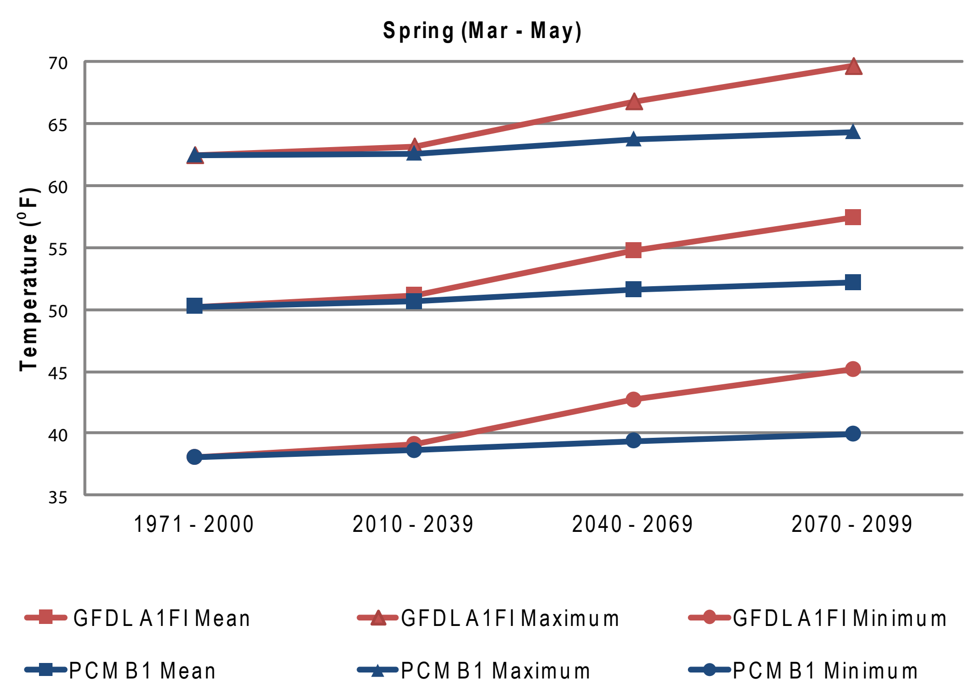

Figure 55.—Projected changes in spring mean, minimum, and maximum temperatures across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations.

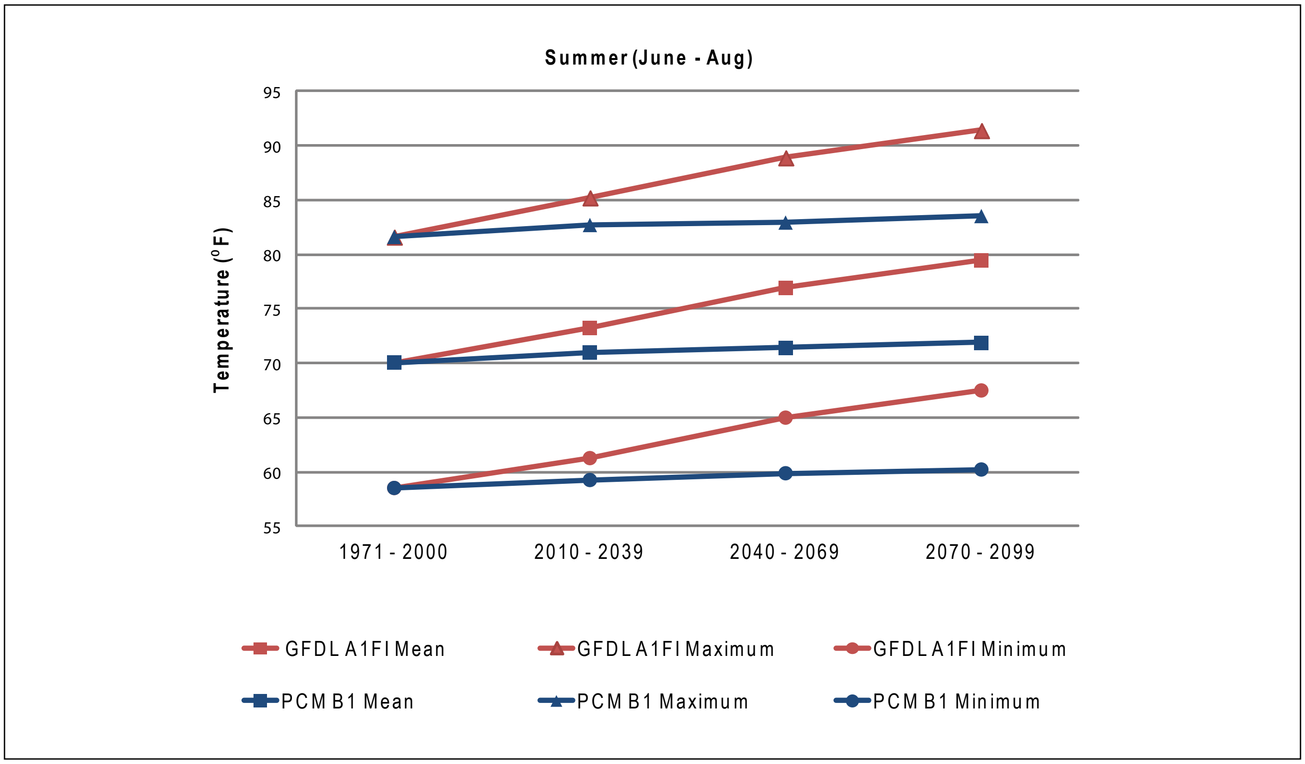

Figure 56.—Projected changes in summer mean, minimum, and maximum temperatures across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations.

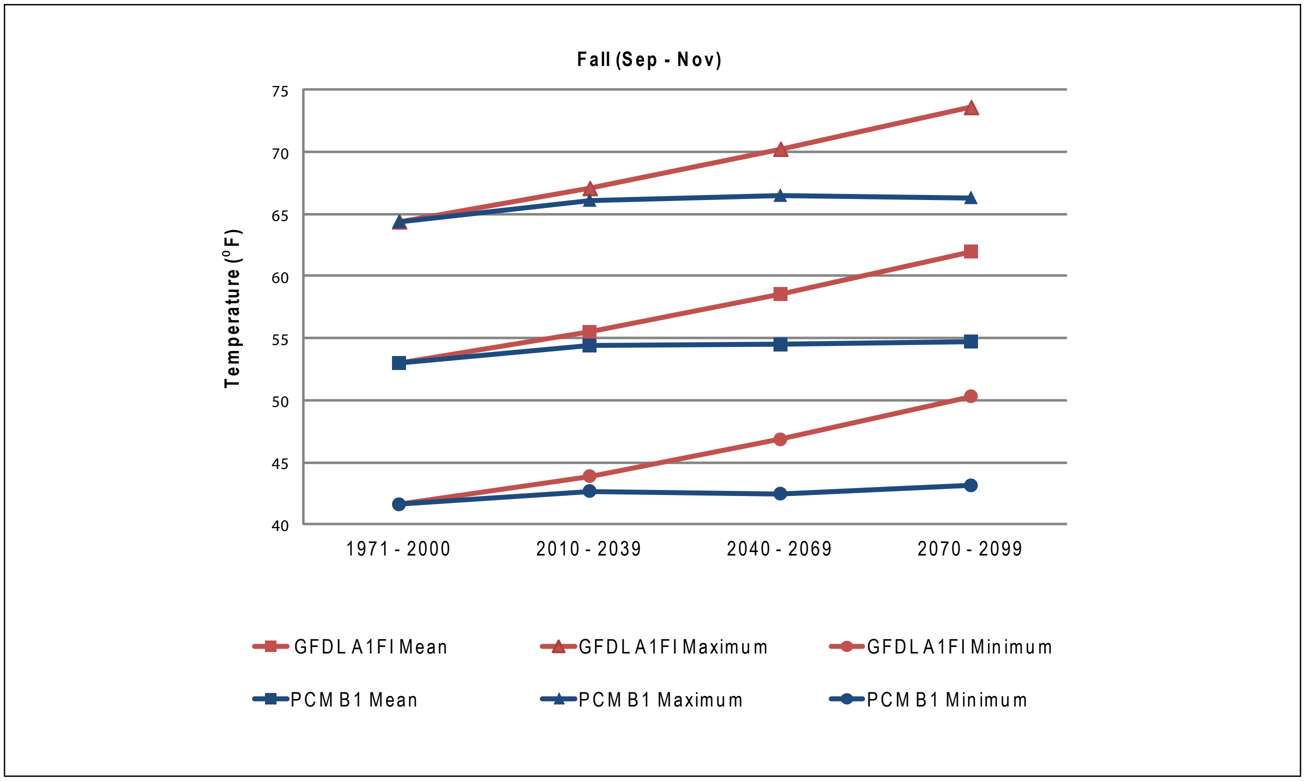

Figure 57.—Projected changes in fall mean, minimum, and maximum temperatures across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations.

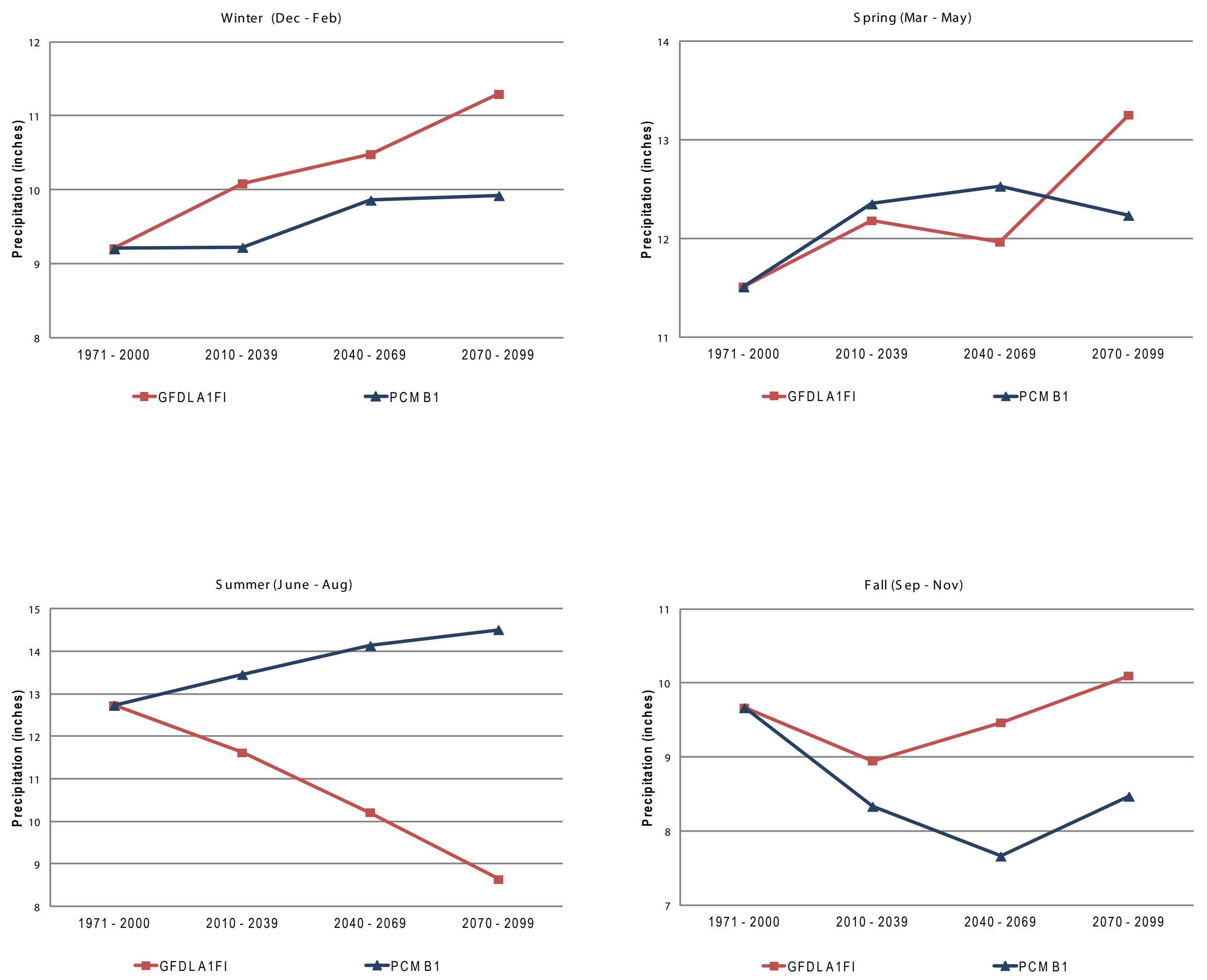

Figure 58.—Projected changes in seasonal precipitation across the assessment area averaged over 30-year periods. The 1971 through 2000 value is based on observed data from weather stations. Note the precipitation axes are different depending on the season.

# APPENDIX 4: ADDITIONAL IMPACT MODEL RESULTS

This appendix provides supplementary information to Chapter 5. The following pages contain additional model results and modifying factors from the Climate Change Tree Atlas, LINKAGES, and LANDIS PRO models. Scientific names for all species are provided in Appendix 1. See Chapter 2 for a description of the models and Chapter 5 for a discussion of model results, uncertainty, and limitations.

## CLIMATE CHANGE TREE ATLAS MODEL RESULTS

Tables 29 through 36 show results of the DISTRIB model used in the Tree Atlas averaged over the whole assessment area, and for each section within the assessment area. Section 221E was further divided based on state boundaries into West Virginia 221E and Ohio 221E. Measured area-weighted importance values (IVs) from the U.S. Forest Service, Forest Inventory and Analysis (FIA) as well as modeled current (1961 through 1990) and future (2010 through 2039, 2040 through 2069, and 2070 through 2099) IVs from DISTRIB were calculated for each time period. One hundred thirty-four tree species were initially modeled. If a species never had an area-weighted IV greater than 3 (FIA, current modeled, or future) across the region, it was deleted from the list because the species either has not had or is not projected to have habitat in the region or there were not enough data. Therefore, only a subset of 93 of the 134 possible species is shown. Three species (blue ash, southern magnolia, and tamarack) were rare within sections and were modeled only at the regional level. Species establishment, growth, and habitat suitability are a function of current (FIA) values. Therefore, it is possible for model results to show species occupying areas where they do not naturally occur (e.g., pine plantations). Conversely, rare species are especially difficult to model at a large regional scale, and may not appear in the FIA data, despite finer inventory data that document their existence.

A set of rules was established to determine change classes for the years 2070 through 2099, which was used to create tables in Chapter 5. For most species, the following rules applied, based on the ratio of future IVs to current modeled IVs:

| Future:Current modeled IV | Class |
|---|---|
| <0.5 | large decrease |
| 0.5 through 0.8 | small decrease |
| >0.8 through <1.2 | no change |
| 1.2 through 2.0 | small increase |
| >2 | large increase |

A few exceptions applied to these general rules. When there was a zero in the numerator or denominator, a ratio could not be calculated. Instead, a species was classified as gaining new habitat if its FIA value was 0 and the future IV was greater than 3. A species' habitat was considered to be extirpated if the future IV was zero and FIA values were greater than 3.

Special rules were created for rare species. A species was considered rare if it had a current modeled area-weighted IV that equaled less than 10 percent of the number of pixels in the assessment area (each pixel is a 12.5-mile cell). The change classes are calculated differently for these species because their current infrequency tends to inflate the percentage change that is projected. The cutoffs for each portion of the assessment area were as follows:

| Section | Pixels | Cutoff IV for rare species |
|---|---|---|
| Assessment area | 332 | 33 |
| 221F | 54 | 5 |
| OH 221E | 85 | 9 |
| WV 221E | 65 | 7 |
| M221A | 37 | 4 |
| M221B | 53 | 5 |
| M221C | 38 | 4 |

When a species was below the cutoff above, it was considered rare, and the following rules applied:

| Future:Current modeled IV | Class |
|---|---|
| <0.2 | large decrease |
| 0.2 through <0.6 | small decrease |
| 0.6 through <4 | no change |
| 4 through 8 | small increase |
| >8 | large increase (not used when current modeled IV ≤3) |

“Extirpated” was not used in this case because of low confidence.

Special rules also applied to species that were known to be present (current FIA IV >0) but not modeled as present (current modeled = 0). In these cases, the FIA IV was used in place of the current modeled IV to calculate ratios. Then, change class rules were applied based on the FIA IV.

Tables 37 and 38 describe the modifying factors and adaptability scores used in the Tree Atlas. These factors were developed by using a literature-based scoring system to capture the potential adaptability of species to changes in climate that cannot be adequately captured by DISTRIB (Matthews et al. 2011). This approach was used to assess the capacity for each species to adapt and considered nine biological traits reflecting innate characteristics including competition ability for light and edaphic specificity. Twelve disturbance characteristics addressed the general response of a species to events such as drought, insect pests, and fire. This information distinguishes between species likely to be more tolerant (or sensitive) to environmental changes than the habitat models alone suggest.

For each biological and disturbance factor, a species was scored on a scale from -3 through +3. A score of -3 indicated a very negative response of that species to that factor. A score of +3 indicated a very positive response to that factor. To account for confidence in the literature about these factors, each of these scores was then multiplied by 0.5, 0.75, or 1, with 0.5 indicating low confidence and 1 indicating high confidence. Finally the score was further weighted by its relevance to future projected climate change by multiplying it by a relevance factor. A score of 4 indicated highly relevant and 1 indicated not highly relevant to climate change. Means for individual biological scores and disturbance scores were then calculated to arrive at an overall biological and disturbance score for the species.

To arrive at an overall adaptability score for the species that could be compared across all modeled tree species, the mean, rescaled (0 through 6) values for biological and disturbance characteristics were plotted to form two sides of a right triangle; the hypotenuse was then a combination (disturbance and biological characteristics) metric, ranging from 0 through 8.5 (Fig. 59).

Note that modifying factors and adaptability scores are calculated for a species across its entire range. Many species may have higher or lower adaptability in certain areas. For example, a species with a low flooding tolerance may have higher adaptability in areas not subject to flooding. Likewise, local impacts of insects and disease may reduce the adaptability of a species in that area. Only the traits that elicited a combination of a strong positive or negative response, high certainty, and high future relevance for a combined score of 4.5 or greater are listed in the following tables for each species.

Mixed hardwoods on the Shawnee State Forest, Ohio. Photo by the Ohio Department of Natural Resources, used with permission.

Table 29.—Complete DISTRIB model results[a] for the 93 tree species in the assessment area

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| Common Name | FIA IV | Current IV | Model Reliability | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI |
| American basswood | 357 | 335 | Medium | 317 | 243 | 296 | 114 | 294 | 97 | 0.95 | 0.73 | 0.88 | 0.34 | 0.88 | 0.29 | No Change | Large Decrease |
| American beech | 1319 | 1275 | High | 1280 | 948 | 1275 | 647 | 1272 | 547 | 1.00 | 0.74 | 1.00 | 0.51 | 1.00 | 0.43 | No Change | Large Decrease |
| American chestnut | 78 | 59 | Medium | 66 | 63 | 61 | 56 | 60 | 55 | 1.12 | 1.07 | 1.03 | 0.95 | 1.02 | 0.93 | No Change | No Change |
| American elm | 1170 | 1102 | Medium | 1012 | 1040 | 892 | 967 | 895 | 751 | 0.92 | 0.94 | 0.81 | 0.88 | 0.81 | 0.68 | No Change | Small Decrease |
| American holly | 13 | 2 | High | 5 | 3 | 5 | 2 | 5 | 2 | 2.50 | 1.50 | 2.50 | 1.00 | 2.50 | 1.00 | No Change | No Change |
| American hornbeam | 407 | 403 | Medium | 372 | 365 | 367 | 408 | 368 | 421 | 0.92 | 0.91 | 0.91 | 1.01 | 0.91 | 1.05 | No Change | No Change |
| Balsam fir | 3 | 7 | High | 7 | 1 | 7 | 1 | 3 | 1 | 1.00 | 0.14 | 1.00 | 0.14 | 0.43 | 0.14 | Small Decrease | Large Decrease |
| Bear oak (scrub oak) | 17 | 18 | Low | 12 | 13 | 10 | 14 | 12 | 14 | 0.67 | 0.72 | 0.56 | 0.78 | 0.67 | 0.78 | No Change | No Change |
| Bigtooth aspen | 243 | 251 | High | 173 | 51 | 121 | 4 | 100 | 0 | 0.69 | 0.20 | 0.48 | 0.02 | 0.40 | 0.00 | Large Decrease | Extirpated |
| Bitternut hickory | 56 | 44 | Low | 63 | 219 | 82 | 329 | 110 | 367 | 1.43 | 4.98 | 1.86 | 7.48 | 2.50 | 8.34 | Large Increase | Large Increase |
| Black ash | 23 | 20 | High | 6 | 3 | 3 | 4 | 2 | 5 | 0.30 | 0.15 | 0.15 | 0.20 | 0.10 | 0.25 | Large Decrease | Small Decrease |
| Black cherry | 2163 | 2337 | High | 1864 | 1094 | 1577 | 660 | 1481 | 536 | 0.80 | 0.47 | 0.68 | 0.28 | 0.63 | 0.23 | Small Decrease | Large Decrease |
| Black hickory | 0 | 7 | High | 5 | 293 | 11 | 859 | 24 | 1171 | 0.71 | 41.86 | 1.57 | 122.71 | 3.43 | 167.29 | No Change | Large Increase |
| Black locust | 904 | 900 | Low | 855 | 789 | 819 | 660 | 781 | 590 | 0.95 | 0.88 | 0.91 | 0.73 | 0.87 | 0.66 | No Change | Small Decrease |
| Black maple | 87 | 47 | Low | 57 | 24 | 54 | 14 | 49 | 14 | 1.21 | 0.51 | 1.15 | 0.30 | 1.04 | 0.30 | No Change | Large Decrease |
| Black oak | 916 | 985 | High | 978 | 1559 | 1018 | 2203 | 1037 | 2118 | 0.99 | 1.58 | 1.03 | 2.24 | 1.05 | 2.15 | No Change | Large Increase |
| Black walnut | 434 | 485 | Medium | 526 | 559 | 576 | 577 | 609 | 463 | 1.09 | 1.15 | 1.19 | 1.19 | 1.26 | 0.96 | Small Increase | No Change |
| Black willow | 63 | 56 | Low | 40 | 124 | 36 | 218 | 42 | 223 | 0.71 | 2.21 | 0.64 | 3.89 | 0.75 | 3.98 | Small Decrease | Large Increase |
| Blackgum | 703 | 799 | High | 843 | 867 | 899 | 854 | 910 | 854 | 1.06 | 1.09 | 1.13 | 1.07 | 1.14 | 1.07 | No Change | No Change |
| Blackjack oak | 11 | 8 | Medium | 17 | 333 | 24 | 1088 | 42 | 1473 | 2.13 | 41.63 | 3.00 | 136.00 | 5.25 | 184.13 | Small Increase | Large Increase |
| Blue ash | 8 | 0 | Low | 6 | 5 | 5 | 5 | 5 | 3 | NA | NA | NA | NA | NA | NA | No Change | Small Decrease |
| Boxelder | 214 | 222 | Medium | 194 | 234 | 211 | 293 | 209 | 284 | 0.87 | 1.05 | 0.95 | 1.32 | 0.94 | 1.28 | No Change | Small Increase |
| Bur oak | 16 | 5 | Medium | 7 | 15 | 9 | 54 | 8 | 70 | 1.40 | 3.00 | 1.80 | 10.80 | 1.60 | 14.00 | No Change | Large Increase |
| Butternut | 71 | 10 | Low | 37 | 10 | 25 | 4 | 19 | 0 | 3.70 | 1.00 | 2.50 | 0.40 | 1.90 | 0.00 | No Change | Extirpated |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 239 | 0 | 584 | NA | NA | NA | Migrant | NA | Migrant | NA | New Habitat |
| Chestnut oak | 1621 | 1577 | High | 1658 | 1503 | 1703 | 1082 | 1622 | 979 | 1.05 | 0.95 | 1.08 | 0.69 | 1.03 | 0.62 | No Change | Small Decrease |
| Chinkapin oak | 42 | 42 | Medium | 73 | 270 | 109 | 327 | 156 | 324 | 1.74 | 6.43 | 2.60 | 7.79 | 3.71 | 7.71 | Large Increase | Large Increase |
| Chokecherry | 19 | 32 | Low | 11 | 4 | 8 | 0 | 8 | 0 | 0.34 | 0.13 | 0.25 | 0.00 | 0.25 | 0.00 | Small Decrease | Extirpated |
| Common persimmon | 70 | 59 | Medium | 97 | 343 | 113 | 571 | 128 | 810 | 1.64 | 5.81 | 1.92 | 9.68 | 2.17 | 13.73 | Large Increase | Large Increase |
| Cucumbertree | 213 | 173 | High | 187 | 175 | 186 | 156 | 189 | 151 | 1.08 | 1.01 | 1.08 | 0.90 | 1.09 | 0.87 | No Change | No Change |
| Eastern cottonwood | 58 | 56 | Low | 31 | 89 | 26 | 142 | 31 | 171 | 0.55 | 1.59 | 0.46 | 2.54 | 0.55 | 3.05 | Small Decrease | Large Increase |
| Eastern hemlock | 259 | 325 | High | 281 | 255 | 278 | 210 | 276 | 196 | 0.87 | 0.79 | 0.86 | 0.65 | 0.85 | 0.60 | No Change | Small Decrease |
| Eastern hophornbeam | 420 | 485 | Medium | 424 | 459 | 408 | 549 | 411 | 637 | 0.87 | 0.95 | 0.84 | 1.13 | 0.85 | 1.31 | No Change | Small Increase |
| Eastern redbud | 294 | 295 | Medium | 357 | 517 | 406 | 661 | 413 | 556 | 1.21 | 1.75 | 1.38 | 2.24 | 1.40 | 1.89 | Small Increase | Small Increase |
| Eastern redcedar | 98 | 193 | Medium | 337 | 1048 | 464 | 1456 | 590 | 1648 | 1.75 | 5.43 | 2.40 | 7.54 | 3.06 | 8.54 | Large Increase | Large Increase |
| Eastern white pine | 354 | 446 | High | 386 | 353 | 378 | 217 | 370 | 196 | 0.87 | 0.79 | 0.85 | 0.49 | 0.83 | 0.44 | No Change | Large Decrease |
| Flowering dogwood | 1625 | 1571 | High | 1686 | 1724 | 1723 | 1440 | 1730 | 1141 | 1.07 | 1.10 | 1.10 | 0.92 | 1.10 | 0.73 | No Change | Small Decrease |
| Green ash | 88 | 103 | Medium | 97 | 206 | 126 | 448 | 145 | 535 | 0.94 | 2.00 | 1.22 | 4.35 | 1.41 | 5.19 | Small Increase | Large Increase |
| Hackberry | 91 | 102 | Medium | 122 | 308 | 149 | 418 | 167 | 423 | 1.20 | 3.02 | 1.46 | 4.10 | 1.64 | 4.15 | Small Increase | Large Increase |
| Honeylocust | 86 | 72 | Low | 108 | 179 | 118 | 282 | 124 | 350 | 1.50 | 2.49 | 1.64 | 3.92 | 1.72 | 4.86 | Small Increase | Large Increase |
| Loblolly pine | 3 | 15 | High | 9 | 47 | 39 | 233 | 30 | 563 | 0.60 | 3.13 | 2.60 | 15.53 | 2.00 | 37.53 | No Change | Large Increase |
| Mockernut hickory | 751 | 838 | High | 814 | 939 | 846 | 1048 | 847 | 1099 | 0.97 | 1.12 | 1.01 | 1.25 | 1.01 | 1.31 | No Change | Small Increase |
| Mountain maple | 23 | 4 | High | 9 | 10 | 9 | 10 | 10 | 10 | 2.25 | 2.50 | 2.25 | 2.50 | 2.50 | 2.50 | No Change | No Change |

(continued on next page)

## Table 29 (continued).

| | | | | DISTRIB results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Northern catalpa | 12 | 4 | Low | 3 | 3 | 3 | 7 | 2 | 20 | 0.75 | 0.75 | 0.75 | 1.75 | 0.50 | 5.00 | No Change | Small Increase |
| Northern pin oak | 6 | 2 | Medium | 4 | 3 | 3 | 1 | 3 | 1 | 2.00 | 1.50 | 1.50 | 0.50 | 1.50 | 0.50 | No Change | No Change |
| Northern red oak | 1397 | 1400 | High | 1313 | 1322 | 1260 | 1206 | 1244 | 1099 | 0.94 | 0.94 | 0.90 | 0.86 | 0.89 | 0.79 | No Change | Small Decrease |
| Northern white-cedar | 0 | 4 | High | 1 | 1 | 1 | 5 | 1 | 6 | 0.25 | 0.25 | 0.25 | 1.25 | 0.25 | 1.50 | Small Decrease | No Change |
| Ohio buckeye | 51 | 32 | Low | 37 | 76 | 41 | 21 | 49 | 5 | 1.16 | 2.38 | 1.28 | 0.66 | 1.53 | 0.16 | No Change | Large Decrease |
| Osage-orange | 63 | 67 | Medium | 67 | 113 | 86 | 159 | 92 | 254 | 1.00 | 1.69 | 1.28 | 2.37 | 1.37 | 3.79 | Small Increase | Large Increase |
| Pawpaw | 172 | 132 | Low | 133 | 132 | 146 | 69 | 144 | 51 | 1.01 | 1.00 | 1.11 | 0.52 | 1.09 | 0.39 | No Change | Large Decrease |
| Pignut hickory | 759 | 864 | High | 848 | 940 | 874 | 810 | 887 | 766 | 0.98 | 1.09 | 1.01 | 0.94 | 1.03 | 0.89 | No Change | No Change |
| Pin cherry | 52 | 18 | Medium | 15 | 3 | 10 | 2 | 7 | 2 | 0.83 | 0.17 | 0.56 | 0.11 | 0.39 | 0.11 | Small Decrease | Large Decrease |
| Pin oak | 128 | 87 | Medium | 79 | 131 | 80 | 197 | 79 | 158 | 0.91 | 1.51 | 0.92 | 2.26 | 0.91 | 1.82 | No Change | Small Increase |
| Pitch pine | 134 | 138 | High | 131 | 129 | 131 | 121 | 124 | 129 | 0.95 | 0.94 | 0.95 | 0.88 | 0.90 | 0.94 | No Change | No Change |
| Post oak | 47 | 57 | High | 120 | 1513 | 176 | 3340 | 257 | 4767 | 2.11 | 26.54 | 3.09 | 58.60 | 4.51 | 83.63 | Large Increase | Large Increase |
| Quaking aspen | 54 | 82 | High | 36 | 5 | 22 | 4 | 14 | 3 | 0.44 | 0.06 | 0.27 | 0.05 | 0.17 | 0.04 | Large Decrease | Large Decrease |
| Red maple | 3395 | 3501 | High | 3240 | 2390 | 3179 | 1664 | 3114 | 1299 | 0.93 | 0.68 | 0.91 | 0.48 | 0.89 | 0.37 | No Change | Large Decrease |
| Red mulberry | 13 | 13 | Low | 13 | 129 | 15 | 295 | 23 | 366 | 1.00 | 9.92 | 1.15 | 22.69 | 1.77 | 28.15 | No Change | Large Increase |
| Red pine | 74 | 51 | Medium | 42 | 20 | 30 | 10 | 24 | 10 | 0.82 | 0.39 | 0.59 | 0.20 | 0.47 | 0.20 | Large Decrease | Large Decrease |
| Red spruce | 67 | 39 | High | 40 | 20 | 33 | 15 | 34 | 14 | 1.03 | 0.51 | 0.85 | 0.39 | 0.87 | 0.36 | No Change | Large Decrease |
| River birch | 20 | 4 | Low | 11 | 14 | 12 | 16 | 10 | 32 | 2.75 | 3.50 | 3.00 | 4.00 | 2.50 | 8.00 | No Change | Small Increase |
| Rock elm | 5 | 1 | Low | 4 | 11 | 3 | 44 | 4 | 20 | 4.00 | 11.00 | 3.00 | 44.00 | 4.00 | 20.00 | No Change | Large Increase |
| Sassafras | 1111 | 1143 | High | 1179 | 1154 | 1191 | 880 | 1229 | 820 | 1.03 | 1.01 | 1.04 | 0.77 | 1.08 | 0.72 | No Change | Small Decrease |
| Scarlet oak | 514 | 582 | High | 612 | 705 | 657 | 522 | 646 | 345 | 1.05 | 1.21 | 1.13 | 0.90 | 1.11 | 0.59 | No Change | Small Decrease |
| Serviceberry | 287 | 259 | Medium | 269 | 239 | 251 | 227 | 243 | 230 | 1.04 | 0.92 | 0.97 | 0.88 | 0.94 | 0.89 | No Change | No Change |
| Shagbark hickory | 144 | 207 | Medium | 204 | 408 | 249 | 558 | 277 | 559 | 0.99 | 1.97 | 1.20 | 2.70 | 1.34 | 2.70 | Small Increase | Large Increase |
| Shingle oak | 31 | 8 | Medium | 22 | 125 | 19 | 123 | 35 | 106 | 2.75 | 15.63 | 2.38 | 15.38 | 4.38 | 13.25 | Small Increase | Large Increase |
| Shortleaf pine | 40 | 53 | High | 79 | 467 | 115 | 1312 | 152 | 1972 | 1.49 | 8.81 | 2.17 | 24.76 | 2.87 | 37.21 | Large Increase | Large Increase |
| Shumard oak | 1 | 0 | Low | 0 | 7 | 0 | 132 | 0 | 282 | NA | NA | NA | NA | NA | NA | NA | Large Increase |
| Silver maple | 183 | 135 | Medium | 96 | 222 | 87 | 407 | 98 | 425 | 0.71 | 1.64 | 0.64 | 3.02 | 0.73 | 3.15 | Small Decrease | Large Increase |
| Slippery elm | 610 | 596 | Medium | 590 | 617 | 558 | 529 | 560 | 402 | 0.99 | 1.04 | 0.94 | 0.89 | 0.94 | 0.67 | No Change | Small Decrease |
| Sourwood | 312 | 362 | High | 400 | 336 | 505 | 275 | 480 | 223 | 1.11 | 0.93 | 1.40 | 0.76 | 1.33 | 0.62 | Small Increase | Small Decrease |
| Southern magnolia | 2 | 4 | Medium | 4 | 1 | 8 | 2 | 4 | 2 | 1.00 | 0.25 | 2.00 | 0.50 | 1.00 | 0.50 | No Change | No Change |
| Southern red oak | 11 | 5 | High | 14 | 136 | 43 | 374 | 54 | 609 | 2.80 | 27.20 | 8.60 | 74.80 | 10.80 | 121.80 | Large Increase | Large Increase |
| Striped maple | 261 | 226 | High | 206 | 142 | 179 | 103 | 170 | 95 | 0.91 | 0.63 | 0.79 | 0.46 | 0.75 | 0.42 | Small Decrease | Large Decrease |
| Sugar maple | 2817 | 2601 | High | 2700 | 2226 | 2681 | 1068 | 2700 | 587 | 1.04 | 0.86 | 1.03 | 0.41 | 1.04 | 0.23 | No Change | Large Decrease |
| Sugarberry | 1 | 1 | Medium | 0 | 57 | 5 | 328 | 9 | 648 | 0.00 | 57.00 | 5.00 | 328.00 | 9.00 | 648.00 | Large Increase | Large Increase |
| Swamp white oak | 59 | 53 | Low | 42 | 51 | 41 | 26 | 43 | 6 | 0.79 | 0.96 | 0.77 | 0.49 | 0.81 | 0.11 | No Change | Large Decrease |
| Sweet birch | 440 | 474 | High | 453 | 353 | 453 | 248 | 451 | 208 | 0.96 | 0.75 | 0.96 | 0.52 | 0.95 | 0.44 | No Change | Large Decrease |
| Sweetgum | 15 | 8 | High | 26 | 85 | 51 | 222 | 78 | 357 | 3.25 | 10.63 | 6.38 | 27.75 | 9.75 | 44.63 | Large Increase | Large Increase |
| Sycamore | 277 | 277 | Medium | 305 | 346 | 310 | 352 | 317 | 368 | 1.10 | 1.25 | 1.12 | 1.27 | 1.14 | 1.33 | No Change | Small Increase |
| Table Mountain pine | 44 | 41 | Medium | 39 | 46 | 39 | 53 | 36 | 63 | 0.95 | 1.12 | 0.95 | 1.29 | 0.88 | 1.54 | No Change | Small Increase |
| Tamarack (native) | 3 | 2 | High | 1 | 1 | 1 | 6 | 1 | 6 | 0.50 | 0.50 | 0.50 | 3.00 | 0.50 | 3.00 | No Change | No Change |
| Tulip tree | 1685 | 1652 | High | 1783 | 1564 | 1895 | 939 | 1939 | 687 | 1.08 | 0.95 | 1.15 | 0.57 | 1.17 | 0.42 | No Change | Large Decrease |
| Virginia pine | 489 | 526 | High | 581 | 579 | 716 | 500 | 700 | 491 | 1.11 | 1.10 | 1.36 | 0.95 | 1.33 | 0.93 | Small Increase | No Change |
| Water locust | 0 | 0 | Low | 0 | 0 | 0 | 6 | 0 | 56 | NA | NA | NA | Migrant | NA | Migrant | NA | New Habitat |

(continued on next page)

**Table 29 (continued).**

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Water oak | 0 | 0 | High | 0 | 0 | 0 | 89 | 0 | 323 | NA | NA | NA | Migrant | NA | Migrant | NA | New Habitat |
| White ash | 1483 | 1657 | High | 1477 | 1250 | 1394 | 827 | 1422 | 747 | 0.89 | 0.75 | 0.84 | 0.50 | 0.86 | 0.45 | No Change | Large Decrease |
| White oak | 1572 | 1643 | High | 1720 | 2487 | 1791 | 2519 | 1853 | 2023 | 1.05 | 1.51 | 1.09 | 1.53 | 1.13 | 1.23 | No Change | Small Increase |
| Willow oak | 2 | 0 | Medium | 0 | 0 | 0 | 1 | 0 | 20 | NA | NA | NA | NA | NA | NA | NA | Large Increase |
| Winged elm | 3 | 2 | High | 11 | 388 | 43 | 1229 | 68 | 2272 | 5.50 | 194.00 | 21.50 | 614.50 | 34.00 | 1136.00 | Large Increase | Large Increase |
| Yellow birch | 151 | 135 | High | 113 | 53 | 106 | 33 | 103 | 29 | 0.84 | 0.39 | 0.79 | 0.24 | 0.76 | 0.22 | Small Decrease | Large Decrease |
| Yellow buckeye | 202 | 161 | Medium | 176 | 175 | 175 | 177 | 176 | 174 | 1.09 | 1.09 | 1.09 | 1.10 | 1.09 | 1.08 | No Change | No Change |

[a] Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

## Table 30.—Complete DISTRIB model results[a] for the 68 tree species in Section 221F

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| American basswood | 73 | 73 | Medium | 56 | 55 | 56 | 11 | 57 | 5 | 0.77 | 0.75 | 0.77 | 0.15 | 0.78 | 0.07 | Decrease | Large Decrease |
| American beech | 228 | 178 | High | 182 | 151 | 180 | 62 | 183 | 51 | 1.02 | 0.85 | 1.01 | 0.35 | 1.03 | 0.29 | No Change | Large Decrease |
| American elm | 495 | 454 | Medium | 468 | 434 | 426 | 403 | 422 | 224 | 1.03 | 0.96 | 0.94 | 0.89 | 0.93 | 0.49 | No Change | Decrease |
| American hornbeam | 79 | 73 | Medium | 68 | 62 | 68 | 69 | 68 | 67 | 0.93 | 0.85 | 0.93 | 0.95 | 0.93 | 0.92 | No Change | No Change |
| Bigtooth aspen | 34 | 57 | High | 53 | 18 | 55 | 0 | 44 | 0 | 0.93 | 0.32 | 0.97 | 0.00 | 0.77 | 0.00 | Decrease | Large Decrease |
| Bitternut hickory | 8 | 22 | Low | 20 | 59 | 37 | 64 | 47 | 58 | 0.91 | 2.68 | 1.68 | 2.91 | 2.14 | 2.64 | Large Increase | Large Increase |
| Black ash | 7 | 20 | High | 5 | 3 | 2 | 4 | 1 | 5 | 0.25 | 0.15 | 0.10 | 0.20 | 0.05 | 0.25 | Large Decrease | Large Decrease |
| Black cherry | 705 | 691 | High | 655 | 289 | 606 | 111 | 546 | 41 | 0.95 | 0.42 | 0.88 | 0.16 | 0.79 | 0.06 | Decrease | Large Decrease |
| Black hickory | 0 | 0 | High | 0 | 7 | 0 | 56 | 0 | 105 | NA | New | NA | New | NA | New | NA | New Habitat |
| Black locust | 74 | 101 | Low | 115 | 114 | 123 | 72 | 121 | 99 | 1.14 | 1.13 | 1.22 | 0.71 | 1.20 | 0.98 | Increase | No Change |
| Black maple | 30 | 17 | Low | 18 | 10 | 18 | 5 | 18 | 5 | 1.06 | 0.59 | 1.06 | 0.29 | 1.06 | 0.29 | No Change | Large Decrease |
| Black oak | 40 | 79 | High | 69 | 132 | 91 | 237 | 96 | 223 | 0.87 | 1.67 | 1.15 | 3.00 | 1.22 | 2.82 | Increase | Large Increase |
| Black walnut | 55 | 80 | Medium | 108 | 137 | 152 | 143 | 162 | 103 | 1.35 | 1.71 | 1.90 | 1.79 | 2.03 | 1.29 | Increase | Increase |
| Black willow | 30 | 36 | Low | 28 | 49 | 26 | 61 | 32 | 57 | 0.78 | 1.36 | 0.72 | 1.69 | 0.89 | 1.58 | No Change | Increase |
| Blackgum | 35 | 34 | High | 50 | 33 | 59 | 32 | 59 | 38 | 1.47 | 0.97 | 1.74 | 0.94 | 1.74 | 1.12 | Increase | No Change |
| Blackjack oak | 0 | 0 | Medium | 0 | 8 | 2 | 120 | 3 | 149 | NA | New | New | New | New | New | New Habitat | New Habitat |
| Boxelder | 31 | 51 | Medium | 44 | 52 | 49 | 64 | 49 | 59 | 0.86 | 1.02 | 0.96 | 1.26 | 0.96 | 1.16 | No Change | Increase |
| Bur oak | 12 | 5 | Medium | 6 | 13 | 8 | 42 | 7 | 43 | 1.20 | 2.60 | 1.60 | 8.40 | 1.40 | 8.60 | Increase | Large Increase |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 2 | 0 | 61 | NA | NA | NA | New | NA | New | NA | New Habitat |
| Chestnut oak | 0 | 12 | High | 29 | 34 | 46 | 6 | 42 | 3 | 2.42 | 2.83 | 3.83 | 0.50 | 3.50 | 0.25 | New Habitat | Large Decrease |
| Chinkapin oak | 0 | 1 | Medium | 4 | 56 | 13 | 64 | 30 | 54 | 4.00 | 56.00 | 13.00 | 64.00 | 30.00 | 54.00 | New Habitat | New Habitat |
| Common persimmon | 0 | 0 | Medium | 0 | 27 | 3 | 45 | 1 | 110 | NA | New | New | New | New | New | New Habitat | New Habitat |
| Cucumbertree | 18 | 5 | High | 11 | 7 | 11 | 5 | 11 | 5 | 2.20 | 1.40 | 2.20 | 1.00 | 2.20 | 1.00 | Large Increase | No Change |
| Eastern cottonwood | 26 | 34 | Low | 20 | 53 | 16 | 79 | 20 | 76 | 0.59 | 1.56 | 0.47 | 2.32 | 0.59 | 2.24 | Decrease | Large Increase |
| Eastern hemlock | 9 | 18 | High | 9 | 3 | 8 | 1 | 5 | 1 | 0.50 | 0.17 | 0.44 | 0.06 | 0.28 | 0.06 | Large Decrease | Large Decrease |
| Eastern hophornbeam | 91 | 123 | Medium | 82 | 98 | 75 | 64 | 73 | 83 | 0.67 | 0.80 | 0.61 | 0.52 | 0.59 | 0.68 | Decrease | Decrease |
| Eastern redcedar | 0 | 6 | Medium | 29 | 173 | 79 | 218 | 111 | 220 | 4.83 | 28.83 | 13.17 | 36.33 | 18.50 | 36.67 | New Habitat | New Habitat |
| Eastern redbud | 0 | 10 | Medium | 30 | 77 | 50 | 159 | 57 | 114 | 3.00 | 7.70 | 5.00 | 15.90 | 5.70 | 11.40 | New Habitat | New Habitat |
| Eastern white pine | 48 | 44 | High | 50 | 40 | 51 | 0 | 41 | 0 | 1.14 | 0.91 | 1.16 | 0.00 | 0.93 | 0.00 | No Change | Large Decrease |
| Flowering dogwood | 115 | 113 | High | 146 | 143 | 155 | 116 | 158 | 115 | 1.29 | 1.27 | 1.37 | 1.03 | 1.40 | 1.02 | Increase | No Change |
| Green ash | 16 | 29 | Medium | 21 | 42 | 38 | 135 | 40 | 146 | 0.72 | 1.45 | 1.31 | 4.66 | 1.38 | 5.03 | Increase | Large Increase |
| Hackberry | 4 | 21 | Medium | 34 | 125 | 51 | 152 | 57 | 133 | 1.62 | 5.95 | 2.43 | 7.24 | 2.71 | 6.33 | Large Increase | Large Increase |
| Honeylocust | 28 | 19 | Low | 47 | 76 | 62 | 97 | 66 | 104 | 2.47 | 4.00 | 3.26 | 5.11 | 3.47 | 5.47 | Large Increase | Large Increase |
| Mockernut hickory | 84 | 101 | High | 93 | 140 | 106 | 170 | 104 | 153 | 0.92 | 1.39 | 1.05 | 1.68 | 1.03 | 1.52 | No Change | Increase |
| Northern pin oak | 4 | 2 | Medium | 4 | 3 | 3 | 1 | 3 | 1 | 2.00 | 1.50 | 1.50 | 0.50 | 1.50 | 0.50 | No Change | Decrease |
| Northern red oak | 191 | 192 | High | 168 | 191 | 169 | 178 | 166 | 116 | 0.88 | 1.00 | 0.88 | 0.93 | 0.87 | 0.60 | No Change | Decrease |
| Northern white-cedar | 0 | 3 | High | 0 | 0 | 0 | 5 | 0 | 6 | 0.00 | 0.00 | 0.00 | 1.67 | 0.00 | 2.00 | NA | No Change |
| Ohio buckeye | 4 | 7 | Low | 12 | 39 | 17 | 16 | 24 | 4 | 1.71 | 5.57 | 2.43 | 2.29 | 3.43 | 0.57 | Large Increase | Decrease |
| Osage-orange | 45 | 26 | Medium | 39 | 60 | 52 | 66 | 52 | 79 | 1.50 | 2.31 | 2.00 | 2.54 | 2.00 | 3.04 | Increase | Large Increase |
| Pignut hickory | 86 | 107 | High | 105 | 152 | 115 | 159 | 114 | 130 | 0.98 | 1.42 | 1.08 | 1.49 | 1.07 | 1.22 | No Change | Increase |
| Pin cherry | 15 | 6 | Medium | 5 | 2 | 5 | 1 | 4 | 1 | 0.83 | 0.33 | 0.83 | 0.17 | 0.67 | 0.17 | Decrease | Large Decrease |
| Pin oak | 106 | 74 | Medium | 68 | 89 | 65 | 107 | 63 | 84 | 0.92 | 1.20 | 0.88 | 1.45 | 0.85 | 1.14 | No Change | No Change |
| Post oak | 0 | 0 | High | 0 | 112 | 9 | 401 | 15 | 655 | NA | New | New | New | New | New | New Habitat | New Habitat |

(continued on next page)

**Table 30 (continued).**

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| Common Name | FIA IV | Current IV | Model Reliability | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI |
| Quaking aspen | 33 | 49 | High | 23 | 0 | 13 | 3 | 7 | 3 | 0.47 | 0.00 | 0.27 | 0.06 | 0.14 | 0.06 | Large Decrease | Large Decrease |
| Red maple | 553 | 537 | High | 418 | 288 | 390 | 237 | 373 | 201 | 0.78 | 0.54 | 0.73 | 0.44 | 0.70 | 0.37 | Decrease | Large Decrease |
| Red mulberry | 0 | 1 | Low | 1 | 49 | 4 | 61 | 7 | 78 | 1.00 | 49.00 | 4.00 | 61.00 | 7.00 | 78.00 | New Habitat | New Habitat |
| Red pine | 29 | 28 | Medium | 26 | 11 | 17 | 9 | 16 | 9 | 0.93 | 0.39 | 0.61 | 0.32 | 0.57 | 0.32 | Decrease | Large Decrease |
| Rock elm | 0 | 0 | Low | 0 | 0 | 0 | 9 | 0 | 11 | NA | NA | NA | New | New | New | NA | New Habitat |
| Sassafras | 32 | 72 | High | 91 | 102 | 112 | 80 | 119 | 97 | 1.26 | 1.42 | 1.56 | 1.11 | 1.65 | 1.35 | Increase | Increase |
| Scarlet oak | 7 | 6 | High | 8 | 21 | 29 | 38 | 28 | 30 | 1.33 | 3.50 | 4.83 | 6.33 | 4.67 | 5.00 | Large Increase | Large Increase |
| Serviceberry | 3 | 2 | Medium | 2 | 1 | 2 | 1 | 2 | 1 | 1.00 | 0.50 | 1.00 | 0.50 | 1.00 | 0.50 | No Change | Decrease |
| Shagbark hickory | 25 | 44 | Medium | 36 | 109 | 61 | 131 | 69 | 79 | 0.82 | 2.48 | 1.39 | 2.98 | 1.57 | 1.80 | Increase | Increase |
| Shingle oak | 7 | 0 | Medium | 5 | 69 | 5 | 67 | 7 | 49 | New | New | New | New | New | New | No Change | Increase |
| Shortleaf pine | 0 | 0 | High | 0 | 0 | 0 | 8 | 0 | 40 | NA | NA | NA | New | New | New | NA | New Habitat |
| Shumard oak | 0 | 0 | Low | 0 | 0 | 0 | 0 | 0 | 27 | NA | NA | NA | NA | New | New | NA | New Habitat |
| Silver maple | 90 | 56 | Medium | 45 | 95 | 43 | 141 | 49 | 104 | 0.80 | 1.70 | 0.77 | 2.52 | 0.88 | 1.86 | No Change | Increase |
| Slippery elm | 101 | 121 | Medium | 139 | 149 | 146 | 141 | 145 | 77 | 1.15 | 1.23 | 1.21 | 1.17 | 1.20 | 0.64 | Increase | Decrease |
| Southern red oak | 0 | 0 | High | 0 | 0 | 0 | 1 | 0 | 14 | NA | NA | NA | New | New | New | NA | New Habitat |
| Sugar maple | 538 | 490 | High | 509 | 480 | 544 | 191 | 562 | 109 | 1.04 | 0.98 | 1.11 | 0.39 | 1.15 | 0.22 | No Change | Large Decrease |
| Sugarberry | 0 | 0 | Medium | 0 | 0 | 0 | 14 | 0 | 121 | NA | NA | NA | New | New | New | NA | New Habitat |
| Swamp white oak | 52 | 48 | Low | 41 | 46 | 39 | 25 | 41 | 6 | 0.85 | 0.96 | 0.81 | 0.52 | 0.85 | 0.13 | No Change | Large Decrease |
| Sweet birch | 1 | 3 | High | 4 | 2 | 9 | 0 | 11 | 0 | 1.33 | 0.67 | 3.00 | 0.00 | 3.67 | 0.00 | No Change | NA |
| Sweetgum | 0 | 0 | High | 0 | 0 | 2 | 1 | 3 | 6 | NA | NA | New | New | New | New | New Habitat | New Habitat |
| Sycamore | 22 | 41 | Medium | 60 | 63 | 63 | 56 | 64 | 61 | 1.46 | 1.54 | 1.54 | 1.37 | 1.56 | 1.49 | Increase | Increase |
| Tulip tree | 66 | 75 | High | 85 | 80 | 118 | 59 | 124 | 52 | 1.13 | 1.07 | 1.57 | 0.79 | 1.65 | 0.69 | Increase | Decrease |
| White oak | 53 | 118 | High | 103 | 230 | 125 | 260 | 134 | 167 | 0.87 | 1.95 | 1.06 | 2.20 | 1.14 | 1.42 | No Change | Increase |
| Winged elm | 0 | 0 | High | 0 | 0 | 0 | 30 | 0 | 217 | NA | NA | NA | New | New | New | NA | New Habitat |
| Yellow birch | 7 | 9 | High | 6 | 0 | 3 | 0 | 1 | 0 | 0.67 | 0.00 | 0.33 | 0.00 | 0.11 | 0.00 | Large Decrease | Large Decrease |

[a] Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

Table 31.—Complete DISTRIB model results[a] for the 72 tree species in Section 221E (Ohio)

| | | | | DISTRIB results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class 2070-2099 |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | | |
| Common Name | FIA IV | Current IV | Model Reliability | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI |
| American basswood | 43 | 55 | Medium | 45 | 38 | 49 | 6 | 49 | 3 | 0.82 | 0.69 | 0.89 | 0.11 | 0.89 | 0.06 | No Change | Large Decrease |
| American beech | 194 | 202 | High | 212 | 149 | 217 | 78 | 228 | 62 | 1.05 | 0.74 | 1.07 | 0.39 | 1.13 | 0.31 | No Change | Large Decrease |
| American elm | 395 | 379 | Medium | 305 | 316 | 254 | 249 | 258 | 177 | 0.81 | 0.83 | 0.67 | 0.66 | 0.68 | 0.47 | Decrease | Decrease |
| American hornbeam | 133 | 108 | Medium | 114 | 112 | 111 | 122 | 113 | 127 | 1.06 | 1.04 | 1.03 | 1.13 | 1.05 | 1.18 | No Change | Increase |
| Bigtooth aspen | 149 | 116 | High | 72 | 11 | 38 | 0 | 35 | 0 | 0.62 | 0.10 | 0.33 | 0.00 | 0.30 | 0.00 | Large Decrease | Extirpated |
| Bitternut hickory | 15 | 12 | Low | 17 | 76 | 20 | 87 | 22 | 95 | 1.42 | 6.33 | 1.67 | 7.25 | 1.83 | 7.92 | Increase | Large Increase |
| Black cherry | 582 | 650 | High | 459 | 223 | 348 | 155 | 335 | 137 | 0.71 | 0.34 | 0.54 | 0.24 | 0.52 | 0.21 | Decrease | Large Decrease |
| Black hickory | 0 | 0 | High | 0 | 115 | 2 | 224 | 6 | 308 | NA | New | New | New | New | New | New Habitat | New Habitat |
| Black locust | 259 | 254 | Low | 203 | 179 | 180 | 158 | 165 | 128 | 0.80 | 0.71 | 0.71 | 0.62 | 0.65 | 0.50 | Decrease | Decrease |
| Black maple | 41 | 23 | Low | 27 | 10 | 25 | 7 | 25 | 7 | 1.17 | 0.44 | 1.09 | 0.30 | 1.09 | 0.30 | No Change | Large Decrease |
| Black oak | 248 | 261 | High | 288 | 508 | 301 | 640 | 303 | 566 | 1.10 | 1.95 | 1.15 | 2.45 | 1.16 | 2.17 | Increase | Large Increase |
| Black walnut | 165 | 171 | Medium | 169 | 166 | 172 | 151 | 175 | 93 | 0.99 | 0.97 | 1.01 | 0.88 | 1.02 | 0.54 | No Change | Decrease |
| Black willow | 15 | 13 | Low | 5 | 46 | 4 | 73 | 4 | 63 | 0.39 | 3.54 | 0.31 | 5.62 | 0.31 | 4.85 | Large Decrease | Large Increase |
| Blackgum | 133 | 144 | High | 174 | 179 | 193 | 151 | 188 | 153 | 1.21 | 1.24 | 1.34 | 1.05 | 1.31 | 1.06 | Increase | No Change |
| Blackjack oak | 2 | 1 | Medium | 4 | 130 | 7 | 339 | 11 | 441 | 4.00 | 130.00 | 7.00 | 339.00 | 11.00 | 441.00 | Increase | Increase |
| Boxelder | 47 | 62 | Medium | 45 | 65 | 52 | 104 | 49 | 98 | 0.73 | 1.05 | 0.84 | 1.68 | 0.79 | 1.58 | Decrease | Increase |
| Bur oak | 2 | 0 | Medium | 0 | 0 | 0 | 8 | 0 | 21 | NA | NA | NA | New | New | New | Large Decrease | Large Increase |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 107 | 0 | 194 | NA | NA | NA | New | New | New | NA | New Habitat |
| Chestnut oak | 220 | 219 | High | 248 | 242 | 278 | 174 | 256 | 167 | 1.13 | 1.11 | 1.27 | 0.80 | 1.17 | 0.76 | Increase | Decrease |
| Chinkapin oak | 13 | 16 | Medium | 32 | 90 | 50 | 87 | 62 | 76 | 2.00 | 5.63 | 3.13 | 5.44 | 3.88 | 4.75 | Large Increase | Large Increase |
| Common persimmon | 32 | 31 | Medium | 46 | 134 | 52 | 142 | 53 | 188 | 1.48 | 4.32 | 1.68 | 4.58 | 1.71 | 6.07 | Increase | Large Increase |
| Cucumbertree | 12 | 2 | High | 7 | 5 | 7 | 4 | 8 | 4 | 3.50 | 2.50 | 3.50 | 2.00 | 4.00 | 2.00 | Large Increase | Increase |
| Eastern cottonwood | 27 | 9 | Low | 9 | 28 | 6 | 46 | 5 | 67 | 1.00 | 3.11 | 0.67 | 5.11 | 0.56 | 7.44 | Decrease | Large Increase |
| Eastern hemlock | 9 | 13 | High | 3 | 3 | 3 | 2 | 4 | 2 | 0.23 | 0.23 | 0.23 | 0.15 | 0.31 | 0.15 | Large Decrease | Large Decrease |
| Eastern hophornbeam | 106 | 120 | Medium | 103 | 110 | 100 | 156 | 103 | 169 | 0.86 | 0.92 | 0.83 | 1.30 | 0.86 | 1.41 | No Change | Increase |
| Eastern redcedar | 47 | 73 | Medium | 141 | 358 | 182 | 390 | 219 | 436 | 1.93 | 4.90 | 2.49 | 5.34 | 3.00 | 5.97 | Large Increase | Large Increase |
| Eastern redbud | 108 | 94 | Medium | 119 | 164 | 131 | 189 | 128 | 136 | 1.27 | 1.75 | 1.39 | 2.01 | 1.36 | 1.45 | Increase | Increase |
| Eastern white pine | 98 | 98 | High | 75 | 49 | 58 | 1 | 55 | 1 | 0.77 | 0.50 | 0.59 | 0.01 | 0.56 | 0.01 | Decrease | Extirpated |
| Flowering dogwood | 595 | 476 | High | 552 | 517 | 546 | 355 | 548 | 265 | 1.16 | 1.09 | 1.15 | 0.75 | 1.15 | 0.56 | Increase | Decrease |
| Green ash | 24 | 25 | Medium | 26 | 73 | 31 | 163 | 37 | 180 | 1.04 | 2.92 | 1.24 | 6.52 | 1.48 | 7.20 | Increase | Large Increase |
| Hackberry | 30 | 39 | Medium | 39 | 101 | 47 | 118 | 55 | 106 | 1.00 | 2.59 | 1.21 | 3.03 | 1.41 | 2.72 | Increase | Large Increase |
| Honeylocust | 40 | 37 | Low | 41 | 67 | 37 | 94 | 39 | 126 | 1.11 | 1.81 | 1.00 | 2.54 | 1.05 | 3.41 | No Change | Large Increase |
| Loblolly pine | 0 | 1 | High | 0 | 4 | 2 | 37 | 1 | 109 | 0.00 | 4.00 | 2.00 | 37.00 | 1.00 | 109.00 | NA | New Habitat |
| Mockernut hickory | 198 | 206 | High | 220 | 245 | 231 | 256 | 230 | 258 | 1.07 | 1.19 | 1.12 | 1.24 | 1.12 | 1.25 | No Change | Increase |
| Northern catalpa | 9 | 1 | Low | 2 | 2 | 2 | 1 | 1 | 1 | 2.00 | 2.00 | 2.00 | 1.00 | 1.00 | 1.00 | No Change | No Change |
| Northern red oak | 233 | 271 | High | 245 | 294 | 249 | 229 | 253 | 220 | 0.90 | 1.09 | 0.92 | 0.85 | 0.93 | 0.81 | No Change | Decrease |
| Ohio buckeye | 29 | 15 | Low | 13 | 27 | 11 | 2 | 13 | 1 | 0.87 | 1.80 | 0.73 | 0.13 | 0.87 | 0.07 | No Change | Large Decrease |
| Osage-orange | 12 | 26 | Medium | 18 | 30 | 21 | 48 | 25 | 93 | 0.69 | 1.15 | 0.81 | 1.85 | 0.96 | 3.58 | No Change | Large Increase |
| Pawpaw | 51 | 48 | Low | 41 | 52 | 48 | 30 | 48 | 18 | 0.85 | 1.08 | 1.00 | 0.63 | 1.00 | 0.38 | No Change | Large Decrease |
| Pignut hickory | 204 | 218 | High | 239 | 265 | 251 | 234 | 259 | 231 | 1.10 | 1.22 | 1.15 | 1.07 | 1.19 | 1.06 | Increase | No Change |
| Pin oak | 16 | 8 | Medium | 7 | 29 | 9 | 68 | 9 | 51 | 0.88 | 3.63 | 1.13 | 8.50 | 1.13 | 6.38 | No Change | Large Increase |
| Pitch pine | 24 | 16 | High | 20 | 15 | 23 | 15 | 21 | 14 | 1.25 | 0.94 | 1.44 | 0.94 | 1.31 | 0.88 | Increase | No Change |
| Post oak | 16 | 17 | High | 40 | 658 | 60 | 1052 | 86 | 1388 | 2.35 | 38.71 | 3.53 | 61.88 | 5.06 | 81.65 | Large Increase | Large Increase |

(continued on next page)

**Table 31 (continued).**

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Quaking aspen | 12 | 10 | High | 3 | 0 | 1 | 0 | 0 | 0 | 0.30 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | Extirpated | Extirpated |
| Red maple | 816 | 769 | High | 734 | 397 | 718 | 265 | 690 | 227 | 0.95 | 0.52 | 0.93 | 0.35 | 0.90 | 0.30 | No Change | Large Decrease |
| Red mulberry | 0 | 2 | Low | 2 | 41 | 2 | 87 | 2 | 93 | 1.00 | 20.50 | 1.00 | 43.50 | 1.00 | 46.50 | NA | New Habitat |
| Red pine | 18 | 6 | Medium | 3 | 1 | 2 | 1 | 0 | 1 | 0.50 | 0.17 | 0.33 | 0.17 | 0.00 | 0.17 | Large Decrease | Large Decrease |
| River birch | 10 | 3 | Low | 5 | 10 | 7 | 13 | 7 | 22 | 1.67 | 3.33 | 2.33 | 4.33 | 2.33 | 7.33 | No Change | Increase |
| Sassafras | 323 | 323 | High | 341 | 328 | 355 | 239 | 365 | 218 | 1.06 | 1.02 | 1.10 | 0.74 | 1.13 | 0.68 | No Change | Decrease |
| Scarlet oak | 88 | 108 | High | 127 | 165 | 135 | 106 | 132 | 74 | 1.18 | 1.53 | 1.25 | 0.98 | 1.22 | 0.69 | Increase | Decrease |
| Serviceberry | 33 | 25 | Medium | 30 | 29 | 28 | 29 | 26 | 27 | 1.20 | 1.16 | 1.12 | 1.16 | 1.04 | 1.08 | No Change | No Change |
| Shagbark hickory | 49 | 76 | Medium | 75 | 143 | 86 | 146 | 94 | 128 | 0.99 | 1.88 | 1.13 | 1.92 | 1.24 | 1.68 | Increase | Increase |
| Shingle oak | 19 | 8 | Medium | 17 | 48 | 13 | 46 | 22 | 45 | 2.13 | 6.00 | 1.63 | 5.75 | 2.75 | 5.63 | No Change | Increase |
| Shortleaf pine | 15 | 15 | High | 26 | 136 | 35 | 299 | 44 | 445 | 1.73 | 9.07 | 2.33 | 19.93 | 2.93 | 29.67 | Large Increase | Large Increase |
| Shumard oak | 0 | 0 | Low | 0 | 3 | 0 | 41 | 0 | 89 | NA | New | NA | New | New | New | NA | NA |
| Silver maple | 57 | 52 | Medium | 29 | 81 | 23 | 185 | 27 | 187 | 0.56 | 1.56 | 0.44 | 3.56 | 0.52 | 3.60 | Decrease | Decrease |
| Slippery elm | 182 | 195 | Medium | 175 | 198 | 167 | 143 | 168 | 95 | 0.90 | 1.02 | 0.86 | 0.73 | 0.86 | 0.49 | No Change | No Change |
| Sourwood | 69 | 49 | High | 81 | 43 | 109 | 34 | 89 | 36 | 1.65 | 0.88 | 2.22 | 0.69 | 1.82 | 0.74 | Increase | Increase |
| Southern red oak | 0 | 1 | High | 3 | 31 | 8 | 83 | 10 | 137 | 3.00 | 31.00 | 8.00 | 83.00 | 10.00 | 137.00 | New Habitat | New Habitat |
| Sugar maple | 665 | 634 | High | 652 | 524 | 651 | 163 | 659 | 76 | 1.03 | 0.83 | 1.03 | 0.26 | 1.04 | 0.12 | No Change | No Change |
| Sugarberry | 0 | 1 | Medium | 0 | 24 | 1 | 123 | 2 | 226 | 0.00 | 24.00 | 1.00 | 123.00 | 2.00 | 226.00 | New Habitat | New Habitat |
| Sweet birch | 8 | 26 | High | 15 | 6 | 23 | 2 | 22 | 2 | 0.58 | 0.23 | 0.89 | 0.08 | 0.85 | 0.08 | Decrease | Decrease |
| Sweetgum | 10 | 1 | High | 6 | 11 | 9 | 25 | 14 | 47 | 6.00 | 11.00 | 9.00 | 25.00 | 14.00 | 47.00 | Increase | Increase |
| Sycamore | 111 | 109 | Medium | 115 | 119 | 115 | 103 | 113 | 95 | 1.06 | 1.09 | 1.06 | 0.95 | 1.04 | 0.87 | No Change | No Change |
| Tulip tree | 473 | 429 | High | 484 | 342 | 499 | 195 | 501 | 159 | 1.13 | 0.80 | 1.16 | 0.46 | 1.17 | 0.37 | Increase | Increase |
| Virginia pine | 117 | 126 | High | 173 | 130 | 222 | 97 | 210 | 106 | 1.37 | 1.03 | 1.76 | 0.77 | 1.67 | 0.84 | Increase | Increase |
| Water locust | 0 | 0 | Low | 0 | 0 | 0 | 1 | 0 | 16 | NA | NA | NA | New | New | New | NA | NA |
| Water oak | 0 | 0 | High | 0 | 0 | 0 | 23 | 0 | 87 | NA | NA | NA | New | New | New | NA | NA |
| White ash | 409 | 444 | High | 391 | 323 | 364 | 202 | 373 | 174 | 0.88 | 0.73 | 0.82 | 0.46 | 0.84 | 0.39 | Decrease | Decrease |
| White oak | 411 | 429 | High | 482 | 784 | 518 | 655 | 532 | 472 | 1.12 | 1.83 | 1.21 | 1.53 | 1.24 | 1.10 | Increase | Increase |
| Winged elm | 0 | 1 | High | 1 | 159 | 7 | 342 | 13 | 682 | 1.00 | 159.00 | 7.00 | 342.00 | 13.00 | 682.00 | New Habitat | New Habitat |
| Yellow buckeye | 57 | 47 | Medium | 49 | 46 | 49 | 50 | 48 | 48 | 1.04 | 0.98 | 1.04 | 1.06 | 1.02 | 1.02 | No Change | No Change |

[a]Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

**Table 32.—Complete DISTRIB model results for the 71 tree species[a] in Section 221E (West Virginia)**

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| American basswood | 58 | 53 | Medium | 59 | 24 | 50 | 4 | 43 | 3 | 1.11 | 0.45 | 0.94 | 0.08 | 0.81 | 0.06 | Decrease | Large Decrease |
| American beech | 215 | 211 | High | 233 | 151 | 232 | 83 | 237 | 76 | 1.10 | 0.72 | 1.10 | 0.39 | 1.12 | 0.36 | Decrease | Large Decrease |
| American chestnut | 7 | 1 | Medium | 2 | 2 | 2 | 0 | 2 | 0 | 2.00 | 2.00 | 2.00 | 0.00 | 2.00 | 0.00 | No Change | Extirpated |
| American elm | 143 | 141 | Medium | 116 | 129 | 100 | 115 | 101 | 120 | 0.82 | 0.92 | 0.71 | 0.82 | 0.72 | 0.85 | Decrease | No Change |
| American hornbeam | 110 | 97 | Medium | 100 | 89 | 99 | 84 | 97 | 87 | 1.03 | 0.92 | 1.02 | 0.87 | 1.00 | 0.90 | Decrease | No Change |
| Bigtooth aspen | 32 | 38 | High | 22 | 2 | 13 | 0 | 6 | 0 | 0.58 | 0.05 | 0.34 | 0.00 | 0.16 | 0.00 | Large Decrease | Extirpated |
| Bitternut hickory | 11 | 5 | Low | 10 | 45 | 8 | 62 | 21 | 74 | 2.00 | 9.00 | 1.60 | 12.40 | 4.20 | 14.80 | Increase | Large Increase |
| Black cherry | 302 | 333 | High | 220 | 121 | 161 | 101 | 154 | 100 | 0.66 | 0.36 | 0.48 | 0.30 | 0.46 | 0.30 | Large Decrease | Large Decrease |
| Black hickory | 0 | 4 | High | 2 | 89 | 3 | 268 | 11 | 302 | 0.50 | 22.25 | 0.75 | 67.00 | 2.75 | 75.50 | New Habitat | New Habitat |
| Black locust | 170 | 142 | Low | 129 | 111 | 118 | 96 | 111 | 82 | 0.91 | 0.78 | 0.83 | 0.68 | 0.78 | 0.58 | Decrease | Decrease |
| Black maple | 7 | 4 | Low | 4 | 1 | 4 | 1 | 2 | 1 | 1.00 | 0.25 | 1.00 | 0.25 | 0.50 | 0.25 | Decrease | Decrease |
| Black oak | 208 | 224 | High | 209 | 337 | 209 | 495 | 213 | 441 | 0.93 | 1.50 | 0.93 | 2.21 | 0.95 | 1.97 | Decrease | Increase |
| Black walnut | 95 | 103 | Medium | 117 | 99 | 110 | 102 | 124 | 83 | 1.14 | 0.96 | 1.07 | 0.99 | 1.20 | 0.81 | Increase | Decrease |
| Black willow | 4 | 0 | Low | 0 | 12 | 0 | 35 | 0 | 42 | NA | New | New | New | New | New | NA | Increase |
| Blackgum | 117 | 137 | High | 141 | 148 | 152 | 151 | 158 | 149 | 1.03 | 1.08 | 1.11 | 1.10 | 1.15 | 1.09 | Decrease | No Change |
| Blackjack oak | 2 | 3 | Medium | 4 | 113 | 4 | 300 | 16 | 356 | 1.33 | 37.67 | 1.33 | 100.00 | 5.33 | 118.67 | Increase | Increase |
| Boxelder | 51 | 57 | Medium | 54 | 60 | 58 | 67 | 60 | 63 | 0.95 | 1.05 | 1.02 | 1.18 | 1.05 | 1.11 | Decrease | No Change |
| Butternut | 12 | 1 | Low | 6 | 0 | 5 | 0 | 3 | 0 | 6.00 | 0.00 | 5.00 | 0.00 | 3.00 | 0.00 | No Change | Extirpated |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 82 | 0 | 150 | NA | NA | NA | New | New | New | NA | New Habitat |
| Chestnut oak | 206 | 235 | High | 238 | 170 | 258 | 114 | 243 | 115 | 1.01 | 0.72 | 1.10 | 0.49 | 1.03 | 0.49 | Decrease | Decrease |
| Chinkapin oak | 5 | 11 | Medium | 18 | 62 | 24 | 64 | 39 | 64 | 1.64 | 5.64 | 2.18 | 5.82 | 3.55 | 5.82 | No Change | Increase |
| Common persimmon | 28 | 23 | Medium | 32 | 76 | 30 | 124 | 33 | 137 | 1.39 | 3.30 | 1.30 | 5.39 | 1.44 | 5.96 | Increase | Large Increase |
| Cucumbertree | 40 | 30 | High | 39 | 34 | 39 | 29 | 39 | 29 | 1.30 | 1.13 | 1.30 | 0.97 | 1.30 | 0.97 | Increase | No Change |
| Eastern hemlock | 12 | 15 | High | 13 | 8 | 15 | 3 | 15 | 4 | 0.87 | 0.53 | 1.00 | 0.20 | 1.00 | 0.27 | Decrease | Large Decrease |
| Eastern hophornbeam | 85 | 84 | Medium | 91 | 92 | 92 | 115 | 92 | 129 | 1.08 | 1.10 | 1.10 | 1.37 | 1.10 | 1.54 | Decrease | Increase |
| Eastern redcedar | 7 | 45 | Medium | 85 | 221 | 101 | 273 | 130 | 298 | 1.89 | 4.91 | 2.24 | 6.07 | 2.89 | 6.62 | Large Increase | Large Increase |
| Eastern redbud | 93 | 94 | Medium | 105 | 119 | 114 | 114 | 112 | 100 | 1.12 | 1.27 | 1.21 | 1.21 | 1.19 | 1.06 | Decrease | No Change |
| Eastern white pine | 14 | 28 | High | 24 | 23 | 29 | 3 | 40 | 1 | 0.86 | 0.82 | 1.04 | 0.11 | 1.43 | 0.04 | Increase | Extirpated |
| Flowering dogwood | 379 | 407 | High | 402 | 391 | 401 | 274 | 403 | 175 | 0.99 | 0.96 | 0.99 | 0.67 | 0.99 | 0.43 | Decrease | Large Decrease |
| Green ash | 23 | 18 | Medium | 24 | 47 | 28 | 75 | 38 | 88 | 1.33 | 2.61 | 1.56 | 4.17 | 2.11 | 4.89 | Large Increase | Large Increase |
| Hackberry | 23 | 14 | Medium | 19 | 36 | 21 | 60 | 22 | 56 | 1.36 | 2.57 | 1.50 | 4.29 | 1.57 | 4.00 | Increase | Large Increase |
| Honeylocust | 4 | 4 | Low | 3 | 14 | 3 | 45 | 5 | 54 | 0.75 | 3.50 | 0.75 | 11.25 | 1.25 | 13.50 | No change | Large Increase |
| Loblolly pine | 2 | 1 | High | 3 | 21 | 17 | 80 | 11 | 169 | 3.00 | 21.00 | 17.00 | 80.00 | 11.00 | 169.00 | Increase | Increase |
| Mockernut hickory | 192 | 211 | High | 203 | 218 | 206 | 229 | 211 | 245 | 0.96 | 1.03 | 0.98 | 1.09 | 1.00 | 1.16 | Decrease | Increase |
| Northern red oak | 218 | 211 | High | 198 | 196 | 194 | 195 | 194 | 207 | 0.94 | 0.93 | 0.92 | 0.92 | 0.92 | 0.98 | Decrease | No Change |
| Ohio buckeye | 3 | 2 | Low | 1 | 0 | 1 | 0 | 1 | 0 | 0.50 | 0.00 | 0.50 | 0.00 | 0.50 | 0.00 | Decrease | Extirpated |
| Osage-orange | 4 | 8 | Medium | 4 | 13 | 5 | 28 | 6 | 54 | 0.50 | 1.63 | 0.63 | 3.50 | 0.75 | 6.75 | No Change | Increase |
| Pawpaw | 60 | 49 | Low | 53 | 48 | 53 | 23 | 53 | 18 | 1.08 | 0.98 | 1.08 | 0.47 | 1.08 | 0.37 | Decrease | Large Decrease |
| Pignut hickory | 191 | 208 | High | 208 | 203 | 207 | 131 | 208 | 119 | 1.00 | 0.98 | 1.00 | 0.63 | 1.00 | 0.57 | Decrease | Decrease |
| Pin cherry | 10 | 2 | Medium | 1 | 0 | 0 | 0 | 0 | 0 | 0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Extirpated | Extirpated |
| Pin oak | 0 | 2 | Medium | 1 | 3 | 1 | 10 | 3 | 15 | 0.50 | 1.50 | 0.50 | 5.00 | 1.50 | 7.50 | New Habitat | New Habitat |
| Pitch pine | 21 | 20 | High | 20 | 11 | 19 | 8 | 16 | 8 | 1.00 | 0.55 | 0.95 | 0.40 | 0.80 | 0.40 | Decrease | Large Decrease |
| Post oak | 20 | 27 | High | 43 | 390 | 42 | 858 | 73 | 1089 | 1.59 | 14.44 | 1.56 | 31.78 | 2.70 | 40.33 | Large Increase | Large Increase |

(continued on next page)

## Table 32 (continued).

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Red maple | 588 | 599 | High | 569 | 360 | 564 | 199 | 546 | 173 | 0.95 | 0.60 | 0.94 | 0.33 | 0.91 | 0.29 | Decrease | Large Decrease |
| Red mulberry | 5 | 4 | Low | 4 | 15 | 4 | 58 | 4 | 63 | 1.00 | 3.75 | 1.00 | 14.50 | 1.00 | 15.75 | No Change | Large Increase |
| Rock elm | 1 | 1 | Low | 3 | 3 | 2 | 10 | 3 | 3 | 3.00 | 3.00 | 2.00 | 10.00 | 3.00 | 3.00 | Large Increase | Large Increase |
| Sassafras | 317 | 305 | High | 315 | 267 | 298 | 175 | 303 | 157 | 1.03 | 0.88 | 0.98 | 0.57 | 0.99 | 0.52 | Decrease | Decrease |
| Scarlet oak | 105 | 121 | High | 127 | 153 | 132 | 60 | 135 | 28 | 1.05 | 1.26 | 1.09 | 0.50 | 1.12 | 0.23 | Decrease | Large Decrease |
| Serviceberry | 32 | 31 | Medium | 32 | 26 | 31 | 28 | 33 | 32 | 1.03 | 0.84 | 1.00 | 0.90 | 1.07 | 1.03 | Decrease | No Change |
| Shagbark hickory | 30 | 46 | Medium | 48 | 65 | 51 | 98 | 57 | 113 | 1.04 | 1.41 | 1.11 | 2.13 | 1.24 | 2.46 | Increase | Large Increase |
| Shortleaf pine | 6 | 13 | High | 21 | 184 | 40 | 459 | 64 | 625 | 1.62 | 14.15 | 3.08 | 35.31 | 4.92 | 48.08 | Large Increase | Large Increase |
| Shumard oak | 0 | 0 | Low | 0 | 3 | 0 | 50 | 0 | 66 | NA | New | NA | New | New | New | NA | New Habitat |
| Silver maple | 9 | 6 | Medium | 3 | 8 | 3 | 12 | 2 | 43 | 0.50 | 1.33 | 0.50 | 2.00 | 0.33 | 7.17 | Large Decrease | Large Increase |
| Slippery elm | 191 | 158 | Medium | 148 | 124 | 128 | 82 | 127 | 67 | 0.94 | 0.79 | 0.81 | 0.52 | 0.80 | 0.42 | Decrease | Large Decrease |
| Sourwood | 75 | 90 | High | 97 | 58 | 121 | 31 | 116 | 13 | 1.08 | 0.64 | 1.34 | 0.34 | 1.29 | 0.14 | Increase | Large Decrease |
| Southern red oak | 4 | 2 | High | 4 | 57 | 19 | 144 | 28 | 204 | 2.00 | 28.50 | 9.50 | 72.00 | 14.00 | 102.00 | Increase | Increase |
| Sugar maple | 563 | 487 | High | 534 | 389 | 516 | 115 | 516 | 46 | 1.10 | 0.80 | 1.06 | 0.24 | 1.06 | 0.09 | Decrease | Large Decrease |
| Sugarberry | 0 | 0 | Medium | 0 | 19 | 1 | 84 | 3 | 120 | NA | New | New | New | New | New | New Habitat | New Habitat |
| Sweet birch | 36 | 38 | High | 41 | 15 | 42 | 5 | 44 | 5 | 1.08 | 0.40 | 1.11 | 0.13 | 1.16 | 0.13 | Decrease | Large Decrease |
| Sweetgum | 2 | 1 | High | 7 | 29 | 19 | 66 | 31 | 91 | 7.00 | 29.00 | 19.00 | 66.00 | 31.00 | 91.00 | Increase | Increase |
| Sycamore | 68 | 66 | Medium | 65 | 66 | 65 | 67 | 66 | 66 | 0.99 | 1.00 | 0.99 | 1.02 | 1.00 | 1.00 | Decrease | No Change |
| Table Mountain pine | 7 | 2 | Medium | 3 | 4 | 2 | 4 | 2 | 4 | 1.50 | 2.00 | 1.00 | 2.00 | 1.00 | 2.00 | No Change | No Change |
| Tulip tree | 454 | 428 | High | 457 | 367 | 462 | 126 | 463 | 100 | 1.07 | 0.86 | 1.08 | 0.29 | 1.08 | 0.23 | Decrease | Large Decrease |
| Virginia pine | 174 | 168 | High | 159 | 149 | 201 | 74 | 202 | 71 | 0.95 | 0.89 | 1.20 | 0.44 | 1.20 | 0.42 | Increase | Large Decrease |
| Water locust | 0 | 0 | Low | 0 | 0 | 0 | 2 | 0 | 16 | NA | NA | NA | New | New | New | NA | New Habitat |
| Water oak | 0 | 0 | High | 0 | 0 | 0 | 31 | 0 | 102 | NA | NA | NA | New | New | New | NA | New Habitat |
| White ash | 341 | 331 | High | 292 | 210 | 270 | 135 | 280 | 129 | 0.88 | 0.63 | 0.82 | 0.41 | 0.85 | 0.39 | Decrease | Large Decrease |
| White oak | 423 | 411 | High | 422 | 596 | 432 | 566 | 452 | 427 | 1.03 | 1.45 | 1.05 | 1.38 | 1.10 | 1.04 | Decrease | No Change |
| Willow oak | 0 | 0 | Medium | 0 | 0 | 0 | 0 | 0 | 9 | NA | NA | NA | NA | New | New | NA | New Habitat |
| Winged elm | 2 | 0 | High | 5 | 127 | 21 | 416 | 33 | 598 | New | New | New | New | New | New | Increase | Increase |
| Yellow buckeye | 77 | 56 | Medium | 64 | 61 | 61 | 57 | 63 | 57 | 1.14 | 1.09 | 1.09 | 1.02 | 1.13 | 1.02 | Decrease | No Change |

[a]Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

## Table 33.—Complete DISTRIB model results for the 73 tree species[a] in Section M221A

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| Common Name | FIA IV | Current IV | Model Reliability | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI | PCM B1 | GFDL A1FI |
| American basswood | 30 | 31 | Medium | 27 | 24 | 21 | 20 | 25 | 21 | 0.87 | 0.77 | 0.68 | 0.65 | 0.81 | 0.68 | Decrease | Decrease |
| American beech | 52 | 63 | High | 61 | 54 | 58 | 63 | 67 | 54 | 0.97 | 0.86 | 0.92 | 1.00 | 1.06 | 0.86 | No Change | No Change |
| American chestnut | 9 | 12 | Medium | 8 | 8 | 8 | 8 | 8 | 8 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | Decrease | Decrease |
| American elm | 15 | 43 | Medium | 26 | 52 | 26 | 76 | 28 | 77 | 0.61 | 1.21 | 0.61 | 1.77 | 0.65 | 1.79 | Decrease | Increase |
| American hornbeam | 10 | 29 | Medium | 14 | 18 | 12 | 31 | 12 | 35 | 0.48 | 0.62 | 0.41 | 1.07 | 0.41 | 1.21 | Large Decrease | Increase |
| Bear oak (scrub oak) | 14 | 7 | Low | 8 | 8 | 7 | 7 | 7 | 8 | 1.14 | 1.14 | 1.00 | 1.00 | 1.00 | 1.14 | No Change | No Change |
| Bigtooth aspen | 8 | 13 | High | 8 | 2 | 2 | 0 | 1 | 0 | 0.62 | 0.15 | 0.15 | 0.00 | 0.08 | 0.00 | Large Decrease | Extirpated |
| Bitternut hickory | 3 | 0 | Low | 2 | 13 | 2 | 35 | 4 | 37 | New | New | New | New | 4.00 | 37.00 | Increase | Increase |
| Black cherry | 168 | 175 | High | 136 | 107 | 101 | 72 | 94 | 73 | 0.78 | 0.61 | 0.58 | 0.41 | 0.54 | 0.42 | Decrease | Large Decrease |
| Black hickory | 0 | 1 | High | 2 | 38 | 5 | 102 | 6 | 124 | 2.00 | 38.00 | 5.00 | 102.00 | 6.00 | 124.00 | New Habitat | New Habitat |
| Black locust | 129 | 114 | Low | 120 | 105 | 111 | 88 | 104 | 67 | 1.05 | 0.92 | 0.97 | 0.77 | 0.91 | 0.59 | No Change | Decrease |
| Black oak | 167 | 148 | High | 156 | 211 | 156 | 289 | 155 | 278 | 1.05 | 1.43 | 1.05 | 1.95 | 1.05 | 1.88 | No Change | Increase |
| Black walnut | 42 | 51 | Medium | 48 | 47 | 49 | 48 | 48 | 40 | 0.94 | 0.92 | 0.96 | 0.94 | 0.94 | 0.78 | No Change | Decrease |
| Black willow | 1 | 1 | Low | 0 | 10 | 0 | 30 | 0 | 30 | 0.00 | 10.00 | 0.00 | 30.00 | 0.00 | 30.00 | NA | Increase |
| Blackgum | 148 | 160 | High | 153 | 150 | 158 | 133 | 159 | 126 | 0.96 | 0.94 | 0.99 | 0.83 | 0.99 | 0.79 | No Change | Decrease |
| Blackjack oak | 6 | 2 | Medium | 6 | 42 | 10 | 121 | 10 | 169 | 3.00 | 21.00 | 5.00 | 60.50 | 5.00 | 84.50 | Increase | Increase |
| Boxelder | 20 | 26 | Medium | 20 | 22 | 17 | 25 | 18 | 28 | 0.77 | 0.85 | 0.65 | 0.96 | 0.69 | 1.08 | Decrease | No Change |
| Butternut | 16 | 4 | Low | 11 | 3 | 4 | 1 | 3 | 0 | 2.75 | 0.75 | 1.00 | 0.25 | 0.75 | 0.00 | Decrease | Extirpated |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 18 | 0 | 68 | NA | NA | NA | New | 0.00 | 68.00 | NA | New Habitat |
| Chestnut oak | 490 | 388 | High | 423 | 348 | 406 | 238 | 377 | 218 | 1.09 | 0.90 | 1.05 | 0.61 | 0.97 | 0.56 | No change | Decrease |
| Chinkapin oak | 14 | 8 | Medium | 9 | 27 | 11 | 36 | 13 | 35 | 1.13 | 3.38 | 1.38 | 4.50 | 1.63 | 4.38 | Increase | Large Increase |
| Chokecherry | 4 | 1 | Low | 3 | 0 | 2 | 0 | 1 | 0 | 3.00 | 0.00 | 2.00 | 0.00 | 1.00 | 0.00 | No Change | Extirpated |
| Common persimmon | 3 | 3 | Medium | 9 | 50 | 15 | 79 | 20 | 103 | 3.00 | 16.67 | 5.00 | 26.33 | 6.67 | 34.33 | Increase | Increase |
| Cucumbertree | 11 | 23 | High | 14 | 18 | 16 | 18 | 14 | 17 | 0.61 | 0.78 | 0.70 | 0.78 | 0.61 | 0.74 | Decrease | Decrease |
| Eastern cottonwood | 1 | 0 | Low | 0 | 1 | 0 | 3 | 0 | 11 | NA | New | NA | New | 0.00 | 11.00 | NA | Increase |
| Eastern hemlock | 27 | 56 | High | 41 | 43 | 38 | 40 | 38 | 39 | 0.73 | 0.77 | 0.68 | 0.71 | 0.68 | 0.70 | Decrease | Decrease |
| Eastern hophornbeam | 33 | 44 | Medium | 37 | 41 | 34 | 62 | 36 | 67 | 0.84 | 0.93 | 0.77 | 1.41 | 0.82 | 1.52 | Decrease | Increase |
| Eastern redcedar | 31 | 40 | Medium | 50 | 127 | 61 | 181 | 70 | 203 | 1.25 | 3.18 | 1.53 | 4.53 | 1.75 | 5.08 | Increase | Large Increase |
| Eastern redbud | 38 | 39 | Medium | 41 | 55 | 41 | 63 | 41 | 56 | 1.05 | 1.41 | 1.05 | 1.62 | 1.05 | 1.44 | No Change | Increase |
| Eastern white pine | 69 | 104 | High | 82 | 66 | 72 | 47 | 67 | 47 | 0.79 | 0.64 | 0.69 | 0.45 | 0.64 | 0.45 | Decrease | Decrease |
| Flowering dogwood | 155 | 162 | High | 160 | 174 | 171 | 164 | 172 | 127 | 0.99 | 1.07 | 1.06 | 1.01 | 1.06 | 0.78 | No Change | Decrease |
| Green ash | 2 | 8 | Medium | 7 | 13 | 6 | 26 | 6 | 40 | 0.88 | 1.63 | 0.75 | 3.25 | 0.75 | 5.00 | Decrease | Large Increase |
| Hackberry | 24 | 18 | Medium | 19 | 26 | 16 | 42 | 17 | 52 | 1.06 | 1.44 | 0.89 | 2.33 | 0.94 | 2.89 | No Change | Large Increase |
| Honeylocust | 0 | 1 | Low | 1 | 2 | 1 | 14 | 0 | 23 | 1.00 | 2.00 | 1.00 | 14.00 | 0.00 | 23.00 | NA | New Habitat |
| Loblolly pine | 1 | 7 | High | 4 | 5 | 8 | 20 | 4 | 52 | 0.57 | 0.71 | 1.14 | 2.86 | 0.57 | 7.43 | Decrease | Large Increase |
| Mockernut hickory | 80 | 92 | High | 89 | 95 | 87 | 100 | 86 | 107 | 0.97 | 1.03 | 0.95 | 1.09 | 0.94 | 1.16 | No Change | Increase |
| Northern red oak | 249 | 222 | High | 213 | 187 | 186 | 148 | 177 | 131 | 0.96 | 0.84 | 0.84 | 0.67 | 0.80 | 0.59 | Decrease | Decrease |
| Osage-orange | 2 | 1 | Medium | 2 | 4 | 2 | 8 | 2 | 15 | 2.00 | 4.00 | 2.00 | 8.00 | 2.00 | 15.00 | No Change | Increase |
| Pawpaw | 4 | 8 | Low | 4 | 5 | 3 | 4 | 3 | 2 | 0.50 | 0.63 | 0.38 | 0.50 | 0.38 | 0.25 | Large Decrease | Large Decrease |
| Pignut hickory | 80 | 98 | High | 91 | 90 | 90 | 78 | 94 | 83 | 0.93 | 0.92 | 0.92 | 0.80 | 0.96 | 0.85 | No Change | Decrease |
| Pin cherry | 7 | 1 | Medium | 2 | 1 | 1 | 1 | 1 | 1 | 2.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | No Change | No Change |
| Pitch pine | 43 | 39 | High | 40 | 37 | 38 | 34 | 36 | 33 | 1.03 | 0.95 | 0.97 | 0.87 | 0.92 | 0.85 | No Change | Decrease |
| Post oak | 0 | 3 | High | 22 | 176 | 39 | 378 | 46 | 505 | 7.33 | 58.67 | 13.00 | 126.00 | 15.33 | 168.33 | New Habitat | New Habitat |

(continued on next page)

## Table 33 (continued).

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Quaking aspen | 6 | 4 | High | 3 | 1 | 3 | 0 | 3 | 0 | 0.75 | 0.25 | 0.75 | 0.00 | 0.75 | 0.00 | Decrease | Extirpated |
| Red maple | 293 | 357 | High | 333 | 272 | 328 | 179 | 324 | 136 | 0.93 | 0.76 | 0.92 | 0.50 | 0.91 | 0.38 | No Change | Large Decrease |
| Red mulberry | 2 | 3 | Low | 2 | 9 | 1 | 32 | 1 | 40 | 0.67 | 3.00 | 0.33 | 10.67 | 0.33 | 13.33 | Decrease | Increase |
| Red spruce | 3 | 3 | High | 2 | 0 | 1 | 0 | 1 | 0 | 0.67 | 0.00 | 0.33 | 0.00 | 0.33 | 0.00 | Decrease | Extirpated |
| Sassafras | 76 | 99 | High | 91 | 109 | 97 | 97 | 107 | 90 | 0.92 | 1.10 | 0.98 | 0.98 | 1.08 | 0.91 | No Change | No Change |
| Scarlet oak | 94 | 114 | High | 110 | 107 | 110 | 83 | 108 | 42 | 0.97 | 0.94 | 0.97 | 0.73 | 0.95 | 0.37 | No Change | Large Decrease |
| Serviceberry | 77 | 63 | Medium | 69 | 55 | 58 | 52 | 52 | 53 | 1.10 | 0.87 | 0.92 | 0.83 | 0.83 | 0.84 | Decrease | Decrease |
| Shagbark hickory | 8 | 14 | Medium | 12 | 27 | 15 | 50 | 17 | 60 | 0.86 | 1.93 | 1.07 | 3.57 | 1.21 | 4.29 | Increase | Large Increase |
| Shortleaf pine | 7 | 6 | High | 7 | 42 | 10 | 126 | 10 | 197 | 1.17 | 7.00 | 1.67 | 21.00 | 1.67 | 32.83 | Increase | Large Increase |
| Shumard oak | 0 | 0 | Low | 0 | 1 | 0 | 19 | 0 | 34 | NA | New | NA | New | 0.00 | 34.00 | NA | New Habitat |
| Silver maple | 24 | 13 | Medium | 14 | 23 | 12 | 46 | 14 | 58 | 1.08 | 1.77 | 0.92 | 3.54 | 1.08 | 4.46 | No Change | Large Increase |
| Slippery elm | 55 | 51 | Medium | 48 | 51 | 38 | 45 | 37 | 41 | 0.94 | 1.00 | 0.75 | 0.88 | 0.73 | 0.80 | Decrease | Decrease |
| Sourwood | 5 | 22 | High | 24 | 15 | 35 | 22 | 32 | 23 | 1.09 | 0.68 | 1.59 | 1.00 | 1.46 | 1.05 | Increase | No Change |
| Southern red oak | 2 | 1 | High | 3 | 15 | 6 | 35 | 5 | 62 | 3.00 | 15.00 | 6.00 | 35.00 | 5.00 | 62.00 | Increase | Increase |
| Striped maple | 44 | 45 | High | 36 | 27 | 26 | 20 | 25 | 21 | 0.80 | 0.60 | 0.58 | 0.44 | 0.56 | 0.47 | Decrease | Decrease |
| Sugar maple | 146 | 173 | High | 151 | 166 | 147 | 121 | 154 | 59 | 0.87 | 0.96 | 0.85 | 0.70 | 0.89 | 0.34 | No Change | Large Decrease |
| Sugarberry | 0 | 0 | Medium | 0 | 12 | 3 | 52 | 4 | 78 | NA | New | New | New | 4.00 | 78.00 | New Habitat | New Habitat |
| Sweet birch | 90 | 98 | High | 83 | 62 | 74 | 47 | 75 | 46 | 0.85 | 0.63 | 0.76 | 0.48 | 0.77 | 0.47 | Decrease | Decrease |
| Sweetgum | 0 | 4 | High | 3 | 10 | 6 | 13 | 9 | 37 | 0.75 | 2.50 | 1.50 | 3.25 | 2.25 | 9.25 | New Habitat | New Habitat |
| Sycamore | 24 | 23 | Medium | 22 | 30 | 20 | 39 | 24 | 40 | 0.96 | 1.30 | 0.87 | 1.70 | 1.04 | 1.74 | No Change | Increase |
| Table Mountain pine | 21 | 20 | Medium | 20 | 25 | 20 | 27 | 18 | 30 | 1.00 | 1.25 | 1.00 | 1.35 | 0.90 | 1.50 | No Change | Increase |
| Tulip tree | 69 | 119 | High | 97 | 102 | 120 | 79 | 134 | 64 | 0.82 | 0.86 | 1.01 | 0.66 | 1.13 | 0.54 | No Change | Decrease |
| Virginia pine | 133 | 109 | High | 129 | 102 | 129 | 86 | 116 | 85 | 1.18 | 0.94 | 1.18 | 0.79 | 1.06 | 0.78 | No Change | Decrease |
| Water locust | 0 | 0 | Low | 0 | 0 | 0 | 2 | 0 | 9 | NA | NA | NA | New | 0.00 | 9.00 | NA | New Habitat |
| Water oak | 0 | 0 | High | 0 | 0 | 0 | 7 | 0 | 46 | NA | NA | NA | New | 0.00 | 46.00 | NA | New Habitat |
| White ash | 102 | 146 | High | 108 | 114 | 94 | 88 | 97 | 80 | 0.74 | 0.78 | 0.64 | 0.60 | 0.66 | 0.55 | Decrease | Decrease |
| White oak | 254 | 254 | High | 265 | 304 | 260 | 300 | 254 | 244 | 1.04 | 1.20 | 1.02 | 1.18 | 1.00 | 0.96 | No Change | No Change |
| Winged elm | 0 | 0 | High | 4 | 44 | 9 | 146 | 14 | 242 | New | New | New | New | 14.00 | 242.00 | New Habitat | New Habitat |
| Yellow birch | 8 | 7 | High | 7 | 4 | 6 | 4 | 6 | 4 | 1.00 | 0.57 | 0.86 | 0.57 | 0.86 | 0.57 | No Change | Decrease |
| Yellow buckeye | 1 | 5 | Medium | 1 | 3 | 2 | 4 | 1 | 4 | 0.20 | 0.60 | 0.40 | 0.80 | 0.20 | 0.80 | Large Decrease | Decrease |

[a] Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

## Table 34.—Complete DISTRIB model results for the 74 tree species[a] in Section M221B

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class 2070-2099 | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| American basswood | 69 | 60 | Medium | 58 | 53 | 53 | 41 | 55 | 30 | 0.97 | 0.88 | 0.88 | 0.68 | 0.92 | 0.50 | No Change | Decrease |
| American beech | 383 | 362 | High | 342 | 231 | 340 | 202 | 306 | 168 | 0.95 | 0.64 | 0.94 | 0.56 | 0.85 | 0.46 | Decrease | Decrease |
| American chestnut | 39 | 32 | Medium | 37 | 37 | 34 | 37 | 35 | 36 | 1.16 | 1.16 | 1.06 | 1.16 | 1.09 | 1.13 | No Change | No Change |
| American elm | 14 | 27 | Medium | 24 | 29 | 24 | 56 | 22 | 78 | 0.89 | 1.07 | 0.89 | 2.07 | 0.82 | 2.89 | Decrease | Large Increase |
| American holly | 5 | 1 | High | 3 | 2 | 2 | 1 | 2 | 1 | 3.00 | 2.00 | 2.00 | 1.00 | 2.00 | 1.00 | No Change | No Change |
| American hornbeam | 35 | 45 | Medium | 33 | 38 | 34 | 50 | 34 | 53 | 0.73 | 0.84 | 0.76 | 1.11 | 0.76 | 1.18 | Decrease | Increase |
| Balsam fir | 3 | 7 | High | 7 | 1 | 7 | 1 | 3 | 1 | 1.00 | 0.14 | 1.00 | 0.14 | 0.43 | 0.14 | Large Decrease | Large Decrease |
| Bear oak (scrub oak) | 2 | 8 | Low | 2 | 3 | 1 | 5 | 3 | 4 | 0.25 | 0.38 | 0.13 | 0.63 | 0.38 | 0.50 | Large Decrease | Decrease |
| Bigtooth aspen | 17 | 22 | High | 16 | 17 | 10 | 4 | 13 | 0 | 0.73 | 0.77 | 0.46 | 0.18 | 0.59 | 0.00 | Decrease | Extirpated |
| Bitternut hickory | 5 | 2 | Low | 2 | 6 | 3 | 33 | 3 | 53 | 1.00 | 3.00 | 1.50 | 16.50 | 1.50 | 26.50 | No Change | Increase |
| Black cherry | 323 | 339 | High | 288 | 275 | 268 | 159 | 269 | 110 | 0.85 | 0.81 | 0.79 | 0.47 | 0.79 | 0.32 | Decrease | Large Decrease |
| Black hickory | 0 | 2 | High | 1 | 2 | 1 | 63 | 1 | 143 | 0.50 | 1.00 | 0.50 | 31.50 | 0.50 | 71.50 | Decrease | Increase |
| Black locust | 161 | 162 | Low | 165 | 161 | 161 | 145 | 154 | 121 | 1.02 | 0.99 | 0.99 | 0.90 | 0.95 | 0.75 | No Change | Decrease |
| Black oak | 100 | 115 | High | 115 | 161 | 121 | 243 | 124 | 305 | 1.00 | 1.40 | 1.05 | 2.11 | 1.08 | 2.65 | No Change | Large Increase |
| Black walnut | 28 | 31 | Medium | 30 | 50 | 35 | 57 | 39 | 63 | 0.97 | 1.61 | 1.13 | 1.84 | 1.26 | 2.03 | Increase | Increase |
| Black willow | 2 | 1 | Low | 1 | 1 | 1 | 4 | 1 | 12 | 1.00 | 1.00 | 1.00 | 4.00 | 1.00 | 12.00 | No Change | Increase |
| Blackgum | 108 | 160 | High | 153 | 180 | 164 | 211 | 171 | 221 | 0.96 | 1.13 | 1.03 | 1.32 | 1.07 | 1.38 | No Change | Increase |
| Blackjack oak | 0 | 0 | Medium | 0 | 3 | 0 | 60 | 0 | 133 | NA | New | NA | New | NA | New | NA | New Habitat |
| Boxelder | 10 | 14 | Medium | 5 | 9 | 8 | 10 | 7 | 16 | 0.36 | 0.64 | 0.57 | 0.71 | 0.50 | 1.14 | Decrease | No Change |
| Butternut | 12 | 3 | Low | 10 | 6 | 9 | 3 | 7 | 0 | 3.33 | 2.00 | 3.00 | 1.00 | 2.33 | 0.00 | No Change | Extirpated |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 0 | 0 | 17 | NA | NA | NA | NA | NA | New | NA | New Habitat |
| Chestnut oak | 339 | 384 | High | 378 | 405 | 375 | 340 | 378 | 274 | 0.98 | 1.06 | 0.98 | 0.89 | 0.98 | 0.71 | No Change | Decrease |
| Chinkapin oak | 2 | 0 | Medium | 2 | 9 | 2 | 31 | 1 | 46 | New | New | New | New | New | New | No Change | Increase |
| Chokecherry | 6 | 10 | Low | 5 | 4 | 5 | 0 | 7 | 0 | 0.50 | 0.40 | 0.50 | 0.00 | 0.70 | 0.00 | Decrease | Extirpated |
| Common persimmon | 0 | 0 | Medium | 3 | 15 | 5 | 85 | 8 | 147 | New | New | New | New | New | New | New Habitat | New Habitat |
| Cucumbertree | 60 | 54 | High | 54 | 55 | 54 | 50 | 57 | 49 | 1.00 | 1.02 | 1.00 | 0.93 | 1.06 | 0.91 | No Change | No Change |
| Eastern hemlock | 110 | 152 | High | 129 | 129 | 131 | 106 | 133 | 93 | 0.85 | 0.85 | 0.86 | 0.70 | 0.88 | 0.61 | No Change | Decrease |
| Eastern hophornbeam | 58 | 62 | Medium | 62 | 61 | 58 | 74 | 58 | 92 | 1.00 | 0.98 | 0.94 | 1.19 | 0.94 | 1.48 | No Change | Increase |
| Eastern redcedar | 8 | 11 | Medium | 10 | 82 | 13 | 239 | 18 | 290 | 0.91 | 7.46 | 1.18 | 21.73 | 1.64 | 26.36 | Increase | Large Increase |
| Eastern redbud | 10 | 11 | Medium | 12 | 31 | 16 | 59 | 19 | 63 | 1.09 | 2.82 | 1.46 | 5.36 | 1.73 | 5.73 | Increase | Large Increase |
| Eastern white pine | 86 | 121 | High | 102 | 120 | 107 | 128 | 103 | 110 | 0.84 | 0.99 | 0.88 | 1.06 | 0.85 | 0.91 | No Change | No Change |
| Flowering dogwood | 132 | 166 | High | 172 | 227 | 190 | 278 | 197 | 271 | 1.04 | 1.37 | 1.15 | 1.68 | 1.19 | 1.63 | Increase | Increase |
| Green ash | 13 | 15 | Medium | 8 | 14 | 8 | 20 | 8 | 32 | 0.53 | 0.93 | 0.53 | 1.33 | 0.53 | 2.13 | Decrease | Large Increase |
| Hackberry | 3 | 1 | Medium | 1 | 1 | 1 | 13 | 1 | 30 | 1.00 | 1.00 | 1.00 | 13.00 | 1.00 | 30.00 | No Change | Increase |
| Honeylocust | 9 | 1 | Low | 4 | 6 | 3 | 14 | 3 | 23 | 4.00 | 6.00 | 3.00 | 14.00 | 3.00 | 23.00 | No Change | Increase |
| Loblolly pine | 0 | 4 | High | 0 | 1 | 4 | 23 | 5 | 80 | 0.00 | 0.25 | 1.00 | 5.75 | 1.25 | 20.00 | No Change | Increase |
| Mockernut hickory | 83 | 92 | High | 87 | 101 | 91 | 137 | 92 | 157 | 0.95 | 1.10 | 0.99 | 1.49 | 1.00 | 1.71 | No Change | Increase |
| Northern red oak | 312 | 303 | High | 297 | 267 | 283 | 249 | 274 | 234 | 0.98 | 0.88 | 0.93 | 0.82 | 0.90 | 0.77 | No Change | Decrease |
| Ohio buckeye | 6 | 4 | Low | 4 | 4 | 4 | 2 | 5 | 0 | 1.00 | 1.00 | 1.00 | 0.50 | 1.25 | 0.00 | No Change | Extirpated |
| Pawpaw | 5 | 2 | Low | 3 | 3 | 3 | 0 | 3 | 0 | 1.50 | 1.50 | 1.50 | 0.00 | 1.50 | 0.00 | No Change | Extirpated |
| Pignut hickory | 83 | 94 | High | 83 | 99 | 88 | 109 | 90 | 104 | 0.88 | 1.05 | 0.94 | 1.16 | 0.96 | 1.11 | No Change | No Change |
| Pin cherry | 11 | 8 | Medium | 6 | 0 | 3 | 0 | 2 | 0 | 0.75 | 0.00 | 0.38 | 0.00 | 0.25 | 0.00 | Large Decrease | Extirpated |
| Pitch pine | 24 | 36 | High | 29 | 42 | 31 | 44 | 32 | 47 | 0.81 | 1.17 | 0.86 | 1.22 | 0.89 | 1.31 | No Change | Increase |

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**Table 34 (continued).**

|  |  |  |  | DISTRIB results |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Modeled IV |  |  |  |  |  | Future : Current Suitable Habitat |  |  |  |  |  | Change Class |
|  |  |  | DISTRIB | 2010-2039 |  | 2040-2069 |  | 2070-2099 |  | 2010-2039 |  | 2040-2069 |  | 2070-2099 |  | 2070-2099 |  |
|  | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Post oak | 3 | 0 | High | 4 | 27 | 6 | 211 | 8 | 437 | New | New | New | New | New | New | Increase | Increase |
| Quaking aspen | 2 | 17 | High | 7 | 4 | 5 | 1 | 4 | 0 | 0.41 | 0.24 | 0.29 | 0.06 | 0.24 | 0.00 | Large Decrease | Extirpated |
| Red maple | 645 | 686 | High | 663 | 640 | 657 | 497 | 660 | 348 | 0.97 | 0.93 | 0.96 | 0.72 | 0.96 | 0.51 | No Change | Decrease |
| Red mulberry | 0 | 0 | Low | 0 | 3 | 0 | 29 | 1 | 44 | NA | New | NA | New | New | New | New Habitat | New Habitat |
| Red pine | 15 | 9 | Medium | 10 | 7 | 10 | 0 | 8 | 0 | 1.11 | 0.78 | 1.11 | 0.00 | 0.89 | 0.00 | No Change | Extirpated |
| Red spruce | 64 | 35 | High | 38 | 20 | 32 | 15 | 33 | 14 | 1.09 | 0.57 | 0.91 | 0.43 | 0.94 | 0.40 | No Change | Large Decrease |
| Sassafras | 121 | 137 | High | 128 | 156 | 131 | 154 | 132 | 140 | 0.93 | 1.14 | 0.96 | 1.12 | 0.96 | 1.02 | No Change | No Change |
| Scarlet oak | 103 | 126 | High | 132 | 140 | 138 | 155 | 137 | 126 | 1.05 | 1.11 | 1.10 | 1.23 | 1.09 | 1.00 | No Change | No Change |
| Serviceberry | 101 | 88 | Medium | 91 | 82 | 89 | 71 | 86 | 71 | 1.03 | 0.93 | 1.01 | 0.81 | 0.98 | 0.81 | No Change | Decrease |
| Shagbark hickory | 17 | 12 | Medium | 13 | 20 | 13 | 51 | 15 | 79 | 1.08 | 1.67 | 1.08 | 4.25 | 1.25 | 6.58 | Increase | Large Increase |
| Shortleaf pine | 4 | 6 | High | 8 | 21 | 9 | 120 | 10 | 264 | 1.33 | 3.50 | 1.50 | 20.00 | 1.67 | 44.00 | Increase | Large Increase |
| Shumard oak | 0 | 0 | Low | 0 | 0 | 0 | 2 | 0 | 19 | NA | NA | NA | New | NA | New | NA | New Habitat |
| Silver maple | 1 | 1 | Medium | 0 | 1 | 1 | 7 | 0 | 14 | 0.00 | 1.00 | 1.00 | 7.00 | 0.00 | 14.00 | Extirpated | Increase |
| Slippery elm | 25 | 26 | Medium | 25 | 42 | 26 | 65 | 29 | 72 | 0.96 | 1.62 | 1.00 | 2.50 | 1.12 | 2.77 | No Change | Large Increase |
| Sourwood | 64 | 87 | High | 84 | 96 | 102 | 81 | 107 | 72 | 0.97 | 1.10 | 1.17 | 0.93 | 1.23 | 0.83 | Increase | Decrease |
| Southern red oak | 2 | 0 | High | 0 | 4 | 1 | 32 | 0 | 79 | NA | New | New | New | NA | New | Extirpated | Increase |
| Striped maple | 154 | 138 | High | 129 | 92 | 119 | 60 | 114 | 50 | 0.94 | 0.67 | 0.86 | 0.44 | 0.83 | 0.36 | Decrease | Large Decrease |
| Sugar maple | 483 | 452 | High | 447 | 356 | 433 | 318 | 415 | 230 | 0.99 | 0.79 | 0.96 | 0.70 | 0.92 | 0.51 | No Change | Decrease |
| Sugarberry | 1 | 0 | Medium | 0 | 0 | 0 | 15 | 0 | 34 | NA | NA | NA | New | NA | New | Extirpated | Increase |
| Sweet birch | 193 | 196 | High | 200 | 183 | 196 | 139 | 196 | 104 | 1.02 | 0.93 | 1.00 | 0.71 | 1.00 | 0.53 | No Change | Decrease |
| Sweetgum | 0 | 0 | High | 0 | 3 | 0 | 42 | 1 | 85 | NA | New | NA | New | New | New | New Habitat | New Habitat |
| Sycamore | 15 | 12 | Medium | 16 | 28 | 18 | 45 | 18 | 51 | 1.33 | 2.33 | 1.50 | 3.75 | 1.50 | 4.25 | Increase | Large Increase |
| Table Mountain pine | 5 | 15 | Medium | 10 | 11 | 12 | 16 | 11 | 21 | 0.67 | 0.73 | 0.80 | 1.07 | 0.73 | 1.40 | Decrease | Increase |
| Tulip tree | 204 | 232 | High | 246 | 278 | 275 | 270 | 297 | 195 | 1.06 | 1.20 | 1.19 | 1.16 | 1.28 | 0.84 | Increase | Decrease |
| Virginia pine | 38 | 63 | High | 60 | 95 | 68 | 128 | 71 | 126 | 0.95 | 1.51 | 1.08 | 2.03 | 1.13 | 2.00 | No Change | Increase |
| Water oak | 0 | 0 | High | 0 | 0 | 0 | 3 | 0 | 17 | NA | NA | NA | New | NA | New | NA | New Habitat |
| White ash | 125 | 141 | High | 123 | 143 | 109 | 129 | 109 | 113 | 0.87 | 1.01 | 0.77 | 0.92 | 0.77 | 0.80 | Decrease | Decrease |
| White oak | 221 | 214 | High | 226 | 280 | 228 | 398 | 239 | 424 | 1.06 | 1.31 | 1.07 | 1.86 | 1.12 | 1.98 | No Change | Increase |
| Winged elm | 0 | 0 | High | 0 | 7 | 0 | 93 | 0 | 207 | NA | New | NA | New | NA | New | NA | New Habitat |
| Yellow birch | 102 | 99 | High | 80 | 41 | 80 | 23 | 79 | 20 | 0.81 | 0.41 | 0.81 | 0.23 | 0.80 | 0.20 | Decrease | Large Decrease |
| Yellow buckeye | 23 | 21 | Medium | 23 | 25 | 25 | 28 | 25 | 27 | 1.10 | 1.19 | 1.19 | 1.33 | 1.19 | 1.29 | Increase | Increase |

[a]Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

## Table 35.—Complete DISTRIB model results for the 62 tree species[a] in Section M221C

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class 2070-2099 | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| American basswood | 81 | 52 | Medium | 66 | 43 | 60 | 28 | 59 | 31 | 1.27 | 0.83 | 1.15 | 0.54 | 1.14 | 0.60 | No Change | Decrease |
| American beech | 227 | 222 | High | 215 | 188 | 213 | 137 | 214 | 118 | 0.97 | 0.85 | 0.96 | 0.62 | 0.96 | 0.53 | No Change | Decrease |
| American chestnut | 19 | 11 | Medium | 17 | 15 | 16 | 10 | 14 | 10 | 1.55 | 1.36 | 1.46 | 0.91 | 1.27 | 0.91 | Increase | No Change |
| American elm | 20 | 16 | Medium | 19 | 22 | 18 | 32 | 18 | 46 | 1.19 | 1.38 | 1.13 | 2.00 | 1.13 | 2.88 | No Change | Large Increase |
| American hornbeam | 39 | 40 | Medium | 37 | 41 | 37 | 42 | 38 | 41 | 0.93 | 1.03 | 0.93 | 1.05 | 0.95 | 1.03 | No Change | No Change |
| Bitternut hickory | 5 | 0 | Low | 5 | 11 | 4 | 35 | 5 | 37 | New | New | New | New | New | New | No Change | Large Increase |
| Black cherry | 56 | 91 | High | 63 | 48 | 54 | 43 | 52 | 59 | 0.69 | 0.53 | 0.59 | 0.47 | 0.57 | 0.65 | Decrease | Decrease |
| Black hickory | 0 | 0 | High | 0 | 29 | 0 | 116 | 0 | 151 | NA | New | NA | New | New | New | NA | New Habitat |
| Black locust | 83 | 94 | Low | 90 | 93 | 93 | 75 | 96 | 70 | 0.96 | 0.99 | 0.99 | 0.80 | 1.02 | 0.75 | No Change | Decrease |
| Black oak | 118 | 118 | High | 107 | 157 | 106 | 219 | 110 | 235 | 0.91 | 1.33 | 0.90 | 1.86 | 0.93 | 1.99 | No Change | Increase |
| Black walnut | 22 | 27 | Medium | 27 | 35 | 27 | 50 | 28 | 67 | 1.00 | 1.30 | 1.00 | 1.85 | 1.04 | 2.48 | No Change | Large Increase |
| Blackgum | 103 | 126 | High | 125 | 135 | 124 | 140 | 128 | 134 | 0.99 | 1.07 | 0.98 | 1.11 | 1.02 | 1.06 | No Change | No Change |
| Blackjack oak | 0 | 1 | Medium | 1 | 21 | 0 | 109 | 0 | 175 | 1.00 | 21.00 | 0.00 | 109.00 | 0.00 | 175.00 | NA | New Habitat |
| Butternut | 11 | 1 | Low | 7 | 0 | 5 | 0 | 5 | 0 | 7.00 | 0.00 | 5.00 | 0.00 | 5.00 | 0.00 | Increase | Extirpated |
| Cedar elm | 0 | 0 | Low | 0 | 0 | 0 | 21 | 0 | 72 | NA | NA | NA | New | New | New | NA | New Habitat |
| Chestnut oak | 238 | 261 | High | 243 | 231 | 248 | 161 | 241 | 156 | 0.93 | 0.89 | 0.95 | 0.62 | 0.92 | 0.60 | No Change | Decrease |
| Chinkapin oak | 5 | 2 | Medium | 2 | 14 | 2 | 32 | 3 | 37 | 1.00 | 7.00 | 1.00 | 16.00 | 1.50 | 18.50 | No Change | Increase |
| Common persimmon | 6 | 2 | Medium | 6 | 26 | 3 | 73 | 5 | 95 | 3.00 | 13.00 | 1.50 | 36.50 | 2.50 | 47.50 | No Change | Increase |
| Cucumbertree | 68 | 55 | High | 58 | 53 | 55 | 47 | 56 | 44 | 1.06 | 0.96 | 1.00 | 0.86 | 1.02 | 0.80 | No Change | Decrease |
| Eastern hemlock | 72 | 62 | High | 72 | 60 | 71 | 49 | 70 | 48 | 1.16 | 0.97 | 1.15 | 0.79 | 1.13 | 0.77 | No Change | Decrease |
| Eastern hophornbeam | 40 | 37 | Medium | 38 | 41 | 37 | 60 | 38 | 75 | 1.03 | 1.11 | 1.00 | 1.62 | 1.03 | 2.03 | No Change | Increase |
| Eastern redcedar | 2 | 4 | Medium | 6 | 45 | 8 | 101 | 12 | 141 | 1.50 | 11.25 | 2.00 | 25.25 | 3.00 | 35.25 | Large Increase | Large Increase |
| Eastern redbud | 29 | 32 | Medium | 34 | 47 | 38 | 52 | 38 | 69 | 1.06 | 1.47 | 1.19 | 1.63 | 1.19 | 2.16 | Increase | Large Increase |
| Eastern white pine | 18 | 35 | High | 34 | 42 | 43 | 30 | 47 | 30 | 0.97 | 1.20 | 1.23 | 0.86 | 1.34 | 0.86 | Increase | No Change |
| Flowering dogwood | 207 | 193 | High | 204 | 220 | 209 | 209 | 202 | 154 | 1.06 | 1.14 | 1.08 | 1.08 | 1.05 | 0.80 | No Change | Decrease |
| Green ash | 7 | 6 | Medium | 6 | 7 | 6 | 12 | 7 | 25 | 1.00 | 1.17 | 1.00 | 2.00 | 1.17 | 4.17 | Increase | Large Increase |
| Hackberry | 0 | 0 | Medium | 0 | 2 | 0 | 11 | 1 | 28 | NA | New | NA | New | New | New | NA | New Habitat |
| Loblolly pine | 0 | 2 | High | 2 | 14 | 7 | 66 | 8 | 139 | 1.00 | 7.00 | 3.50 | 33.00 | 4.00 | 69.50 | New Habitat | New Habitat |
| Mockernut hickory | 84 | 103 | High | 91 | 101 | 93 | 111 | 94 | 137 | 0.88 | 0.98 | 0.90 | 1.08 | 0.91 | 1.33 | No Change | Increase |
| Mountain maple | 12 | 3 | High | 8 | 10 | 8 | 10 | 8 | 10 | 2.67 | 3.33 | 2.67 | 3.33 | 2.67 | 3.33 | No Change | No Change |
| Northern red oak | 154 | 156 | High | 149 | 139 | 139 | 166 | 139 | 155 | 0.96 | 0.89 | 0.89 | 1.06 | 0.89 | 0.99 | No Change | No Change |
| Pawpaw | 42 | 23 | Low | 26 | 20 | 26 | 9 | 21 | 8 | 1.13 | 0.87 | 1.13 | 0.39 | 0.91 | 0.35 | No Change | Large Decrease |
| Pignut hickory | 85 | 104 | High | 89 | 91 | 88 | 69 | 87 | 71 | 0.86 | 0.88 | 0.85 | 0.66 | 0.84 | 0.68 | Decrease | Decrease |
| Pitch pine | 13 | 18 | High | 12 | 17 | 11 | 13 | 10 | 20 | 0.67 | 0.94 | 0.61 | 0.72 | 0.56 | 1.11 | Decrease | No Change |
| Post oak | 2 | 6 | High | 6 | 78 | 9 | 305 | 14 | 507 | 1.00 | 13.00 | 1.50 | 50.83 | 2.33 | 84.50 | No Change | Increase |
| Red maple | 417 | 448 | High | 427 | 360 | 425 | 236 | 427 | 168 | 0.95 | 0.80 | 0.95 | 0.53 | 0.95 | 0.38 | No Change | Large Decrease |
| Red mulberry | 5 | 2 | Low | 3 | 6 | 3 | 17 | 4 | 35 | 1.50 | 3.00 | 1.50 | 8.50 | 2.00 | 17.50 | No Change | Increase |
| River birch | 5 | 1 | Low | 3 | 2 | 2 | 2 | 2 | 3 | 3.00 | 2.00 | 2.00 | 2.00 | 2.00 | 3.00 | Increase | Large Increase |
| Sassafras | 210 | 177 | High | 180 | 159 | 166 | 106 | 169 | 93 | 1.02 | 0.90 | 0.94 | 0.60 | 0.96 | 0.53 | No Change | Decrease |
| Scarlet oak | 88 | 83 | High | 82 | 96 | 85 | 68 | 82 | 38 | 0.99 | 1.16 | 1.02 | 0.82 | 0.99 | 0.46 | No Change | Decrease |
| Serviceberry | 30 | 42 | Medium | 35 | 38 | 35 | 38 | 36 | 38 | 0.83 | 0.91 | 0.83 | 0.91 | 0.86 | 0.91 | No Change | No Change |
| Shagbark hickory | 10 | 5 | Medium | 9 | 24 | 9 | 62 | 10 | 82 | 1.80 | 4.80 | 1.80 | 12.40 | 2.00 | 16.40 | Increase | Large Increase |
| Shortleaf pine | 7 | 11 | High | 15 | 67 | 19 | 250 | 21 | 342 | 1.36 | 6.09 | 1.73 | 22.73 | 1.91 | 31.09 | Increase | Large Increase |

(continued on next page)

**Table 35 (continued).**

| | | | | DISTRIB results | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modeled IV | | | | | | Future : Current Suitable Habitat | | | | | | Change Class | |
| | | | DISTRIB | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2010-2039 | | 2040-2069 | | 2070-2099 | | 2070-2099 | |
| | FIA | Current | Model | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL | PCM | GFDL |
| Common Name | IV | IV | Reliability | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI | B1 | A1FI |
| Shumard oak | 1 | 0 | Low | 0 | 0 | 0 | 14 | 0 | 35 | NA | NA | NA | New | New | New | NA | Increase |
| Slippery elm | 35 | 24 | Medium | 34 | 31 | 31 | 35 | 34 | 37 | 1.42 | 1.29 | 1.29 | 1.46 | 1.42 | 1.54 | Increase | Increase |
| Sourwood | 94 | 100 | High | 102 | 113 | 119 | 98 | 119 | 71 | 1.02 | 1.13 | 1.19 | 0.98 | 1.19 | 0.71 | Increase | Decrease |
| Southern red oak | 2 | 1 | High | 2 | 22 | 6 | 65 | 9 | 93 | 2.00 | 22.00 | 6.00 | 65.00 | 9.00 | 93.00 | Increase | Increase |
| Striped maple | 38 | 32 | High | 31 | 18 | 27 | 18 | 24 | 19 | 0.97 | 0.56 | 0.84 | 0.56 | 0.75 | 0.59 | Decrease | Decrease |
| Sugar maple | 355 | 288 | High | 331 | 249 | 313 | 129 | 316 | 53 | 1.15 | 0.87 | 1.09 | 0.45 | 1.10 | 0.18 | No Change | Large Decrease |
| Sugarberry | 0 | 0 | Medium | 0 | 1 | 0 | 27 | 0 | 43 | NA | New | NA | New | New | New | NA | New Habitat |
| Sweet birch | 101 | 100 | High | 99 | 75 | 95 | 48 | 89 | 44 | 0.99 | 0.75 | 0.95 | 0.48 | 0.89 | 0.44 | No Change | Large Decrease |
| Sweetgum | 3 | 2 | High | 8 | 28 | 11 | 69 | 16 | 82 | 4.00 | 14.00 | 5.50 | 34.50 | 8.00 | 41.00 | Increase | Increase |
| Sycamore | 17 | 15 | Medium | 16 | 24 | 16 | 30 | 18 | 39 | 1.07 | 1.60 | 1.07 | 2.00 | 1.20 | 2.60 | Increase | Large Increase |
| Tulip tree | 361 | 323 | High | 356 | 340 | 357 | 186 | 357 | 95 | 1.10 | 1.05 | 1.11 | 0.58 | 1.11 | 0.29 | No Change | Large Decrease |
| Virginia pine | 14 | 42 | High | 40 | 79 | 60 | 93 | 68 | 87 | 0.95 | 1.88 | 1.43 | 2.21 | 1.62 | 2.07 | Increase | Large Increase |
| Water locust | 0 | 0 | Low | 0 | 0 | 0 | 1 | 0 | 9 | NA | NA | NA | New | New | New | NA | New Habitat |
| Water oak | 0 | 0 | High | 0 | 0 | 0 | 21 | 0 | 57 | NA | NA | NA | New | New | New | NA | New Habitat |
| White ash | 70 | 68 | High | 64 | 66 | 61 | 66 | 61 | 75 | 0.94 | 0.97 | 0.90 | 0.97 | 0.90 | 1.10 | No Change | No Change |
| White oak | 145 | 160 | High | 158 | 205 | 163 | 262 | 176 | 230 | 0.99 | 1.28 | 1.02 | 1.64 | 1.10 | 1.44 | No Change | Increase |
| Winged elm | 0 | 1 | High | 1 | 35 | 5 | 153 | 7 | 235 | 1.00 | 35.00 | 5.00 | 153.00 | 7.00 | 235.00 | New Habitat | New Habitat |
| Yellow birch | 26 | 17 | High | 19 | 7 | 16 | 6 | 16 | 5 | 1.12 | 0.41 | 0.94 | 0.35 | 0.94 | 0.29 | No Change | Large Decrease |
| Yellow buckeye | 31 | 29 | Medium | 33 | 34 | 33 | 33 | 34 | 33 | 1.14 | 1.17 | 1.14 | 1.14 | 1.17 | 1.14 | Increase | No Change |

[a] Current importance values (Current IV) are based on results from the DISTRIB model. Early-, mid-, and late-century importance values are average values for the indicated years. Change classes are provided for the end of century (2070 through 2099) period. Explanations for the change classes are described in the text. Future:Current Suitable Habitat is a ratio of projected importance value to current importance value.

**Table 36.—Comparison of change classes for two climate scenarios from the DISTRIB model results for all tree species in six ecological sections of the assessment area**[a]

| | Ecological section within the assessment area boundaries | | | | | |
|---|---|---|---|---|---|---|
| | 221F | | 221E OH | | 221E WV | |
| **Common Name** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** |
| American basswood | Decrease | Large Decrease | No Change | Large Decrease | Decrease | Large Decrease |
| American beech | No Change | Large Decrease | No Change | Large Decrease | Decrease | Large Decrease |
| American chestnut | - | - | - | - | No Change | **Extirpated** |
| American elm | No Change | Decrease | Decrease | Decrease | Decrease | No Change |
| American holly | - | - | - | - | - | - |
| American hornbeam | No Change | No Change | No Change | Increase | Decrease | No Change |
| Balsam fir | - | - | - | - | - | - |
| Bear oak (scrub oak) | - | - | - | - | - | - |
| Bigtooth aspen | Decrease | **Extirpated** | Large Decrease | **Extirpated** | Large Decrease | **Extirpated** |
| Bitternut hickory | Large Increase | Large Increase | Increase | Large Increase | Increase | Large Increase |
| Black ash | Large Decrease | Large Decrease | - | - | - | - |
| Black cherry | Decrease | Large Decrease | Decrease | Large Decrease | Large Decrease | Large Decrease |
| Black hickory | NA | New | New | New | New | New |
| Black locust | Increase | No Change | Decrease | Decrease | Decrease | Decrease |
| Black maple | No Change | Large Decrease | No Change | Large Decrease | Decrease | Decrease |
| Black oak | Increase | Large Increase | Increase | Large Increase | Decrease | Increase |
| Black walnut | Increase | Increase | No Change | Decrease | Increase | Decrease |
| Black willow | No Change | Increase | Large Decrease | Large Increase | NA | Increase |
| Blackgum | Increase | No Change | Increase | No Change | Decrease | No Change |
| Blackjack oak | New | New | Increase | Increase | Increase | Increase |
| Boxelder | No Change | Increase | Decrease | Increase | Decrease | No Change |
| Bur oak | Increase | Large Increase | Large Decrease | Large Increase | - | - |
| Butternut | - | - | - | - | No Change | **Extirpated** |
| Cedar elm | NA | New | NA | New | NA | New |
| Chestnut oak | New | Large Decrease | Increase | Decrease | Decrease | Decrease |
| Chinkapin oak | New | New | Large Increase | Large Increase | No Change | Increase |
| Chokecherry | - | - | - | - | - | - |
| Common persimmon | New | New | Increase | Large Increase | Increase | Large Increase |
| Cucumbertree | Large Increase | No Change | Large Increase | Increase | Increase | No Change |
| Eastern cottonwood | Decrease | Large Increase | Decrease | Large Increase | - | - |
| Eastern hemlock | Large Decrease | Large Decrease | Large Decrease | Large Decrease | Decrease | Large Decrease |
| Eastern hophornbeam | Decrease | Decrease | No Change | Increase | Decrease | Increase |
| Eastern redbud | New | New | Increase | Increase | Decrease | No Change |
| Eastern redcedar | New | New | Large Increase | Large Increase | Large Increase | Large Increase |
| Eastern white pine | No Change | **Extirpated** | Decrease | **Extirpated** | Increase | **Extirpated** |
| Flowering dogwood | Increase | No Change | Increase | Decrease | Decrease | Large Decrease |
| Green ash | Increase | Large Increase | Increase | Large Increase | Large Increase | Large Increase |
| Hackberry | Large Increase | Large Increase | Increase | Large Increase | Increase | Large Increase |
| Honeylocust | Large Increase | Large Increase | No Change | Large Increase | No Change | Large Increase |

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**Table 36 (continued).**

| | Ecological section within the assessment area boundaries | | | | | |
|---|---|---|---|---|---|---|
| | 221F | | 221E OH | | 221E WV | |
| **Common Name** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** |
| Loblolly pine | - | - | NA | New | Increase | Increase |
| Mockernut hickory | No Change | Increase | No Change | Increase | Decrease | Increase |
| Mountain maple | - | - | - | - | - | - |
| Northern catalpa | - | - | No Change | No Change | - | - |
| Northern pin oak | No Change | Decrease | - | - | - | - |
| Northern red oak | No Change | Decrease | No Change | Decrease | Decrease | No Change |
| Northern white-cedar | Decrease | No Change | - | - | - | - |
| Ohio buckeye | Large Increase | Decrease | No Change | Large Decrease | Decrease | Extirpated |
| Osage-orange | Increase | Large Increase | No Change | Large Increase | No Change | Increase |
| Pawpaw | - | - | No Change | Large Decrease | Decrease | Large Decrease |
| Pignut hickory | No Change | Increase | Increase | No Change | Decrease | Decrease |
| Pin cherry | Decrease | Large Decrease | - | - | Extirpated | Extirpated |
| Pin oak | No Change | No Change | No Change | Large Increase | New | New |
| Pitch pine | - | - | Increase | No Change | Decrease | Large Decrease |
| Post oak | New | New | Large Increase | Large Increase | Large Increase | Large Increase |
| Quaking aspen | Large Decrease | Large Decrease | Extirpated | Extirpated | - | - |
| Red maple | Decrease | Large Decrease | No Change | Large Decrease | Decrease | Large Decrease |
| Red mulberry | New | New | NA | New | No Change | Large Increase |
| Red pine | Decrease | Large Decrease | Large Decrease | Large Decrease | - | - |
| Red spruce | - | - | - | - | - | - |
| River birch | - | - | No Change | Increase | - | - |
| Rock elm | NA | New | - | - | Large Increase | Large Increase |
| Sassafras | Increase | Increase | No Change | Decrease | Decrease | Decrease |
| Scarlet oak | Large Increase | Large Increase | Increase | Decrease | Decrease | Large Decrease |
| Serviceberry | No Change | Decrease | No Change | No Change | Decrease | No Change |
| Shagbark hickory | Increase | Increase | Increase | Increase | Increase | Large Increase |
| Shingle oak | No Change | Increase | No Change | Increase | - | - |
| Shortleaf pine | NA | New | Large Increase | Large Increase | Large Increase | Large Increase |
| Shumard oak | NA | New | NA | NA | NA | New |
| Silver maple | No Change | Increase | Decrease | Decrease | Large Decrease | Large Increase |
| Slippery elm | Increase | Decrease | No Change | No Change | Decrease | Large Decrease |
| Sourwood | - | - | Increase | Increase | Increase | Large Decrease |
| Southern red oak | NA | New | New | New | Increase | Increase |
| Striped maple | - | - | - | - | - | - |
| Sugar maple | No Change | Large Decrease | No Change | No Change | Decrease | Large Decrease |
| Sugarberry | NA | New | New | New | New | New |
| Swamp white oak | No Change | Large Decrease | - | - | - | - |
| Sweet birch | No Change | Extirpated | Decrease | Decrease | Decrease | Large Decrease |
| Sweetgum | New | New | Increase | Increase | Increase | Increase |
| Sycamore | Increase | Increase | No Change | No Change | Decrease | No Change |

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**Table 36 (continued).**

| | Ecological section within the assessment area boundaries | | | | | |
|---|---|---|---|---|---|---|
| | 221F | | 221E OH | | 221E WV | |
| **Common Name** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** |
| Table Mountain pine | - | - | - | - | No Change | No Change |
| Tulip tree | Increase | Decrease | Increase | Increase | Decrease | Large Decrease |
| Virginia pine | - | - | Increase | Increase | Increase | Large Decrease |
| Water oak | - | - | NA | NA | NA | New |
| Water locust | - | - | NA | NA | NA | New |
| White ash | No Change | Large Decrease | Decrease | Decrease | Decrease | Large Decrease |
| White oak | No Change | Increase | Increase | Increase | Decrease | No Change |
| Willow oak | - | - | - | - | NA | New |
| Winged elm | NA | New | New | New | Increase | Increase |
| Yellow birch | Large Decrease | **Extirpated** | - | - | - | - |
| Yellow buckeye | - | - | No Change | No Change | Decrease | No Change |

[a] Change classes are provided for the end-of-century (2070 through 2099) period. Explanations for the change classes are described in the text. Blue ash, southern magnolia, and tamarack were present only at the regional level and do not appear here.

(continued on next page)

**Table 36 (continued).—Comparison of change classes for two climate scenarios from the DISTRIB model results for all tree species in six ecological sections of the assessment area[a]**

| | Ecological section within the assessment area boundaries | | | | | |
|---|---|---|---|---|---|---|
| | M221C | | M221B | | M221A | |
| **Common Name** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** |
| American basswood | No Change | Decrease | No Change | Decrease | Decrease | Decrease |
| American beech | No Change | Decrease | Decrease | Decrease | No Change | No Change |
| American chestnut | Increase | No Change | No Change | No Change | Decrease | Decrease |
| American elm | No Change | Large Increase | Decrease | Large Increase | Decrease | Increase |
| American holly | - | - | No Change | No Change | - | - |
| American hornbeam | No Change | No Change | Decrease | Increase | Large Decrease | Increase |
| Balsam fir | - | - | Large Decrease | Large Decrease | - | - |
| Bear oak (scrub oak) | - | - | Large Decrease | Decrease | No Change | No Change |
| Bigtooth aspen | - | - | Decrease | Extirpated | Large Decrease | Extirpated |
| Bitternut hickory | No Change | Large Increase | No Change | Increase | Increase | Increase |
| Black ash | - | - | - | - | - | - |
| Black cherry | Decrease | Decrease | Decrease | Large Decrease | Decrease | Large Decrease |
| Black hickory | NA | New | Decrease | Increase | New | New |
| Black locust | No Change | Decrease | No Change | Decrease | No Change | Decrease |
| Black maple | - | - | - | - | - | - |
| Black oak | No Change | Increase | No Change | Large Increase | No Change | Increase |
| Black walnut | No Change | Large Increase | Increase | Increase | No Change | Decrease |
| Black willow | - | - | No Change | Increase | NA | Increase |
| Blackgum | No Change | No Change | No Change | Increase | No Change | Decrease |
| Blackjack oak | NA | New | NA | New | Increase | Increase |
| Boxelder | - | - | Decrease | No Change | Decrease | No Change |
| Bur oak | - | - | - | - | - | - |
| Butternut | Increase | Extirpated | No Change | Extirpated | Decrease | Extirpated |
| Cedar elm | NA | New | NA | New | NA | New |
| Chestnut oak | No Change | Decrease | No Change | Decrease | No Change | Decrease |
| Chinkapin oak | No Change | Increase | No Change | Increase | Increase | Large Increase |
| Chokecherry | - | - | Decrease | Extirpated | No Change | Extirpated |
| Common persimmon | No Change | Increase | New | New | Increase | Increase |
| Cucumbertree | No Change | Decrease | No Change | No Change | Decrease | Decrease |
| Eastern cottonwood | - | - | - | - | NA | Increase |
| Eastern hemlock | No Change | Decrease | No Change | Decrease | Decrease | Decrease |
| Eastern hophornbeam | No Change | Increase | No Change | Increase | Decrease | Increase |
| Eastern redbud | Increase | Large Increase | Increase | Large Increase | No Change | Increase |
| Eastern redcedar | Large Increase | Large Increase | Increase | Large Increase | Increase | Large Increase |
| Eastern white pine | Increase | No Change | No Change | No Change | Decrease | Decrease |
| Flowering dogwood | No Change | Decrease | Increase | Increase | No Change | Decrease |
| Green ash | Increase | Large Increase | Decrease | Large Increase | Decrease | Large Increase |
| Hackberry | NA | New | No Change | Increase | No Change | Large Increase |
| Honeylocust | - | - | No Change | Increase | NA | New |

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**Table 36 (continued).**

| | Ecological section within the assessment area boundaries | | | | | |
|---|---|---|---|---|---|---|
| | M221C | | M221B | | M221A | |
| **Common Name** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** |
| Loblolly pine | New | New | No Change | Increase | Decrease | Large Increase |
| Mockernut hickory | No Change | Increase | No Change | Increase | No Change | Increase |
| Mountain maple | No Change | No Change | - | - | - | - |
| Northern catalpa | - | - | - | - | - | - |
| Northern pin oak | - | - | - | - | - | - |
| Northern red oak | No Change | No Change | No Change | Decrease | Decrease | Decrease |
| Northern white-cedar | - | - | - | - | - | - |
| Ohio buckeye | - | - | No Change | Extirpated | - | - |
| Osage-orange | - | - | - | - | No Change | Increase |
| Pawpaw | No Change | Large Decrease | No Change | Extirpated | Large Decrease | Large Decrease |
| Pignut hickory | Decrease | Decrease | No Change | No Change | No Change | Decrease |
| Pin cherry | - | - | Large Decrease | Extirpated | No Change | No Change |
| Pin oak | - | - | - | - | - | - |
| Pitch pine | Decrease | No Change | No Change | Increase | No Change | Decrease |
| Post oak | No Change | Increase | Increase | Increase | New | New |
| Quaking aspen | - | - | Large Decrease | Extirpated | Decrease | Extirpated |
| Red maple | No Change | Large Decrease | No Change | Decrease | No Change | Large Decrease |
| Red mulberry | No Change | Increase | New | New | Decrease | Increase |
| Red pine | - | - | No Change | Extirpated | - | - |
| Red spruce | - | - | No Change | Large Decrease | Decrease | Extirpated |
| River birch | Increase | Large Increase | - | - | - | - |
| Rock elm | - | - | - | - | - | - |
| Sassafras | No Change | Decrease | No Change | No Change | No Change | No Change |
| Scarlet oak | No Change | Decrease | No Change | No Change | No Change | Large Decrease |
| Serviceberry | No Change | No Change | No Change | Decrease | Decrease | Decrease |
| Shagbark hickory | Increase | Large Increase | Increase | Large Increase | Increase | Large Increase |
| Shingle oak | - | - | - | - | - | - |
| Shortleaf pine | Increase | Large Increase | Increase | Large Increase | Increase | Large Increase |
| Shumard oak | NA | Increase | NA | New | NA | New |
| Silver maple | - | - | Extirpated | Increase | No Change | Large Increase |
| Slippery elm | Increase | Increase | No Change | Large Increase | Decrease | Decrease |
| Sourwood | Increase | Decrease | Increase | Decrease | Increase | No Change |
| Southern red oak | Increase | Increase | Extirpated | Increase | Increase | Increase |
| Striped maple | Decrease | Decrease | Decrease | Large Decrease | Decrease | Decrease |
| Sugar maple | No Change | Large Decrease | No Change | Decrease | No Change | Large Decrease |
| Sugarberry | NA | New | Extirpated | Increase | New | New |
| Swamp white oak | - | - | - | - | - | - |
| Sweet birch | No Change | Large Decrease | No Change | Decrease | Decrease | Decrease |
| Sweetgum | Increase | Increase | New | New | New | New |
| Sycamore | Increase | Large Increase | Increase | Large Increase | No Change | Increase |

(continued on next page)

**Table 36 (continued).**

| | Ecological section within the assessment area boundaries | | | | | |
|---|---|---|---|---|---|---|
| | M221C | | M221B | | M221A | |
| **Common Name** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** | **PCM B1** | **GFDL A1FI** |
| Table Mountain pine | - | - | Decrease | Increase | No Change | Increase |
| Tulip tree | No Change | Large Decrease | Increase | Decrease | No Change | Decrease |
| Virginia pine | Increase | Large Increase | No Change | Increase | No Change | Decrease |
| Water oak | NA | New | NA | New | NA | New |
| Water locust | NA | New | - | - | NA | New |
| White ash | No Change | No Change | Decrease | Decrease | Decrease | Decrease |
| White oak | No Change | Increase | No Change | Increase | No Change | No Change |
| Willow oak | - | - | - | - | - | - |
| Winged elm | New | New | NA | New | New | New |
| Yellow birch | No Change | Large Decrease | Decrease | Large Decrease | No Change | Decrease |
| Yellow buckeye | Increase | No Change | Increase | Increase | Large Decrease | Decrease |

[a] Change classes are provided for the end-of-century (2070 through 2099) period. Explanations for the change classes are described in the text. Blue ash, southern magnolia, and tamarack were present only at the regional level and do not appear here.

**Table 37.—Modifying factor and adaptability information for the 93 tree species in the assessment area that were modeled by using DISTRIB**

| | DISTRIB | Modifying Factors[a] | | Adaptability Scores | | | |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Model Reliability** | **Positive Traits** | **Negative Traits** | **DistFact** | **BioFact** | **Adapt** | **Adapt Class** |
| American basswood | Medium | COL | FTK | 0.3 | 0.2 | 4.6 | o |
| American beech | High | COL | INS FTK | -1.1 | 0.0 | 3.6 | o |
| American chestnut | Medium | COL | DISE FTK | 0.1 | 0.3 | 4.5 | o |
| American elm | Medium | ESP | DISE INS | -0.8 | 0.3 | 4.0 | o |
| American holly | High | COL ESP | FTK | -0.1 | 0.5 | 4.5 | o |
| American hornbeam | Medium | COL SES | FTK DRO | 0.6 | 0.6 | 5.1 | o |
| Balsam fir | High | COL | INS FTK DRO | -3.0 | -0.4 | 2.7 | - |
| Bear oak (scrub oak) | Low | FRG VRE | COL FTK | 1.0 | -0.8 | 4.6 | o |
| Bigtooth aspen | High | FRG DISP | COL DRO FTK | 1.0 | 0.2 | 5.1 | o |
| Bitternut hickory | Low | DRO | COL | 2.2 | -0.8 | 5.6 | + |
| Black ash | High | | INS COL DISP DRO SES FTK ESP | -1.3 | -3.0 | 1.7 | - |
| Black cherry | High | DRO ESP | INS FTK COL | -1.6 | -0.3 | 3.0 | - |
| Black hickory | High | | ESP COL | 1.0 | -2.3 | 4.1 | o |
| Black locust | Low | | COL INS | 0.0 | -0.6 | 3.8 | o |
| Black maple | Low | COL ESP | FTK | 0.5 | 0.9 | 5.2 | o |
| Black oak | High | DRO ESP | INS DISE | 0.5 | 0.4 | 4.9 | o |
| Black walnut | Medium | SES | COL DRO | 0.4 | -0.8 | 4.0 | o |
| Black willow | Low | | COL FTK DRO | -0.3 | -2.1 | 2.8 | - |
| Blackgum | High | COL FTK | | 1.5 | 0.8 | 5.9 | + |
| Blackjack oak | Medium | DRO SES FRG VRE | COL FTK | 1.6 | 0.2 | 5.6 | + |
| Blue ash | Low | | INS DISP FTK COL ESP | -0.4 | -2.4 | 2.7 | - |
| Boxelder | Medium | SES DISP DRO COL SES | FTK | 2.4 | 2.1 | 7.4 | + |
| Bur oak | Medium | DRO FTK | | 2.8 | -0.2 | 6.4 | + |
| Butternut | Low | | FTK COL DRO DISE | -1.4 | -1.3 | 2.3 | - |
| Cedar elm | Low | | DISE | -0.3 | -1.2 | 3.3 | o |
| Chestnut oak | High | SES VRE ESP FTK | INS DISE | 1.4 | 1.3 | 6.1 | + |
| Chinkapin oak | Medium | SES | | 1.2 | -0.7 | 4.8 | o |
| Chokecherry | Low | | COL | 0.2 | -0.9 | 3.8 | o |
| Common persimmon | Medium | COL ESP | | 1.2 | 1.0 | 5.8 | + |
| Cucumbertree | High | | FTK | 0.0 | -1.1 | 3.6 | o |
| Eastern cottonwood | Low | SES | INS COL DISE FTK | 0.2 | -0.8 | 3.9 | o |
| Eastern hemlock | High | COL | INS DRO | -1.3 | -0.9 | 2.7 | - |
| Eastern hophornbeam | Medium | COL ESP SES | | 1.7 | 1.3 | 6.4 | + |
| Eastern redcedar | Medium | DRO | FTK COL INS | 0.6 | -1.5 | 3.9 | o |
| Eastern redbud | Medium | | | 0.9 | 0.0 | 4.9 | o |
| Eastern white pine | High | DISP | DRO FTK INS | -2.0 | 0.1 | 3.3 | o |
| Flowering dogwood | High | COL | | 0.1 | 1.0 | 5.0 | o |
| Green ash | Medium | | INS FTK COL | -0.1 | -0.3 | 4.0 | o |
| Hackberry | Medium | DRO | FTK | 1.7 | 0.3 | 5.7 | + |
| Honeylocust | Low | | COL | 1.9 | -0.5 | 5.5 | + |
| Loblolly pine | High | ESP | INS INP DRO COL | -0.5 | -0.7 | 3.4 | o |
| Mockernut hickory | High | | FTK | 1.7 | -0.3 | 5.4 | + |
| Mountain maple | High | COL VRE ESP | DRO FTK | 0.8 | 1.5 | 5.9 | + |
| Northern catalpa | Low | | COL ESP | 0.9 | -1.6 | 4.2 | o |
| Northern pin oak | Medium | DRO FTK | COL | 2.5 | -0.6 | 6.0 | + |
| Northern red oak | High | | INS | 1.4 | 0.1 | 5.4 | + |

(continued on next page)

Table 37 (continued).

| | DISTRIB | Modifying Factors[a] | | Adaptability Scores | | | |
|---|---|---|---|---|---|---|---|
| **Common Name** | **Model Reliability** | **Positive Traits** | **Negative Traits** | **DistFact** | **BioFact** | **Adapt** | **Adapt Class** |
| Northern white-cedar | High | COL | FTK | -0.7 | 0.5 | 4.2 | o |
| Ohio buckeye | Low | COL | SES FTK | 0.4 | -1.9 | 3.5 | o |
| Osage-orange | Medium | ESP ESP | | 2.3 | 0.3 | 6.3 | + |
| Pawpaw | Low | COL | DRO | -0.5 | -0.3 | 3.7 | o |
| Pignut hickory | High | ESP | INS DRO | 0.2 | 0.4 | 4.7 | o |
| Pin cherry | Medium | SES FRG FTK | COL | 0.5 | -0.7 | 4.2 | o |
| Pin oak | Medium | | FTK COL INS DISE | -0.7 | -1.4 | 2.8 | - |
| Pitch pine | High | | COL INS | 0.6 | -1.8 | 3.8 | o |
| Post oak | High | DRO SES FTK | COL INS DISE | 2.2 | -0.6 | 5.7 | + |
| Quaking aspen | High | SES FRG ESP | COL DRO FTK | 0.6 | 0.0 | 4.7 | o |
| Red maple | High | SES ESP ESP COL DISP | | 3.0 | 3.0 | 8.5 | + |
| Red mulberry | Low | COL DISP | FTK | 0.1 | 0.6 | 4.7 | o |
| Red pine | Medium | | INS COL DISP | 0.9 | -2.4 | 3.9 | o |
| Red spruce | High | ESP COL | FTK SES | -1.3 | -0.6 | 2.9 | - |
| River birch | Low | DISP | FTK COL DRO | -0.5 | -0.3 | 3.7 | o |
| Rock elm | Low | | ESP ESP SES | -0.2 | -2.6 | 2.8 | - |
| Sassafras | High | | COL FTK | 0.5 | -0.6 | 4.2 | o |
| Scarlet oak | High | VRE ESP ESP | INS DISE FTK | -0.4 | 0.7 | 4.6 | o |
| Serviceberry | Medium | COL SES | DRO | -0.4 | 1.0 | 4.8 | o |
| Shagbark hickory | Medium | | INS FTK | -0.2 | 0.4 | 4.4 | o |
| Shingle oak | Medium | ESP | COL | 1.3 | -0.7 | 4.9 | o |
| Shortleaf pine | High | ESP | COL INS DRO | 0.0 | -1.0 | 3.6 | o |
| Shumard oak | Low | DRO SES | COL | 2.5 | -1.0 | 5.8 | + |
| Silver maple | Medium | DISP SES COL | DRO FTK | 0.1 | 1.6 | 5.6 | + |
| Slippery elm | Medium | COL | FTK DISE | 0.0 | 0.7 | 4.8 | o |
| Sourwood | High | COL ESP | | 2.6 | 1.0 | 6.9 | + |
| Southern magnolia | Medium | SES COL FTK | DRO EHS | 0.6 | 0.4 | 4.9 | o |
| Southern red oak | High | SES | | 1.2 | 0.2 | 5.3 | + |
| Striped maple | High | COL SES | DRO | 1.0 | 0.3 | 5.1 | o |
| Sugar maple | High | COL ESP | | 0.9 | 1.3 | 5.8 | + |
| Sugarberry | Medium | COL SES | FTK | -0.2 | 0.6 | 4.6 | o |
| Swamp white oak | Low | | | 1.0 | -0.3 | 4.9 | o |
| Sweet birch | High | DISP | FTK COL INS DISE | -1.3 | -0.3 | 3.2 | - |
| Sweetgum | High | VRE ESP | FTK COL DRO | -0.4 | 0.2 | 4.1 | o |
| Sycamore | Medium | | | 1.3 | -0.9 | 4.8 | o |
| Table Mountain pine | Medium | DRO | COL | 2.6 | -1.1 | 5.9 | + |
| Tamarack (native) | High | | FTK COL INS | -0.5 | -1.2 | 3.1 | - |
| Tulip tree | High | SES DISP ESP | INP | 0.1 | 1.3 | 5.3 | + |
| Virginia pine | High | | COL POL | 0.1 | -0.8 | 3.8 | o |
| Water locust | Low | | | 0.0 | -0.6 | 3.8 | o |
| Water oak | High | SES | FTK COL | -0.2 | -0.6 | 3.7 | o |
| White ash | High | | INS FTK COL | -2.0 | -0.5 | 2.7 | - |
| White oak | High | ESP ESP SES FTK | INS DISE | 1.7 | 1.0 | 6.1 | + |
| Willow oak | Medium | SES SES | COL | 0.6 | 0.0 | 4.7 | o |
| Winged elm | High | | INS DISE | -0.6 | -0.3 | 3.6 | o |
| Yellow birch | High | DISP | FTK INS DISE | -1.4 | 0.0 | 3.4 | o |
| Yellow buckeye | Medium | COL | DRO SES FTK ESP DISP | 0.0 | -2.1 | 3.1 | - |

[a] Modifying factor codes are described in Table 38. Adaptability scores are described in the appendix text.

Table 38.—Key to modifying factor codes[a]

| Code | Title | Type | Description (if positive) | Description (if negative) |
|---|---|---|---|---|
| COL | Competition-light | Biological | Tolerant of shade or limited light conditions | Intolerant of shade or limited light conditions |
| DISE | Disease | Disturbance | N/A | Has a high number and/or severity of known pathogens that attack the species |
| DISP | Dispersal | Biological | High ability to effectively produce and distribute seeds | N/A |
| DRO | Drought | Biological | Drought-tolerant | Susceptible to drought |
| ESP | Edaphic specificity | Biological | Wide range of soil requirements | Narrow range of soil requirements |
| EHS | Environmental habitat specificity | Biological | Wide range of suitable habitat conditions | Narrow range of suitable habitat conditions |
| FRG | Fire regeneration | Disturbance | Regenerates well after fire | N/A |
| FTK | Fire topkill | Disturbance | Resistant to fire topkill | Susceptible to fire topkill |
| INP | Invasive plants | Disturbance | N/A | Strong negative effects of invasive plants on the species, either through competition for nutrients or as a pathogen |
| INS | Insect pests | Disturbance | N/A | Has a high number and/or severity of known insects that attack the species |
| POL | Pollution | Disturbance | N/A | Strong negative effects of pollution on the species |
| SES | Seedling establishment | Biological | High ability to regenerate with seeds to maintain future populations | Low ability to regenerate with seeds to maintain future populations |
| VRE | Vegetative reproduction | Biological | Capable of vegetative reproduction through stump sprouts or cloning | N/A |

[a] These codes are used to describe positive or negative modifying factors in Table 37. A species was given that code if information from the literature suggested that it had these characteristics (Matthews et al. 2011). See Matthews et al. (2011) for a more thorough description of these factors and how they were assessed.

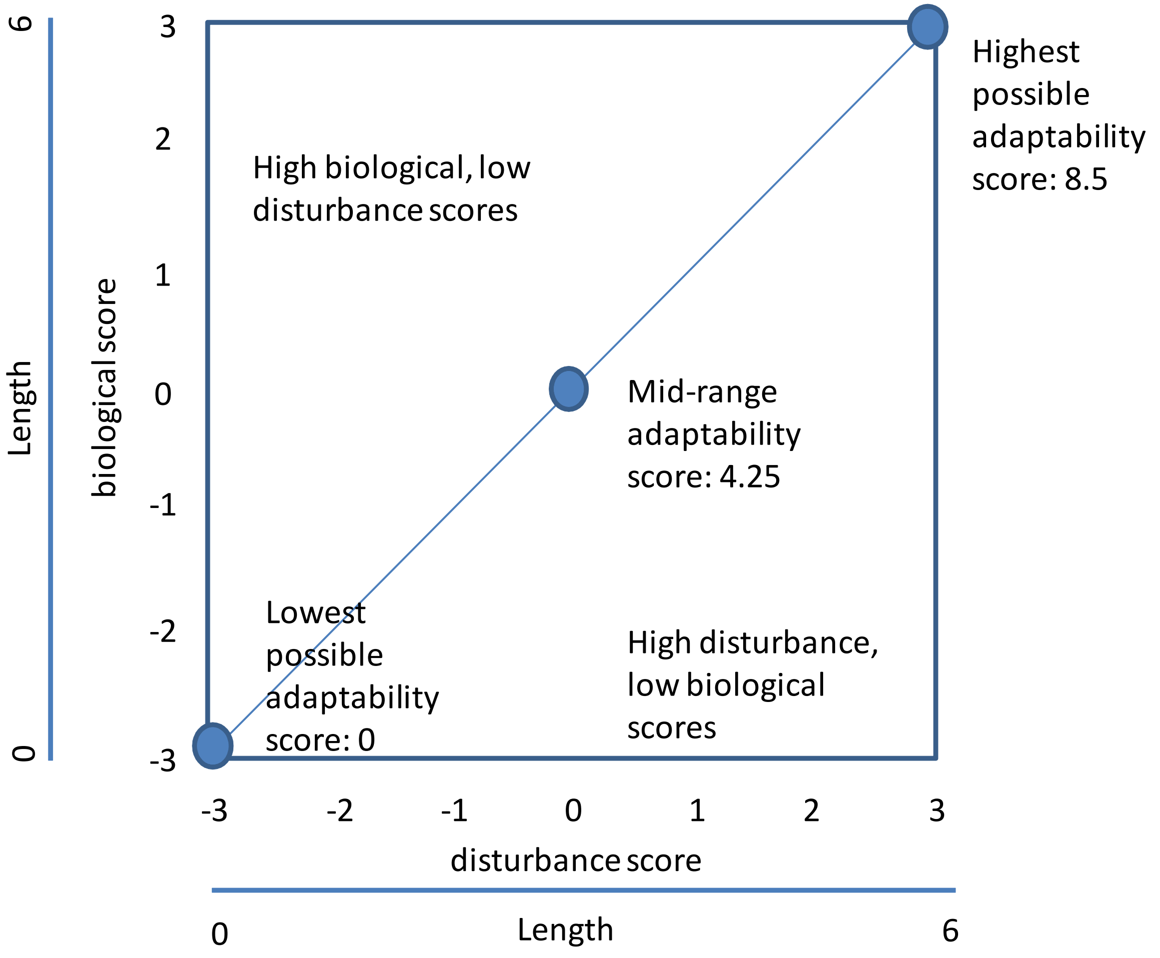

Figure 59.—Schematic showing how adaptability was determined for information for tree species modeled using the Climate Change Tree Atlas.

# LINKAGES MODEL RESULTS

Species establishment probabilities for 23 tree species predicted by the LINKAGES model are presented for the assessment area as a whole, and for each section within the assessment area (Table 39). Early growth potential was also mapped for each species modeled by LINKAGES (Fig. 60). Change in early growth was calculated by dividing the modeled future biomass by the current climate biomass. Change was classified according to the ratios tabulated at right.

| Modeled:Current biomass | Class |
|---|---|
| <0.4 | large decrease |
| 0.4 through <0.8 | small decrease |
| 0.8 through <1.2 | no change |
| 1.2 through <2.0 | small increase |
| >2.0 | large increase |
| current climate = 0 and future climate model = 0 | not present |
| current climate > 0 and future climate model = 0 | extirpated |

**Table 39.— Changes in early growth of tree species predicted by the LINKAGES model for two climate scenarios at the end of the century (2080 through 2099) compared to current climate (1990 through 2009) for 23 species in the assessment area**

| | | Current Climate | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|
| Species | Section[a] | SEP[b] | SEP[b] | % change | SEP[b] | % change |
| American beech | Assessment area | 0.22 | 0.22 | 0.0 | 0.02 | -90.9 |
| | 221E | 0.22 | 0.21 | -5.5 | 0.00 | Extirpated |
| | 221F | 0.26 | 0.26 | 0.7 | 0.00 | Extirpated |
| | M221A | 0.13 | 0.15 | 14.9 | 0.00 | Extirpated |
| | M221B | 0.23 | 0.24 | 3.5 | 0.14 | -38.1 |
| | M221C | 0.24 | 0.23 | -5.8 | 0.00 | Extirpated |
| American elm | Assessment area | 0.14 | 0.16 | 14.3 | 0.18 | 28.6 |
| | 221E | 0.16 | 0.19 | 14.4 | 0.19 | 14.4 |
| | 221F | 0.13 | 0.16 | 23.0 | 0.18 | 40.8 |
| | M221A | 0.07 | 0.12 | 76.3 | 0.14 | 111.2 |
| | M221B | 0.10 | 0.13 | 22.3 | 0.18 | 77.7 |
| | M221C | 0.16 | 0.18 | 12.7 | 0.19 | 17.1 |
| Balsam fir | Assessment area | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | 221E | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | 221F | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | M221A | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | M221B | 0.02 | 0.01 | -36.8 | 0.00 | Extirpated |
| | M221C | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| Black cherry | Assessment area | 0.28 | 0.30 | 7.1 | 0.30 | 7.1 |
| | 221E | 0.31 | 0.32 | 1.5 | 0.31 | -2.1 |
| | 221F | 0.30 | 0.32 | 6.4 | 0.32 | 8.3 |
| | M221A | 0.11 | 0.18 | 65.0 | 0.21 | 93.9 |
| | M221B | 0.26 | 0.28 | 8.5 | 0.31 | 19.9 |
| | M221C | 0.32 | 0.32 | 1.8 | 0.31 | -1.3 |
| Blackgum | Assessment area | 0.16 | 0.19 | 18.8 | 0.21 | 31.3 |
| | 221E | 0.18 | 0.21 | 14.7 | 0.21 | 16.8 |
| | 221F | 0.15 | 0.18 | 20.2 | 0.22 | 44.7 |
| | M221A | 0.08 | 0.13 | 75.0 | 0.16 | 109.3 |
| | M221B | 0.12 | 0.14 | 22.6 | 0.21 | 78.1 |
| | M221C | 0.18 | 0.21 | 14.3 | 0.22 | 19.3 |

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**Table 39 (continued).**

| Species | Section[a] | Current Climate SEP[b] | PCM B1 SEP[b] | PCM B1 % change | GFDL A1FI SEP[b] | GFDL A1FI % change |
|---|---|---|---|---|---|---|
| Black oak | Assessment area | 0.19 | 0.20 | 5.3 | 0.13 | -31.6 |
| | 221E | 0.20 | 0.21 | 0.5 | 0.08 | -63.1 |
| | 221F | 0.20 | 0.21 | 2.1 | 0.20 | -0.4 |
| | M221A | 0.11 | 0.16 | 47.6 | 0.15 | 40.2 |
| | M221B | 0.18 | 0.19 | 8.0 | 0.20 | 10.7 |
| | M221C | 0.20 | 0.21 | 0.8 | 0.13 | -37.5 |
| Chestnut oak | Assessment area | 0.20 | 0.20 | 0.0 | 0.12 | -40.0 |
| | 221E | 0.21 | 0.21 | 0.1 | 0.06 | -72.0 |
| | 221F | 0.21 | 0.21 | 0.0 | 0.20 | -6.1 |
| | M221A | 0.10 | 0.15 | 45.2 | 0.14 | 32.0 |
| | M221B | 0.19 | 0.20 | 5.2 | 0.20 | 3.3 |
| | M221C | 0.21 | 0.21 | -0.2 | 0.13 | -37.9 |
| Eastern red cedar | Assessment area | 0.20 | 0.24 | 20.0 | 0.26 | 30.0 |
| | 221E | 0.23 | 0.26 | 14.7 | 0.26 | 15.3 |
| | 221F | 0.21 | 0.25 | 21.9 | 0.28 | 36.5 |
| | M221A | 0.09 | 0.13 | 43.1 | 0.16 | 67.3 |
| | M221B | 0.15 | 0.19 | 23.6 | 0.26 | 71.4 |
| | M221C | 0.24 | 0.27 | 14.1 | 0.28 | 17.3 |
| Eastern hemlock | Assessment area | 0.13 | 0.13 | 0.0 | 0.01 | -92.3 |
| | 221E | 0.14 | 0.12 | -15.2 | 0.00 | Extirpated |
| | 221F | 0.15 | 0.15 | 0.5 | 0.00 | -99.8 |
| | M221A | 0.06 | 0.09 | 43.6 | 0.00 | Extirpated |
| | M221B | 0.14 | 0.14 | 1.4 | 0.07 | -46.7 |
| | M221C | 0.15 | 0.13 | -13.6 | 0.00 | Extirpated |
| Eastern white pine | Assessment area | 0.34 | 0.35 | 2.9 | 0.04 | -88.2 |
| | 221E | 0.35 | 0.35 | 1.8 | 0.00 | Extirpated |
| | 221F | 0.38 | 0.38 | 0.0 | 0.01 | -98.3 |
| | M221A | 0.21 | 0.25 | 18.2 | 0.00 | Extirpated |
| | M221B | 0.35 | 0.36 | 2.5 | 0.24 | -31.0 |
| | M221C | 0.37 | 0.38 | 2.1 | 0.00 | Extirpated |
| Flowering dogwood | Assessment area | 0.05 | 0.08 | 60.0 | 0.10 | 100.0 |
| | 221E | 0.07 | 0.10 | 41.9 | 0.10 | 49.5 |
| | 221F | 0.04 | 0.06 | 66.0 | 0.10 | 162.6 |
| | M221A | 0.03 | 0.05 | 118.1 | 0.07 | 187.9 |
| | M221B | 0.02 | 0.04 | 80.9 | 0.10 | 318.3 |
| | M221C | 0.06 | 0.09 | 45.7 | 0.10 | 61.1 |
| Loblolly pine | Assessment area | 0.13 | 0.29 | 123.1 | 0.51 | 292.3 |
| | 221E | 0.20 | 0.39 | 94.3 | 0.54 | 167.9 |
| | 221F | 0.03 | 0.17 | 464.8 | 0.50 | 1535.1 |
| | M221A | 0.08 | 0.27 | 260.2 | 0.51 | 577.5 |
| | M221B | 0.02 | 0.10 | 455.6 | 0.45 | 2496.5 |
| | M221C | 0.17 | 0.35 | 106.1 | 0.53 | 212.1 |
| Northern red oak | Assessment area | 0.29 | 0.31 | 6.9 | 0.18 | -37.9 |
| | 221E | 0.29 | 0.31 | 6.2 | 0.09 | -70.4 |
| | 221F | 0.33 | 0.33 | 0.9 | 0.31 | -5.1 |
| | M221A | 0.17 | 0.20 | 19.5 | 0.18 | 5.5 |
| | M221B | 0.30 | 0.31 | 3.5 | 0.30 | 1.0 |
| | M221C | 0.32 | 0.33 | 3.9 | 0.20 | -36.4 |

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Table 39 (continued).

| Species | Section[a] | Current Climate SEP[b] | PCM B1 SEP[b] | PCM B1 % change | GFDL A1FI SEP[b] | GFDL A1FI % change |
|---|---|---|---|---|---|---|
| Pignut hickory | Assessment area | 0.35 | 0.37 | 5.7 | 0.36 | 2.9 |
| | 221E | 0.38 | 0.39 | 2.1 | 0.36 | -6.5 |
| | 221F | 0.37 | 0.38 | 5.2 | 0.39 | 5.8 |
| | M221A | 0.15 | 0.25 | 62.0 | 0.28 | 81.6 |
| | M221B | 0.31 | 0.34 | 10.8 | 0.38 | 23.2 |
| | M221C | 0.38 | 0.39 | 1.1 | 0.38 | -2.1 |
| Post oak | Assessment area | 0.05 | 0.10 | 100.0 | 0.17 | 240.0 |
| | 221E | 0.07 | 0.13 | 81.7 | 0.18 | 149.8 |
| | 221F | 0.03 | 0.06 | 103.5 | 0.18 | 458.5 |
| | M221A | 0.03 | 0.08 | 182.8 | 0.14 | 401.6 |
| | M221B | 0.02 | 0.04 | 147.2 | 0.15 | 795.6 |
| | M221C | 0.06 | 0.12 | 86.7 | 0.18 | 184.1 |
| Red maple | Assessment area | 0.31 | 0.34 | 9.7 | 0.37 | 19.4 |
| | 221E | 0.34 | 0.36 | 7.8 | 0.37 | 10.7 |
| | 221F | 0.31 | 0.33 | 9.2 | 0.37 | 22.5 |
| | M221A | 0.24 | 0.32 | 33.4 | 0.35 | 45.3 |
| | M221B | 0.27 | 0.30 | 10.8 | 0.37 | 34.1 |
| | M221C | 0.33 | 0.36 | 7.9 | 0.37 | 12.7 |
| Red spruce | Assessment area | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | 221E | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | 221F | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | M221A | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| | M221B | 0.02 | 0.01 | -49.9 | 0.00 | Extirpated |
| | M221C | 0.00 | 0.00 | 0.0 | 0.00 | 0.0 |
| Scarlet oak | Assessment area | 0.17 | 0.17 | 0.0 | 0.04 | -76.5 |
| | 221E | 0.18 | 0.18 | 0.5 | 0.00 | -99.7 |
| | 221F | 0.18 | 0.18 | 1.1 | 0.07 | -60.7 |
| | M221A | 0.09 | 0.13 | 44.4 | 0.02 | -74.8 |
| | M221B | 0.17 | 0.17 | 3.2 | 0.14 | -19.6 |
| | M221C | 0.18 | 0.18 | -0.2 | 0.01 | -96.5 |
| Shortleaf pine | Assessment area | 0.08 | 0.22 | 175.0 | 0.35 | 337.5 |
| | 221E | 0.14 | 0.31 | 125.3 | 0.36 | 159.2 |
| | 221F | 0.02 | 0.12 | 536.6 | 0.38 | 2017.0 |
| | M221A | 0.03 | 0.14 | 305.5 | 0.22 | 529.6 |
| | M221B | 0.01 | 0.07 | 830.0 | 0.34 | 4515.9 |
| | M221C | 0.11 | 0.29 | 153.4 | 0.38 | 232.5 |
| Sugar maple | Assessment area | 0.51 | 0.50 | -2.0 | 0.05 | -90.2 |
| | 221E | 0.52 | 0.49 | -4.5 | 0.00 | Extirpated |
| | 221F | 0.52 | 0.52 | -0.1 | 0.00 | -99.2 |
| | M221A | 0.44 | 0.49 | 11.0 | 0.00 | -100.0 |
| | M221B | 0.51 | 0.52 | 0.8 | 0.33 | -34.5 |
| | M221C | 0.52 | 0.51 | -2.0 | 0.00 | Extirpated |
| Tulip tree | Assessment area | 0.76 | 0.83 | 9.2 | 0.86 | 13.2 |
| | 221E | 0.77 | 0.85 | 10.9 | 0.85 | 11.0 |
| | 221F | 0.92 | 0.97 | 4.6 | 0.98 | 6.1 |
| | M221A | 0.22 | 0.38 | 69.6 | 0.48 | 112.6 |
| | M221B | 0.78 | 0.84 | 7.1 | 0.91 | 15.8 |
| | M221C | 0.88 | 0.93 | 5.9 | 0.94 | 7.0 |

(continued on next page)

**Table 39 (continued).**

| Species | Section[a] | Current Climate SEP[b] | PCM B1 SEP[b] | PCM B1 % change | GFDL A1FI SEP[b] | GFDL A1FI % change |
|---|---|---|---|---|---|---|
| White ash | Assessment area | 0.43 | 0.53 | 23.3 | 0.41 | -4.7 |
| | 221E | 0.37 | 0.49 | 34.2 | 0.25 | -32.1 |
| | 221F | 0.76 | 0.79 | 5.0 | 0.79 | 4.6 |
| | M221A | 0.03 | 0.06 | 88.5 | 0.06 | 113.1 |
| | M221B | 0.50 | 0.56 | 12.8 | 0.60 | 20.6 |
| | M221C | 0.49 | 0.62 | 28.3 | 0.51 | 4.5 |
| White oak | Assessment area | 0.32 | 0.35 | 9.4 | 0.35 | 9.4 |
| | 221E | 0.33 | 0.35 | 7.3 | 0.35 | 5.7 |
| | 221F | 0.36 | 0.38 | 4.9 | 0.38 | 5.5 |
| | M221A | 0.19 | 0.23 | 23.6 | 0.25 | 34.4 |
| | M221B | 0.31 | 0.33 | 8.1 | 0.36 | 17.6 |
| | M221C | 0.36 | 0.37 | 4.5 | 0.37 | 4.9 |

[a] Assessment area values were derived from the weighted average of sections.

[b] Species establishment probabilities (SEP) are derived from LINKAGES model results. SEP is a value reflecting the ability of a species to establish and grow on a site, is scaled 0 through 1, and is relative to the other species considered. It is important to look at absolute and percentage changes together; in some cases a small absolute change can result in a large percentage change.

A forest road on the Monongahela National Forest, West Virginia. Photo by Patricia Butler, NIACS and Michigan Tech, used with permission.

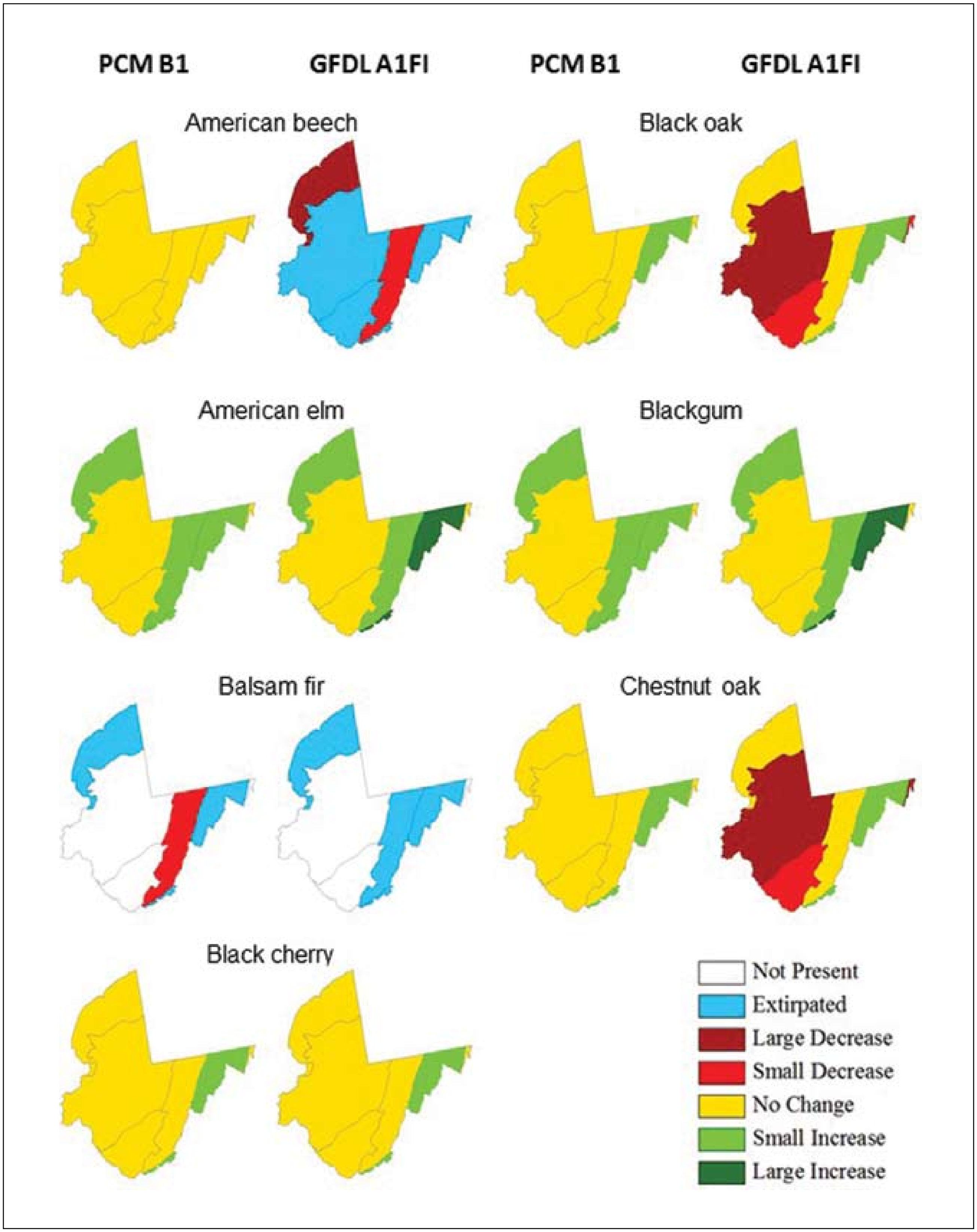

Figure 60.—Changes in early growth of tree species under two climate scenarios for the end of the century (2080 through 2099) compared to current climate (1990 through 2009). Change is based on predicted biomass by the LINKAGES model after 30 years of establishment and growth from bare ground and calculated as predicted biomass for each future climate scenario divided by predicted biomass under current climate, and then put into categories.

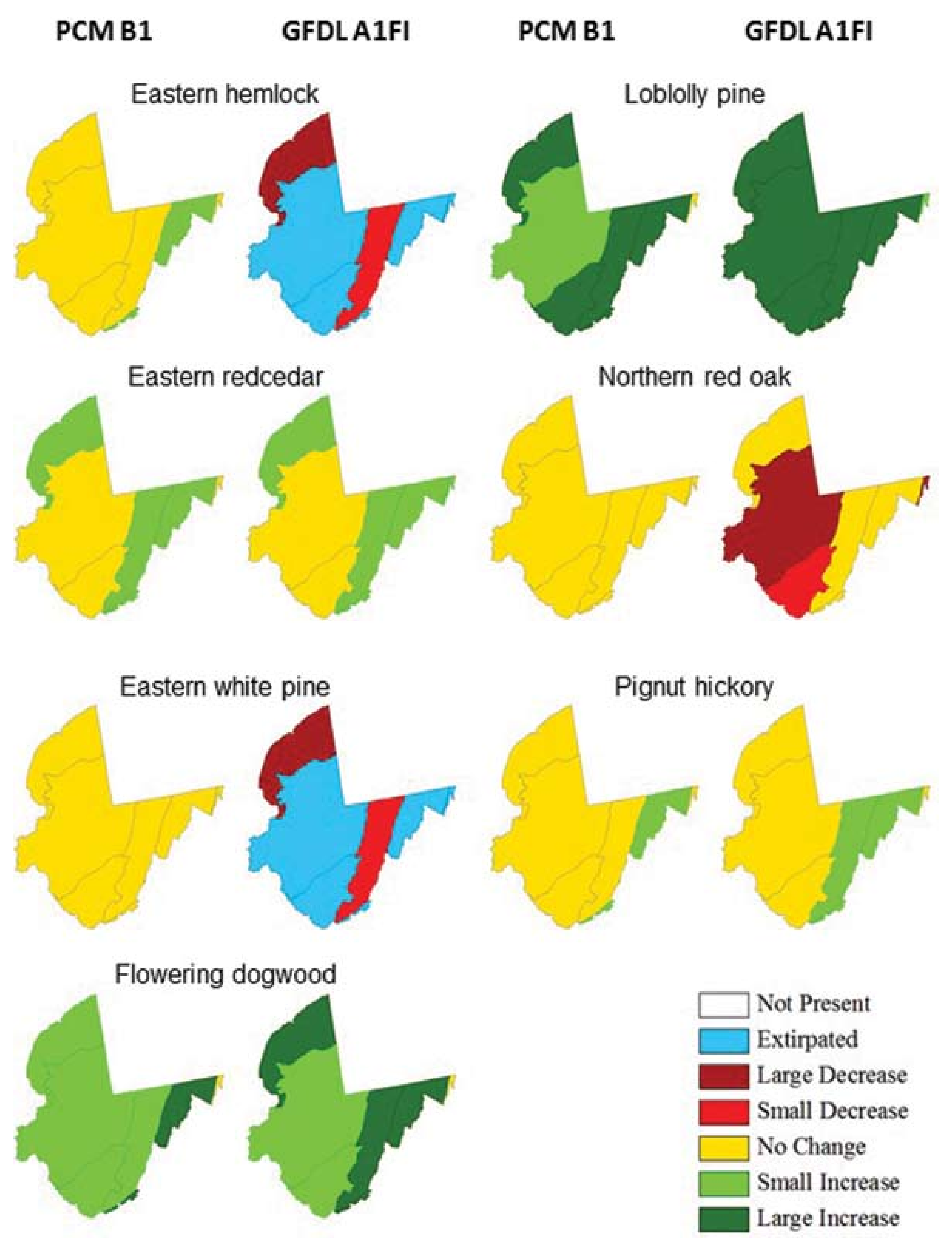

Figure 60 (continued).

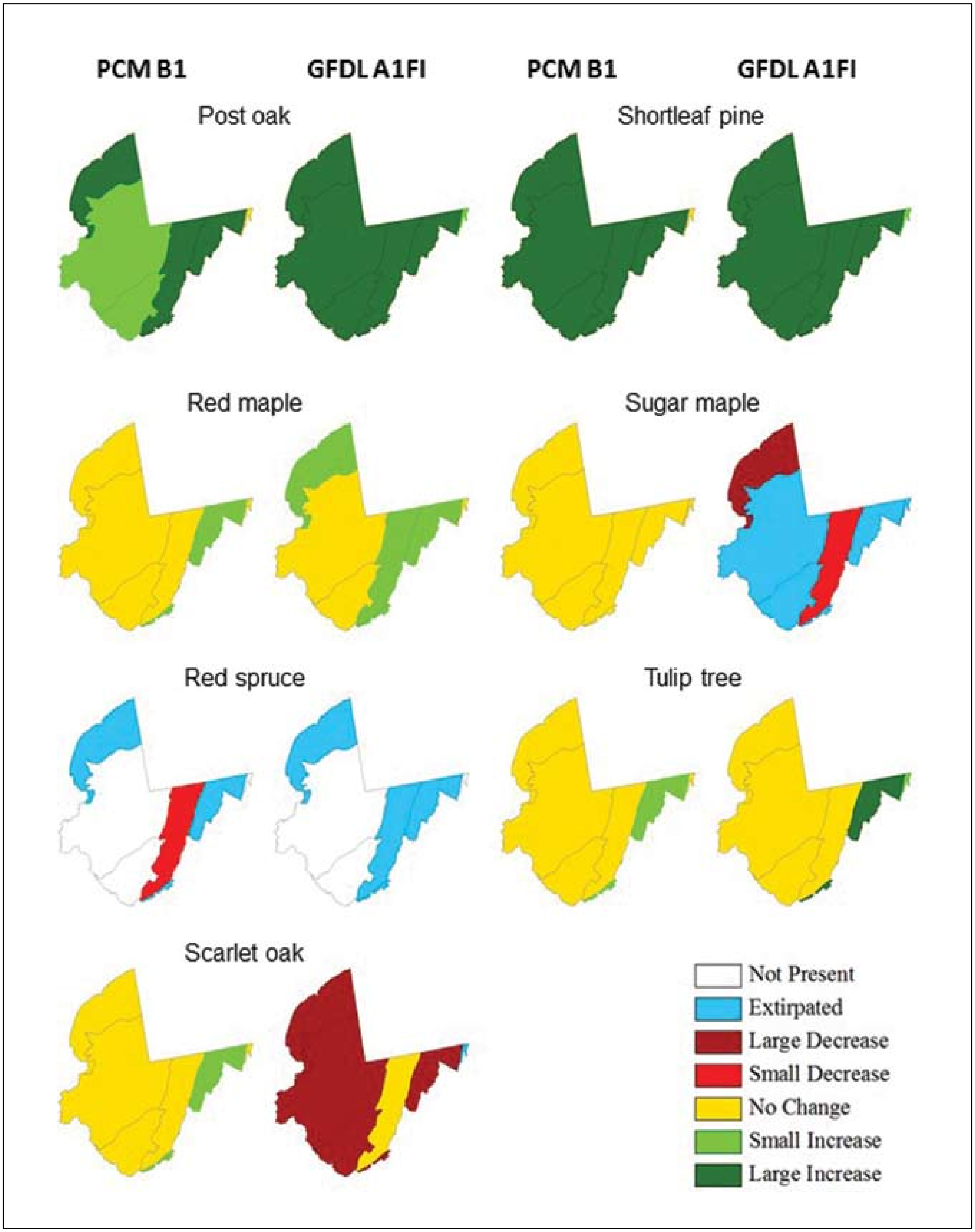

Figure 60 (continued).

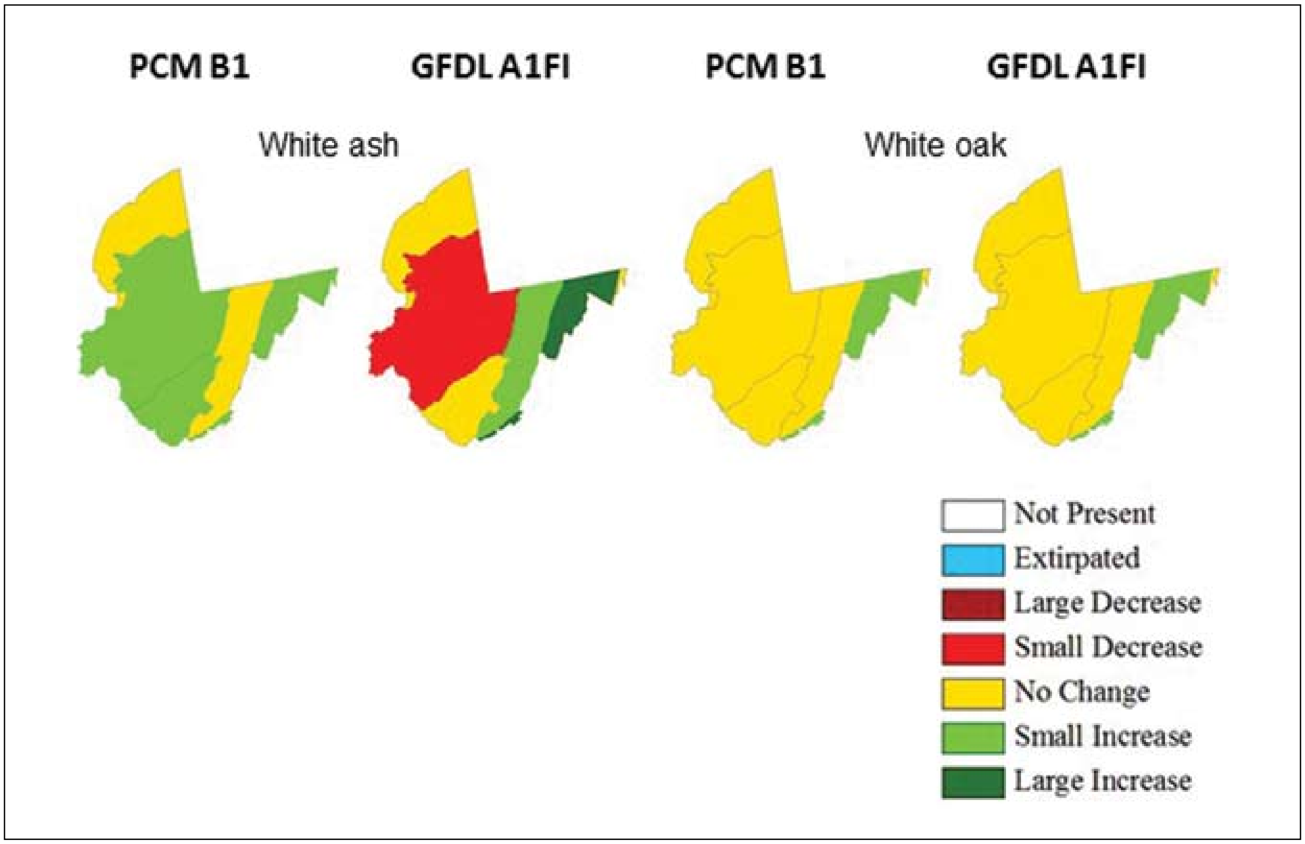

Figure 60 (continued).

## LANDIS PRO MODEL RESULTS

In contrast to predictions by LINKAGES, LANDIS PRO simulates stand- and landscape-level processes such as competition, management, seed dispersal, and disturbance. In the scenarios below, however, these factors were held constant among model simulations, so that differences among current climate and future climate scenarios are the result of the effects of precipitation and temperature on species basal area (square feet per acre) and trees per acre.

Percentage change over time within a climate scenario (columns) shows how current species are predicted to change under that scenario (Tables 40 through 42). The relative differences in the values for percentage change across scenarios indicate the differences between climate scenarios. It is important to consider both the absolute and the percentage change, especially if considering multiple species. Percentage changes are relative only to a particular species and may exaggerate a projected change. Figures 61 through 64 present these changes in basal area and trees per acre for PCM B1 and GFDL A1FI. The width of a line represents the species' relative abundance; over time the width of the line increases or decreases in response to climate variables.

## REFERENCES

Matthews, S.N.; Iverson, L.R.; Prasad, A.M.; Peters, M.P.; Rodewald, P.G. 2011. **Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history-factors.** Forest Ecology and Management. 262(8): 1460-1472.

Table 40.—Absolute and percentage change in basal area (BA) and trees per acre (TPA) predicted by the LANDIS PRO model for 17 species for current climate and two climate scenarios for the assessment area in year 2040

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree species | Section[a] | BA in 2009 | BA in 2040 | Change from 2009[b] | BA in 2040 | Change from current climate[c] | BA in 2040 | Change from current climate[c] | TPA in 2009 | TPA in 2040 | Change from 2009[b] | TPA in 2040 | Change from current climate[c] | TPA in 2040 | Change from current climate[c] |
| American beech | Assessment area | 5.1 | 4.4 | -15% | 4.4 | 1% | 4.3 | -2% | 26.8 | 15.5 | -42% | 15.7 | 1% | 12.8 | -18% |
| | 221E | 3.9 | 3.8 | -3% | 3.8 | 0% | 3.6 | -5% | 19.7 | 13.3 | -32% | 13.6 | 2% | 10.5 | -21% |
| | 221F | 4.5 | 4.0 | -11% | 4.1 | 2% | 3.9 | -3% | 16.7 | 15.3 | -8% | 15.2 | -1% | 12.8 | -16% |
| | M221A | 7.2 | 5.4 | -25% | 5.7 | 6% | 5.6 | 4% | 39.8 | 18.1 | -55% | 18.8 | 4% | 15.0 | -17% |
| | M221B | 6.6 | 4.9 | -26% | 5.0 | 2% | 5.0 | 2% | 36.0 | 17.9 | -50% | 17.9 | 0% | 15.5 | -13% |
| | M221C | 6.1 | 5.0 | -18% | 5.0 | 0% | 4.8 | -4% | 36.2 | 18.2 | -50% | 18.1 | -1% | 15.2 | -16% |
| Black cherry | Assessment area | 7.3 | 9.0 | 23% | 9.0 | 0% | 9.4 | 4% | 18.9 | 12.8 | -33% | 12.9 | 1% | 11.5 | -10% |
| | 221E | 7.2 | 9.1 | 26% | 9.1 | 0% | 9.4 | 3% | 19.3 | 13.5 | -30% | 13.7 | 1% | 12.1 | -10% |
| | 221F | 13.8 | 16.7 | 21% | 16.8 | 1% | 17.6 | 5% | 42.3 | 34.2 | -19% | 34.4 | 1% | 30.9 | -10% |
| | M221A | 8.0 | 8.8 | 10% | 8.9 | 1% | 9.1 | 3% | 15.8 | 8.4 | -47% | 8.7 | 4% | 7.6 | -10% |
| | M221B | 7.4 | 9.1 | 23% | 9.1 | 0% | 9.4 | 3% | 15.4 | 8.9 | -42% | 9.0 | 1% | 8.2 | -8% |
| | M221C | 3.6 | 4.3 | 19% | 4.3 | 0% | 4.6 | 7% | 10.8 | 5.6 | -48% | 5.6 | 0% | 4.9 | -13% |
| Black oak | Assessment area | 6.8 | 4.8 | -30% | 4.8 | 0% | 3.4 | -30% | 8.4 | 3.9 | -54% | 4.0 | 2% | 3.1 | -21% |
| | 221E | 7.3 | 5.2 | -29% | 5.2 | 0% | 3.6 | -31% | 9.5 | 4.4 | -54% | 4.5 | 2% | 3.5 | -20% |
| | 221F | 2.1 | 1.4 | -33% | 1.4 | 0% | 0.8 | -43% | 1.5 | 1.1 | -27% | 1.1 | 0% | 0.8 | -27% |
| | M221A | 6.4 | 4.2 | -34% | 4.2 | 0% | 3.0 | -29% | 8.9 | 3.7 | -58% | 3.9 | 5% | 3.1 | -16% |
| | M221B | 7.0 | 5.1 | -27% | 5.1 | 0% | 3.7 | -27% | 9.0 | 4.0 | -56% | 4.0 | 0% | 3.2 | -20% |
| | M221C | 8.0 | 5.4 | -33% | 5.4 | 0% | 3.8 | -30% | 7.7 | 3.9 | -49% | 4.0 | 3% | 3.0 | -23% |
| Chestnut oak | Assessment area | 5.6 | 4.5 | -20% | 4.6 | 2% | 4.4 | -2% | 14.9 | 25.8 | 73% | 27.0 | 5% | 24.4 | -5% |
| | 221E | 4.2 | 3.6 | -14% | 3.6 | 0% | 3.4 | -6% | 9.6 | 20.1 | 109% | 21.2 | 5% | 16.5 | -18% |
| | 221F | 0.2 | 0.1 | -50% | 0.1 | 0% | 0.1 | 0% | 0.9 | 1.8 | 100% | 1.6 | -11% | 1.7 | -6% |
| | M221A | 8.3 | 6.5 | -22% | 6.9 | 6% | 6.8 | 5% | 21.7 | 31.6 | 46% | 36.2 | 15% | 36.2 | 15% |
| | M221B | 8.3 | 6.5 | -22% | 6.6 | 2% | 6.7 | 3% | 24.2 | 41.0 | 69% | 41.2 | 0% | 42.9 | 5% |
| | M221C | 8.2 | 6.1 | -26% | 6.2 | 2% | 5.8 | -5% | 24.1 | 35.6 | 48% | 36.8 | 3% | 32.8 | -8% |
| Eastern hemlock | Assessment area | 1.7 | 1.2 | -29% | 1.2 | 1% | 1.1 | -5% | 6.1 | 3.2 | -47% | 3.3 | 3% | 2.5 | -21% |
| | 221E | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.4 | 0% | 1.7 | 1.0 | -41% | 1.1 | 10% | 0.8 | -20% |
| | 221F | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 0.7 | 1.1 | 57% | 1.0 | -9% | 0.7 | -36% |
| | M221A | 3.2 | 2.1 | -34% | 2.2 | 5% | 2.0 | -5% | 9.4 | 5.2 | -45% | 5.5 | 6% | 3.9 | -25% |
| | M221B | 3.4 | 2.3 | -32% | 2.3 | 0% | 2.2 | -4% | 11.0 | 6.2 | -44% | 6.3 | 2% | 5.1 | -18% |
| | M221C | 3.1 | 2.3 | -26% | 2.3 | 0% | 2.1 | -9% | 15.3 | 6.7 | -56% | 6.8 | 1% | 5.2 | -22% |
| Eastern redcedar | Assessment area | 0.1 | 0.0 | -56% | 0.0 | 0% | 0.0 | 0% | 0.8 | 0.8 | 2% | 0.8 | 0% | 0.5 | -41% |
| | 221E | 0.1 | 0.0 | -100% | 0.0 | 0% | 0.0 | 0% | 0.7 | 0.4 | -43% | 0.4 | 0% | 0.2 | -50% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 1.6 | 2.9 | 81% | 3.2 | 10% | 1.8 | -38% |
| | M221B | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 1.2 | 1.4 | 17% | 1.3 | -7% | 0.9 | -36% |
| | M221C | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.4 | 0.4 | 0% | 0.4 | 0% | 0.2 | -50% |

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**Table 40 (continued).**

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree species | Section[a] | BA in 2009 | BA in 2040 | Change from 2009[b] | BA in 2040 | Change from current climate[c] | BA in 2040 | Change from current climate[c] | TPA in 2009 | TPA in 2040 | Change from 2009[b] | TPA in 2040 | Change from current climate[c] | TPA in 2040 | Change from current climate[c] |
| Eastern whitepine | Assessment area | 1.2 | 1.2 | 7% | 1.2 | 0% | 1.2 | -7% | 7.3 | 6.6 | -10% | 6.8 | 3% | 4.6 | -30% |
| | 221E | 0.9 | 1.0 | 11% | 1.0 | 0% | 0.9 | -10% | 4.7 | 4.8 | 2% | 5.0 | 4% | 3.2 | -33% |
| | 221F | 0.4 | 0.4 | 0% | 0.4 | 0% | 0.4 | 0% | 1.3 | 4.1 | 215% | 4.1 | 0% | 2.5 | -39% |
| | M221A | 1.4 | 1.8 | 29% | 1.8 | 0% | 1.7 | -6% | 12.8 | 11.1 | -13% | 12.0 | 8% | 7.8 | -30% |
| | M221B | 1.9 | 2.2 | 16% | 2.2 | 0% | 2.1 | -5% | 14.7 | 12.8 | -13% | 12.7 | -1% | 9.6 | -25% |
| | M221C | 1.4 | 1.0 | -29% | 1.0 | 0% | 0.9 | -10% | 6.8 | 3.2 | -53% | 3.4 | 6% | 2.1 | -34% |
| Loblolly pine | Assessment area | 0.1 | 0.1 | 39% | 0.1 | 0% | 0.1 | 17% | 0.5 | 0.3 | -34% | 0.4 | 15% | 0.3 | 0% |
| | 221E | 0.1 | 0.2 | 100% | 0.2 | 0% | 0.2 | 0% | 0.8 | 0.6 | -25% | 0.7 | 17% | 0.6 | 0% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 0.4 | 0.1 | -75% | 0.1 | 0% | 0.1 | 0% |
| | M221B | 0.1 | 0.0 | -100% | 0.0 | 0% | 0.1 | NA | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% |
| | M221C | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| Northern red oak | Assessment area | 6.8 | 7.7 | 14% | 7.8 | 1% | 8.0 | 3% | 11.9 | 6.8 | -43% | 7.5 | 11% | 6.9 | 2% |
| | 221E | 5.2 | 6.1 | 17% | 6.1 | 0% | 6.3 | 3% | 10.2 | 6.1 | -40% | 6.5 | 7% | 5.9 | -3% |
| | 221F | 5.9 | 6.1 | 3% | 6.3 | 3% | 6.2 | 2% | 10.9 | 6.2 | -43% | 8.3 | 34% | 8.2 | 32% |
| | M221A | 8.7 | 9.4 | 8% | 9.5 | 1% | 9.8 | 4% | 13.6 | 7.6 | -44% | 8.5 | 12% | 7.7 | 1% |
| | M221B | 9.3 | 10.8 | 16% | 10.9 | 1% | 11.2 | 4% | 16.6 | 8.2 | -51% | 9.2 | 12% | 8.6 | 5% |
| | M221C | 7.9 | 9.1 | 15% | 9.2 | 1% | 9.2 | 1% | 11.3 | 6.9 | -39% | 7.4 | 7% | 6.7 | -3% |
| Pignut hickory | Assessment area | 2.6 | 2.5 | -2% | 2.6 | 1% | 2.6 | 1% | 7.3 | 6.3 | -14% | 6.5 | 3% | 5.9 | -7% |
| | 221E | 2.6 | 2.6 | 0% | 2.6 | 0% | 2.6 | 0% | 6.9 | 6.4 | -7% | 6.6 | 3% | 5.7 | -11% |
| | 221F | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.4 | 0% | 0.7 | 1.0 | 43% | 1.0 | 0% | 1.0 | 0% |
| | M221A | 2.9 | 2.9 | 0% | 3.0 | 3% | 3.0 | 3% | 10.3 | 7.2 | -30% | 7.9 | 10% | 7.1 | -1% |
| | M221B | 2.9 | 2.9 | 0% | 3.0 | 3% | 3.1 | 7% | 9.8 | 8.3 | -15% | 8.3 | 0% | 8.0 | -4% |
| | M221C | 3.0 | 2.8 | -7% | 2.8 | 0% | 2.7 | -4% | 7.6 | 6.1 | -20% | 6.3 | 3% | 5.7 | -7% |
| Red maple | Assessment area | 16.0 | 22.7 | 42% | 22.9 | 1% | 24.6 | 8% | 77.4 | 61.4 | -21% | 62.8 | 2% | 59.0 | -4% |
| | 221E | 13.8 | 21.0 | 52% | 21.1 | 0% | 22.9 | 9% | 72.7 | 60.5 | -17% | 62.0 | 2% | 57.2 | -5% |
| | 221F | 23.6 | 32.3 | 37% | 32.6 | 1% | 34.2 | 6% | 81.6 | 110.8 | 36% | 111.7 | 1% | 109.1 | -2% |
| | M221A | 18.0 | 22.4 | 24% | 22.8 | 2% | 24.0 | 7% | 66.8 | 50.9 | -24% | 55.5 | 9% | 53.8 | 6% |
| | M221B | 17.5 | 23.2 | 33% | 23.5 | 1% | 25.0 | 8% | 77.0 | 49.0 | -36% | 49.4 | 1% | 47.9 | -2% |
| | M221C | 15.5 | 22.3 | 44% | 22.4 | 0% | 24.4 | 9% | 97.2 | 57.7 | -41% | 58.6 | 2% | 52.8 | -8% |
| Red spruce | Assessment area | 1.0 | 0.5 | -50% | 0.5 | 2% | 0.5 | -6% | 5.1 | 1.3 | -74% | 1.3 | 0% | 1.0 | 0% |
| | 221E | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 1.7 | 0.2 | -88% | 0.2 | 0% | 0.1 | -50% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 3.4 | 1.7 | -50% | 1.8 | 6% | 1.6 | -6% | 17.0 | 3.2 | -81% | 3.3 | 3% | 2.5 | -22% |
| | M221B | 2.5 | 1.4 | -44% | 1.4 | 0% | 1.3 | -7% | 13.0 | 4.8 | -63% | 4.6 | -4% | 3.6 | -25% |
| | M221C | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 1.4 | 0.2 | -86% | 0.2 | 0% | 0.1 | -50% |

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**Table 40 (continued).**

|  |  | Current climate |  |  | PCM B1 |  | GFDL A1FI |  | Current climate |  |  | PCM B1 |  | GFDL A1FI |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree species | Section[a] | BA in 2009 | BA in 2040 | Change from 2009[b] | BA in 2040 | Change from current climate[c] | BA in 2040 | Change from current climate[c] | TPA in 2009 | TPA in 2040 | Change from 2009[b] | TPA in 2040 | Change from current climate[c] | TPA in 2040 | Change from current climate[c] |
| Scarlet oak | Assessment area | 4.8 | 3.5 | -27% | 3.5 | 0% | 2.4 | -33% | 4.0 | 2.3 | -43% | 2.3 | 2% | 1.8 | -23% |
|  | 221E | 3.4 | 2.0 | -41% | 2.0 | 0% | 1.2 | -40% | 2.5 | 1.4 | -44% | 1.4 | 0% | 1.0 | -29% |
|  | 221F | 0.3 | 0.3 | 0% | 0.3 | 0% | 0.3 | 0% | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.4 | 0% |
|  | M221A | 6.7 | 5.5 | -18% | 5.4 | -2% | 4.1 | -25% | 6.4 | 3.5 | -45% | 3.6 | 3% | 2.8 | -20% |
|  | M221B | 7.4 | 6.3 | -15% | 6.3 | 0% | 4.5 | -29% | 6.7 | 3.9 | -42% | 4.0 | 3% | 3.2 | -18% |
|  | M221C | 7.8 | 5.6 | -28% | 5.6 | 0% | 3.5 | -38% | 6.2 | 3.5 | -44% | 3.6 | 3% | 2.6 | -26% |
| Sugar maple | Assessment area | 6.1 | 7.2 | 17% | 7.3 | 2% | 7.1 | -1% | 54.1 | 54.4 | 0% | 55.7 | 2% | 39.6 | -27% |
|  | 221E | 5.9 | 7.3 | 24% | 7.4 | 1% | 7.1 | -3% | 53.4 | 55.9 | 5% | 57.7 | 3% | 38.1 | -32% |
|  | 221F | 7.0 | 8.4 | 20% | 8.5 | 1% | 8.3 | -1% | 73.8 | 73.4 | -1% | 72.3 | -1% | 51.3 | -30% |
|  | M221A | 6.8 | 7.4 | 9% | 7.9 | 7% | 7.7 | 4% | 47.2 | 62.1 | 32% | 67.8 | 9% | 49.4 | -20% |
|  | M221B | 6.4 | 6.9 | 8% | 7.0 | 1% | 7.1 | 3% | 49.9 | 48.0 | -4% | 47.7 | -1% | 39.3 | -18% |
|  | M221C | 5.5 | 6.1 | 11% | 6.2 | 2% | 6.0 | -2% | 54.7 | 41.4 | -24% | 41.9 | 1% | 31.8 | -23% |
| Tulip tree | Assessment area | 6.5 | 8.4 | 31% | 8.6 | 1% | 8.7 | 3% | 22.9 | 67.3 | 194% | 69.6 | 3% | 68.5 | 2% |
|  | 221E | 6.6 | 9.0 | 36% | 9.1 | 1% | 9.1 | 1% | 25.0 | 76.0 | 204% | 79.5 | 5% | 75.7 | 0% |
|  | 221F | 2.1 | 3.5 | 67% | 3.5 | 0% | 3.8 | 9% | 9.5 | 62.1 | 554% | 61.1 | -2% | 59.0 | -5% |
|  | M221A | 5.8 | 6.1 | 5% | 6.3 | 3% | 6.3 | 3% | 14.1 | 21.3 | 51% | 24.1 | 13% | 22.4 | 5% |
|  | M221B | 5.7 | 7.2 | 26% | 7.3 | 1% | 7.7 | 7% | 16.9 | 53.3 | 215% | 52.4 | -2% | 57.8 | 8% |
|  | M221C | 9.9 | 12.5 | 26% | 12.7 | 2% | 13.0 | 4% | 36.6 | 88.7 | 142% | 92.4 | 4% | 93.1 | 5% |
| White ash | Assessment area | 2.5 | 2.8 | 14% | 2.8 | 0% | 2.8 | -2% | 11.9 | 10.9 | -8% | 11.3 | 4% | 9.6 | -12% |
|  | 221E | 2.7 | 3.1 | 15% | 3.1 | 0% | 3.0 | -3% | 14.0 | 10.4 | -26% | 11.0 | 6% | 8.6 | -17% |
|  | 221F | 4.8 | 5.5 | 15% | 5.6 | 2% | 5.3 | -4% | 19.5 | 35.9 | 84% | 36.3 | 1% | 32.9 | -8% |
|  | M221A | 1.9 | 2.1 | 11% | 2.1 | 0% | 2.1 | 0% | 8.1 | 3.8 | -53% | 4.1 | 8% | 3.4 | -11% |
|  | M221B | 1.7 | 2.0 | 18% | 2.0 | 0% | 2.1 | 5% | 8.0 | 8.5 | 6% | 8.6 | 1% | 8.1 | -5% |
|  | M221C | 1.7 | 1.8 | 6% | 1.8 | 0% | 1.8 | 0% | 8.0 | 5.9 | -26% | 6.1 | 3% | 5.1 | -14% |
| White oak | Assessment area | 5.7 | 5.9 | 3% | 6.0 | 2% | 6.0 | 2% | 12.8 | 36.6 | 185% | 38.1 | 4% | 35.2 | -4% |
|  | 221E | 6.6 | 7.1 | 8% | 7.2 | 1% | 7.0 | -1% | 15.0 | 43.2 | 188% | 45.2 | 5% | 40.0 | -7% |
|  | 221F | 1.1 | 1.4 | 27% | 1.4 | 0% | 1.4 | 0% | 2.9 | 13.8 | 376% | 14.1 | 2% | 12.8 | -7% |
|  | M221A | 5.6 | 5.2 | -7% | 5.5 | 6% | 5.7 | 10% | 12.8 | 29.8 | 133% | 33.0 | 11% | 30.2 | 1% |
|  | M221B | 5.6 | 5.4 | -4% | 5.5 | 2% | 5.8 | 7% | 12.3 | 34.5 | 180% | 34.9 | 1% | 35.0 | 1% |
|  | M221C | 5.7 | 5.6 | -2% | 5.7 | 2% | 5.8 | 4% | 12.2 | 35.3 | 189% | 36.2 | 3% | 35.9 | 2% |

[a] Assessment area values were derived from the weighted average of sections.

[b] Change under current climate represents the difference from 2009 through 2100 due to succession and management, but not climate.

[c] Change from current climate for PCM B1 and GFDL A1FI represents the difference between these scenarios and current climate in 2100 and represents the potential change due to climate change.

**Table 41.—Absolute and percentage change in basal area (BA) and trees per acre (TPA) predicted by the LANDIS PRO model for 17 species under current climate and two climate scenarios for the assessment area in year 2070**

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree species | Section[a] | BA in 2009 | BA in 2070 | Change from 2009[b] | BA in 2070 | Change from current climate[c] | BA in 2070 | Change from current climate[c] | TPA in 2009 | TPA in 2070 | Change from 2009[b] | TPA in 2070 | Change from current climate[c] | TPA in 2070 | Change from current climate[c] |
| AmerAmerican beech | Assessment area | 5.1 | 4.4 | -14% | 4.4 | 1% | 4.3 | -3% | 26.8 | 12.9 | -52% | 12.7 | -1% | 10.3 | -20% |
| | 221E | 3.9 | 3.8 | -3% | 3.8 | 0% | 3.6 | -5% | 19.7 | 11.0 | -44% | 10.7 | -3% | 8.1 | -26% |
| | 221F | 4.5 | 3.8 | -16% | 3.9 | 3% | 3.7 | -3% | 16.7 | 11.8 | -29% | 11.9 | 1% | 9.1 | -23% |
| | M221A | 7.2 | 5.6 | -22% | 5.9 | 5% | 5.6 | 0% | 39.8 | 14.7 | -63% | 15.7 | 7% | 12.1 | -18% |
| | M221B | 6.6 | 5.1 | -23% | 5.1 | 0% | 5.1 | 0% | 36.0 | 15.8 | -56% | 15.7 | -1% | 14.5 | -8% |
| | M221C | 6.1 | 5.1 | -16% | 5.1 | 0% | 4.9 | -4% | 36.2 | 14.9 | -59% | 14.2 | -5% | 12.1 | -19% |
| Black cherry | Assessment area | 7.3 | 7.6 | 4% | 7.8 | 1% | 7.7 | 1% | 18.9 | 9.4 | -51% | 9.5 | 1% | 9.2 | -1% |
| | 221E | 7.2 | 7.8 | 8% | 8.0 | 3% | 7.9 | 1% | 19.3 | 10.0 | -48% | 10.0 | 0% | 9.7 | -3% |
| | 221F | 13.8 | 15.6 | 13% | 15.5 | -1% | 15.6 | 0% | 42.3 | 26.5 | -37% | 26.6 | 0% | 26.0 | -2% |
| | M221A | 8.0 | 6.4 | -20% | 6.4 | 0% | 6.5 | 2% | 15.8 | 5.3 | -66% | 5.6 | 6% | 5.6 | 6% |
| | M221B | 7.4 | 7.1 | -4% | 7.1 | 0% | 7.0 | -1% | 15.4 | 6.2 | -60% | 6.4 | 3% | 6.4 | 3% |
| | M221C | 3.6 | 4.1 | 14% | 4.2 | 2% | 4.1 | 0% | 10.8 | 4.0 | -63% | 4.1 | 2% | 4.0 | 0% |
| Black oak | Assessment area | 6.8 | 2.1 | -69% | 2.2 | 3% | 2.1 | 1% | 8.4 | 2.4 | -72% | 2.4 | 2% | 2.3 | -4% |
| | 221E | 7.3 | 2.4 | -67% | 2.5 | 4% | 2.4 | 0% | 9.5 | 2.8 | -71% | 2.8 | 0% | 2.6 | -7% |
| | 221F | 2.1 | 0.4 | -81% | 0.4 | 0% | 0.4 | 0% | 1.5 | 0.6 | -60% | 0.6 | 0% | 0.6 | 0% |
| | M221A | 6.4 | 1.9 | -70% | 2.0 | 5% | 2.0 | 5% | 8.9 | 2.2 | -75% | 2.4 | 9% | 2.3 | 5% |
| | M221B | 7.0 | 2.3 | -67% | 2.3 | 0% | 2.4 | 4% | 9.0 | 2.3 | -74% | 2.4 | 4% | 2.4 | 4% |
| | M221C | 8.0 | 2.1 | -74% | 2.1 | 0% | 2.1 | 0% | 7.7 | 2.2 | -71% | 2.2 | 0% | 2.1 | -5% |
| Chestnut oak | Assessment area | 5.6 | 4.7 | -17% | 4.8 | 3% | 4.5 | -3% | 14.9 | 29.4 | 97% | 31.2 | 6% | 25.5 | -13% |
| | 221E | 4.2 | 3.6 | -14% | 3.7 | 3% | 3.3 | -8% | 9.6 | 22.4 | 133% | 22.6 | 1% | 14.6 | -35% |
| | 221F | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 0.9 | 1.4 | 56% | 1.4 | 0% | 1.3 | -7% |
| | M221A | 8.3 | 6.8 | -18% | 7.5 | 10% | 7.3 | 7% | 21.7 | 36.5 | 68% | 46.8 | 28% | 44.2 | 21% |
| | M221B | 8.3 | 7.1 | -14% | 7.2 | 1% | 7.2 | 1% | 24.2 | 48.4 | 100% | 52.0 | 7% | 50.2 | 4% |
| | M221C | 8.2 | 6.4 | -22% | 6.5 | 2% | 6.0 | -6% | 24.1 | 40.0 | 66% | 40.8 | 2% | 32.4 | -19% |
| Eastern hemlock | Assessment area | 1.7 | 1.1 | -34% | 1.1 | 1% | 1.1 | -1% | 6.1 | 2.9 | -52% | 2.8 | -3% | 2.1 | -27% |
| | 221E | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.4 | 0% | 1.7 | 1.1 | -35% | 1.1 | 0% | 0.7 | -36% |
| | 221F | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 0.7 | 1.2 | 71% | 1.3 | 8% | 0.6 | -50% |
| | M221A | 3.2 | 1.9 | -41% | 2.0 | 5% | 1.9 | 0% | 9.4 | 4.0 | -57% | 4.4 | 10% | 2.9 | -28% |
| | M221B | 3.4 | 2.1 | -38% | 2.1 | 0% | 2.1 | 0% | 11.0 | 5.5 | -50% | 5.4 | -2% | 4.7 | -15% |
| | M221C | 3.1 | 2.1 | -32% | 2.1 | 0% | 2.0 | -5% | 15.3 | 5.8 | -62% | 5.1 | -12% | 3.9 | -33% |
| Eastern redcedar | Assessment area | 0.1 | 0.0 | -56% | 0.0 | 0% | 0.0 | 0% | 0.8 | 0.2 | -75% | 0.2 | 0% | 0.2 | 0% |
| | 221E | 0.1 | 0.0 | -100% | 0.0 | 0% | 0.0 | 0% | 0.7 | 0.1 | -86% | 0.1 | 0% | 0.1 | 0% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 1.6 | 0.8 | -50% | 0.9 | 13% | 0.8 | 0% |
| | M221B | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 1.2 | 0.3 | -75% | 0.3 | 0% | 0.3 | 0% |
| | M221C | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.4 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% |

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**Table 41 (continued).**

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tree species** | **Section[a]** | **BA in 2009** | **BA in 2070** | **Change from 2009[b]** | **BA in 2070** | **Change from current climate[c]** | **BA in 2070** | **Change from current climate[c]** | **TPA in 2009** | **TPA in 2070** | **Change from 2009[b]** | **TPA in 2070** | **Change from current climate[c]** | **TPA in 2070** | **Change from current climate[c]** |
| Eastern white pine | Assessment area | 1.2 | 1.1 | -2% | 1.1 | 1% | 1.1 | -6% | 7.3 | 3.7 | -49% | 3.7 | 1% | 2.7 | -26% |
| | 221E | 0.9 | 0.9 | 0% | 0.9 | 0% | 0.8 | -11% | 4.7 | 2.9 | -38% | 2.8 | -3% | 1.8 | -38% |
| | 221F | 0.4 | 0.4 | 0% | 0.4 | 0% | 0.4 | 0% | 1.3 | 2.0 | 54% | 2.1 | 5% | 1.2 | -40% |
| | M221A | 1.4 | 1.7 | 21% | 1.8 | 6% | 1.6 | -6% | 12.8 | 6.7 | -48% | 7.2 | 7% | 4.8 | -28% |
| | M221B | 1.9 | 2.0 | 5% | 2.0 | 0% | 2.0 | 0% | 14.7 | 6.8 | -54% | 6.9 | 1% | 6.2 | -9% |
| | M221C | 1.4 | 0.9 | -36% | 0.9 | 0% | 0.8 | -11% | 6.8 | 1.7 | -75% | 1.7 | 0% | 1.1 | -35% |
| Loblolly pine | Assessment area | 0.1 | 0.2 | 127% | 0.2 | 0% | 0.2 | 0% | 0.5 | 0.2 | -54% | 0.3 | 22% | 0.3 | 22% |
| | 221E | 0.1 | 0.3 | 200% | 0.3 | 0% | 0.3 | 0% | 0.8 | 0.4 | -50% | 0.5 | 25% | 0.5 | 25% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 0.4 | 0.1 | -75% | 0.1 | 0% | 0.1 | 0% |
| | M221B | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% |
| | M221C | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| Northern red oak | Assessment area | 6.8 | 5.8 | -15% | 5.9 | 3% | 5.9 | 2% | 11.9 | 4.9 | -59% | 6.4 | 32% | 5.9 | 22% |
| | 221E | 5.2 | 4.7 | -10% | 4.9 | 4% | 4.8 | 2% | 10.2 | 4.9 | -52% | 5.7 | 16% | 4.9 | 0% |
| | 221F | 5.9 | 4.5 | -24% | 4.8 | 7% | 4.9 | 9% | 10.9 | 4.0 | -63% | 8.4 | 110% | 8.1 | 103% |
| | M221A | 8.7 | 6.6 | -24% | 6.7 | 2% | 6.7 | 2% | 13.6 | 5.2 | -62% | 6.8 | 31% | 6.5 | 25% |
| | M221B | 9.3 | 7.8 | -16% | 8.0 | 3% | 8.1 | 4% | 16.6 | 4.9 | -70% | 7.6 | 55% | 7.6 | 55% |
| | M221C | 7.9 | 6.9 | -13% | 6.9 | 0% | 6.8 | -1% | 11.3 | 4.9 | -57% | 5.9 | 20% | 5.4 | 10% |
| Pignut hickory | Assessment area | 2.6 | 2.7 | 4% | 2.7 | 2% | 2.7 | 0% | 7.3 | 5.6 | -24% | 5.8 | 4% | 5.6 | 0% |
| | 221E | 2.6 | 2.7 | 4% | 2.8 | 4% | 2.7 | 0% | 6.9 | 5.8 | -16% | 5.8 | 0% | 5.4 | -7% |
| | 221F | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.4 | 0% | 0.7 | 1.0 | 43% | 1.0 | 0% | 1.0 | 0% |
| | M221A | 2.9 | 3.0 | 3% | 3.1 | 3% | 3.1 | 3% | 10.3 | 5.5 | -47% | 6.6 | 20% | 6.6 | 20% |
| | M221B | 2.9 | 3.2 | 10% | 3.2 | 0% | 3.2 | 0% | 9.8 | 7.2 | -27% | 7.7 | 7% | 7.7 | 7% |
| | M221C | 3.0 | 3.0 | 0% | 3.0 | 0% | 2.9 | -3% | 7.6 | 5.6 | -26% | 5.9 | 5% | 5.4 | -4% |
| Red maple | Assessment area | 16.0 | 27.6 | 73% | 27.9 | 1% | 27.6 | 0% | 77.4 | 58.2 | -25% | 60.5 | 4% | 59.6 | 2% |
| | 221E | 13.8 | 26.6 | 93% | 27.0 | 2% | 26.4 | -1% | 72.7 | 58.7 | -19% | 59.3 | 1% | 57.6 | -2% |
| | 221F | 23.6 | 35.9 | 52% | 35.9 | 0% | 35.8 | 0% | 81.6 | 108.7 | 33% | 114.5 | 5% | 113.0 | 4% |
| | M221A | 18.0 | 24.8 | 38% | 25.7 | 4% | 25.8 | 4% | 66.8 | 51.7 | -23% | 61.1 | 18% | 59.8 | 16% |
| | M221B | 17.5 | 26.7 | 53% | 26.6 | 0% | 27.1 | 1% | 77.0 | 44.8 | -42% | 46.1 | 3% | 48.2 | 8% |
| | M221C | 15.5 | 28.8 | 86% | 29.1 | 1% | 28.4 | -1% | 97.2 | 48.6 | -50% | 50.9 | 5% | 49.4 | 2% |
| Red spruce | Assessment area | 1.0 | 0.4 | -57% | 0.4 | 0% | 0.4 | 0% | 5.1 | 0.7 | -86% | 0.7 | 0% | 0.6 | 0% |
| | 221E | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 1.7 | 0.1 | -94% | 0.1 | 0% | 0.1 | 0% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 3.4 | 1.4 | -59% | 1.4 | 0% | 1.4 | 0% | 17.0 | 1.5 | -91% | 1.5 | 0% | 1.4 | -7% |
| | M221B | 2.5 | 1.2 | -52% | 1.2 | 0% | 1.2 | 0% | 13.0 | 2.8 | -78% | 2.7 | -4% | 2.2 | -21% |
| | M221C | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 1.4 | 0.1 | -93% | 0.1 | 0% | 0.1 | 0% |

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Table 41 (continued).

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tree species** | **Section[a]** | **BA in 2009** | **BA in 2070** | **Change from 2009[b]** | **BA in 2070** | **Change from current climate[c]** | **BA in 2070** | **Change from current climate[c]** | **TPA in 2009** | **TPA in 2070** | **Change from 2009[b]** | **TPA in 2070** | **Change from current climate[c]** | **TPA in 2070** | **Change from current climate[c]** |
| Scarlet oak | Assessment area | 4.8 | 0.9 | -81% | 0.9 | 0% | 0.9 | -2% | 4.0 | 1.3 | -68% | 1.3 | 3% | 1.2 | -10% |
| | 221E | 3.4 | 0.5 | -85% | 0.5 | 0% | 0.5 | 0% | 2.5 | 0.8 | -68% | 0.8 | 0% | 0.7 | -13% |
| | 221F | 0.3 | 0.2 | -33% | 0.2 | 0% | 0.2 | 0% | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.3 | -25% |
| | M221A | 6.7 | 1.5 | -78% | 1.5 | 0% | 1.5 | 0% | 6.4 | 1.8 | -72% | 2.0 | 11% | 1.7 | -6% |
| | M221B | 7.4 | 1.6 | -78% | 1.6 | 0% | 1.6 | 0% | 6.7 | 2.2 | -67% | 2.2 | 0% | 2.1 | -5% |
| | M221C | 7.8 | 1.5 | -81% | 1.5 | 0% | 1.4 | -7% | 6.2 | 2.0 | -68% | 2.1 | 5% | 1.7 | -15% |
| Sugar maple | Assessment area | 6.1 | 7.5 | 23% | 7.6 | 1% | 7.2 | -4% | 54.1 | 43.2 | -20% | 42.0 | -3% | 30.3 | -30% |
| | 221E | 5.9 | 7.6 | 29% | 7.7 | 1% | 7.2 | -5% | 53.4 | 42.0 | -21% | 40.5 | -4% | 27.5 | -35% |
| | 221F | 7.0 | 8.5 | 21% | 8.6 | 1% | 8.3 | -2% | 73.8 | 44.7 | -39% | 44.4 | -1% | 30.2 | -32% |
| | M221A | 6.8 | 8.1 | 19% | 8.5 | 5% | 8.0 | -1% | 47.2 | 63.3 | 34% | 64.3 | 2% | 41.6 | -34% |
| | M221B | 6.4 | 7.3 | 14% | 7.3 | 0% | 7.3 | 0% | 49.9 | 42.9 | -14% | 41.3 | -4% | 37.6 | -12% |
| | M221C | 5.5 | 6.4 | 16% | 6.4 | 0% | 6.1 | -5% | 54.7 | 33.6 | -39% | 31.9 | -5% | 23.1 | -31% |
| Tulip tree | Assessment area | 6.5 | 9.9 | 53% | 10.0 | 2% | 9.8 | -1% | 22.9 | 80.2 | 251% | 84.6 | 5% | 81.2 | 1% |
| | 221E | 6.6 | 10.4 | 58% | 10.6 | 2% | 10.2 | -2% | 25.0 | 91.0 | 264% | 94.4 | 4% | 88.6 | -3% |
| | 221F | 2.1 | 4.9 | 133% | 4.9 | 0% | 4.9 | 0% | 9.5 | 83.1 | 775% | 84.6 | 2% | 83.1 | 0% |
| | M221A | 5.8 | 6.0 | 3% | 6.3 | 5% | 6.5 | 8% | 14.1 | 19.9 | 41% | 24.8 | 25% | 27.2 | 37% |
| | M221B | 5.7 | 8.7 | 53% | 8.8 | 1% | 8.9 | 2% | 16.9 | 65.4 | 287% | 70.5 | 8% | 72.8 | 11% |
| | M221C | 9.9 | 14.9 | 51% | 15.0 | 1% | 14.6 | -2% | 36.6 | 100.6 | 175% | 108.7 | 8% | 101.1 | 0% |
| White ash | Assessment area | 2.5 | 3.0 | 20% | 3.0 | 1% | 2.9 | -1% | 11.9 | 8.7 | -27% | 9.2 | 6% | 8.2 | -6% |
| | 221E | 2.7 | 3.3 | 22% | 3.3 | 0% | 3.2 | -3% | 14.0 | 8.0 | -43% | 8.7 | 9% | 6.9 | -14% |
| | 221F | 4.8 | 5.3 | 10% | 5.2 | -2% | 5.2 | -2% | 19.5 | 30.9 | 58% | 30.5 | -1% | 29.8 | -4% |
| | M221A | 1.9 | 2.2 | 16% | 2.3 | 5% | 2.2 | 0% | 8.1 | 2.3 | -72% | 2.6 | 13% | 2.6 | 13% |
| | M221B | 1.7 | 2.2 | 29% | 2.3 | 5% | 2.3 | 5% | 8.0 | 7.2 | -10% | 7.8 | 8% | 7.8 | 8% |
| | M221C | 1.7 | 2.0 | 18% | 2.1 | 5% | 2.0 | 0% | 8.0 | 4.4 | -45% | 4.8 | 9% | 4.3 | -2% |
| White oak | Assessment area | 5.7 | 6.9 | 21% | 7.1 | 3% | 6.8 | -2% | 12.8 | 48.5 | 278% | 51.1 | 5% | 48.1 | -1% |
| | 221E | 6.6 | 8.1 | 23% | 8.3 | 2% | 7.8 | -4% | 15.0 | 56.8 | 279% | 58.4 | 3% | 53.8 | -5% |
| | 221F | 1.1 | 1.5 | 36% | 1.6 | 7% | 1.5 | 0% | 2.9 | 18.4 | 534% | 18.9 | 3% | 17.8 | -3% |
| | M221A | 5.6 | 6.3 | 13% | 6.7 | 6% | 6.5 | 3% | 12.8 | 38.2 | 198% | 46.1 | 21% | 43.9 | 15% |
| | M221B | 5.6 | 6.7 | 20% | 6.8 | 1% | 6.8 | 1% | 12.3 | 47.5 | 286% | 51.2 | 8% | 51.0 | 7% |
| | M221C | 5.7 | 6.9 | 21% | 7.0 | 1% | 6.7 | -3% | 12.2 | 46.8 | 284% | 49.2 | 5% | 46.2 | -1% |

[a] Assessment area values were derived from the weighted average of sections.

[b] Change under current climate represents the difference from 2009 through 2100 due to succession and management, but not climate.

[c] Change from current climate for PCM B1 and GFDL A1FI represents the difference between these scenarios and current climate in 2100 and represents the potential change due to climate change.

Table 42.—Absolute and percent change in basal area (BA) and trees per acre (TPA) predicted by the LANDIS PRO model for 17 species for current climate and two climate scenarios for the assessment area in year 2100

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree species | Section[a] | BA in 2009 | BA in 2100 | Change from 2009[b] | BA in 2100 | Change from current climate[c] | BA in 2100 | Change from current climate[c] | TPA in 2009 | TPA in 2100 | Change from 2009[b] | TPA in 2100 | Change from current climate[c] | TPA in 2100 | Change from current climate[c] |
| American beech | Assessment area | 5.1 | 4.6 | -9% | 4.6 | 0% | 4.2 | -10% | 26.8 | 14.2 | -47% | 13.9 | -2% | 8.1 | -43% |
| | 221E | 3.9 | 4.0 | 3% | 4.0 | 0% | 3.5 | -13% | 19.7 | 11.4 | -42% | 11.0 | -4% | 5.9 | -48% |
| | 221F | 4.5 | 3.6 | -20% | 3.7 | 3% | 3.2 | -11% | 16.7 | 12.7 | -24% | 13.2 | 4% | 5.4 | -57% |
| | M221A | 7.2 | 5.7 | -21% | 6.0 | 5% | 5.3 | -7% | 39.8 | 14.7 | -63% | 15.3 | 4% | 8.2 | -44% |
| | M221B | 6.6 | 5.5 | -17% | 5.5 | 0% | 5.3 | -4% | 36.0 | 17.9 | -50% | 18.1 | 1% | 14.0 | -22% |
| | M221C | 6.1 | 5.4 | -11% | 5.3 | -2% | 4.8 | -11% | 36.2 | 19.0 | -48% | 17.4 | -8% | 9.2 | -52% |
| Black cherry | Assessment area | 7.3 | 4.6 | -38% | 4.6 | 1% | 4.5 | -1% | 18.9 | 7.2 | -62% | 7.3 | 2% | 7.3 | 2% |
| | 221E | 7.2 | 4.8 | -33% | 4.9 | 2% | 4.7 | -2% | 19.3 | 7.6 | -61% | 7.7 | 1% | 7.6 | 0% |
| | 221F | 13.8 | 10.6 | -23% | 10.6 | 0% | 10.5 | -1% | 42.3 | 21.8 | -48% | 21.7 | 0% | 21.3 | -2% |
| | M221A | 8.0 | 3.0 | -63% | 3.0 | 0% | 3.0 | 0% | 15.8 | 3.2 | -80% | 3.8 | 19% | 4.0 | 25% |
| | M221B | 7.4 | 3.5 | -53% | 3.5 | 0% | 3.5 | 0% | 15.4 | 4.6 | -70% | 4.9 | 7% | 5.1 | 11% |
| | M221C | 3.6 | 2.7 | -25% | 2.8 | 4% | 2.7 | 0% | 10.8 | 3.2 | -70% | 3.2 | 0% | 3.2 | 0% |
| Black oak | Assessment area | 6.8 | 1.5 | -78% | 1.5 | 1% | 1.5 | -2% | 8.4 | 2.0 | -77% | 2.0 | 1% | 1.8 | -10% |
| | 221E | 7.3 | 1.7 | -77% | 1.7 | 0% | 1.6 | -6% | 9.5 | 2.3 | -76% | 2.3 | 0% | 1.9 | -17% |
| | 221F | 2.1 | 0.3 | -86% | 0.3 | 0% | 0.3 | 0% | 1.5 | 0.5 | -67% | 0.5 | 0% | 0.5 | 0% |
| | M221A | 6.4 | 1.5 | -77% | 1.6 | 7% | 1.6 | 7% | 8.9 | 1.7 | -81% | 1.9 | 12% | 1.9 | 12% |
| | M221B | 7.0 | 1.6 | -77% | 1.6 | 0% | 1.7 | 6% | 9.0 | 2.0 | -78% | 2.0 | 0% | 2.1 | 5% |
| | M221C | 8.0 | 1.6 | -80% | 1.6 | 0% | 1.5 | -6% | 7.7 | 1.8 | -77% | 1.8 | 0% | 1.6 | -11% |
| Chestnut oak | Assessment area | 5.6 | 4.9 | -12% | 5.1 | 3% | 4.6 | -5% | 14.9 | 30.9 | 108% | 32.6 | 5% | 25.0 | -19% |
| | 221E | 4.2 | 3.6 | -14% | 3.7 | 3% | 3.1 | -14% | 9.6 | 21.7 | 126% | 21.8 | 0% | 10.0 | -54% |
| | 221F | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 0.9 | 1.5 | 67% | 1.6 | 7% | 1.5 | 0% |
| | M221A | 8.3 | 7.4 | -11% | 8.2 | 11% | 8.1 | 9% | 21.7 | 43.6 | 101% | 58.3 | 34% | 60.9 | 40% |
| | M221B | 8.3 | 7.7 | -7% | 7.8 | 1% | 7.8 | 1% | 24.2 | 53.5 | 121% | 55.1 | 3% | 53.7 | 0% |
| | M221C | 8.2 | 6.8 | -17% | 6.8 | 0% | 6.1 | -10% | 24.1 | 41.6 | 73% | 41.1 | -1% | 28.6 | -31% |
| Eastern hemlock | Assessment area | 1.7 | 1.1 | -35% | 1.1 | 1% | 1.0 | -9% | 6.1 | 3.8 | -38% | 3.6 | -6% | 2.0 | -47% |
| | 221E | 0.5 | 0.4 | -20% | 0.4 | 0% | 0.3 | -25% | 1.7 | 1.4 | -18% | 1.3 | -7% | 0.6 | -57% |
| | 221F | 0.2 | 0.2 | 0% | 0.2 | 0% | 0.2 | 0% | 0.7 | 1.5 | 114% | 1.5 | 0% | 0.5 | -67% |
| | M221A | 3.2 | 1.8 | -44% | 1.9 | 6% | 1.8 | 0% | 9.4 | 4.2 | -55% | 4.8 | 14% | 2.2 | -48% |
| | M221B | 3.4 | 2.1 | -38% | 2.1 | 0% | 2.0 | -5% | 11.0 | 8.1 | -26% | 7.8 | -4% | 5.7 | -30% |
| | M221C | 3.1 | 2.0 | -35% | 2.0 | 0% | 1.8 | -10% | 15.3 | 7.3 | -52% | 6.1 | -16% | 2.9 | -60% |
| Eastern redcedar | Assessment area | 0.1 | 0.0 | -89% | 0.0 | 0% | 0.0 | 0% | 0.8 | 0.1 | -91% | 0.0 | 0% | 0.1 | 87% |
| | 221E | 0.1 | 0.0 | -100% | 0.0 | 0% | 0.0 | 0% | 0.7 | 0.0 | -100% | 0.0 | 0% | 0.1 | NA |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 0.2 | 0.1 | -50% | 0.1 | 0% | 0.1 | 0% | 1.6 | 0.5 | -69% | 0.3 | -40% | 0.6 | 20% |
| | M221B | 0.1 | 0.0 | -100% | 0.0 | 0% | 0.0 | 0% | 1.2 | 0.1 | -92% | 0.1 | 0% | 0.1 | 0% |
| | M221C | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.4 | 0.0 | -100% | 0.0 | 0% | 0.0 | 0% |

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Table 42 (continued).

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree species | Section$^a$ | BA in 2009 | BA in 2100 | Change from 2009$^b$ | BA in 2100 | Change from current climate$^c$ | BA in 2100 | Change from current climate$^c$ | TPA in 2009 | TPA in 2100 | Change from 2009$^b$ | TPA in 2100 | Change from current climate$^c$ | TPA in 2100 | Change from current climate$^c$ |
| Eastern white pine | Assessment area | 1.2 | 1.0 | -13% | 1.0 | 0% | 0.9 | -7% | 7.3 | 2.5 | -66% | 2.4 | -2% | 1.3 | -46% |
| | 221E | 0.9 | 0.8 | -11% | 0.8 | 0% | 0.7 | -13% | 4.7 | 1.8 | -62% | 1.8 | 0% | 0.7 | -61% |
| | 221F | 0.4 | 0.3 | -25% | 0.3 | 0% | 0.3 | 0% | 1.3 | 1.6 | 23% | 1.5 | -6% | 0.4 | -75% |
| | M221A | 1.4 | 1.6 | 14% | 1.6 | 0% | 1.4 | -13% | 12.8 | 4.7 | -63% | 5.1 | 9% | 1.9 | -60% |
| | M221B | 1.9 | 1.8 | -5% | 1.8 | 0% | 1.8 | 0% | 14.7 | 4.8 | -67% | 4.4 | -8% | 3.9 | -19% |
| | M221C | 1.4 | 0.8 | -43% | 0.8 | 0% | 0.8 | 0% | 6.8 | 1.1 | -84% | 1.0 | -9% | 0.5 | -55% |
| Loblolly pine | Assessment area | 0.1 | 0.2 | 127% | 0.2 | 0% | 0.2 | 0% | 0.5 | 0.2 | -68% | 0.2 | 43% | 0.3 | 81% |
| | 221E | 0.1 | 0.3 | 200% | 0.3 | 0% | 0.3 | 0% | 0.8 | 0.3 | -63% | 0.4 | 33% | 0.5 | 67% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 0.4 | 0.1 | -75% | 0.1 | 0% | 0.2 | 100% |
| | M221B | 0.1 | 0.1 | 0% | 0.1 | 0% | 0.1 | 0% | 0.3 | 0.0 | -100% | 0.1 | NA | 0.1 | NA |
| | M221C | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| Northern red oak | Assessment area | 6.8 | 2.8 | -58% | 3.3 | 15% | 3.1 | 9% | 11.9 | 3.6 | -70% | 6.0 | 68% | 5.2 | 45% |
| | 221E | 5.2 | 2.8 | -46% | 3.1 | 11% | 2.8 | 0% | 10.2 | 4.0 | -61% | 5.2 | 30% | 3.8 | -5% |
| | 221F | 5.9 | 2.2 | -63% | 3.1 | 41% | 3.1 | 41% | 10.9 | 2.7 | -75% | 9.4 | 248% | 9.0 | 233% |
| | M221A | 8.7 | 2.8 | -68% | 3.3 | 18% | 3.2 | 14% | 13.6 | 3.6 | -74% | 5.6 | 56% | 5.6 | 56% |
| | M221B | 9.3 | 3.2 | -66% | 3.9 | 22% | 3.9 | 22% | 16.6 | 2.8 | -83% | 7.2 | 157% | 7.3 | 161% |
| | M221C | 7.9 | 2.8 | -65% | 3.0 | 7% | 2.8 | 0% | 11.3 | 3.6 | -68% | 5.3 | 47% | 4.5 | 25% |
| Pignut hickory | Assessment area | 2.6 | 2.7 | 5% | 2.8 | 3% | 2.7 | 1% | 7.3 | 5.4 | -27% | 5.6 | 4% | 5.6 | 4% |
| | 221E | 2.6 | 2.7 | 4% | 2.8 | 4% | 2.7 | 0% | 6.9 | 5.4 | -22% | 5.4 | 0% | 5.1 | -6% |
| | 221F | 0.5 | 0.3 | -40% | 0.3 | 0% | 0.3 | 0% | 0.7 | 1.1 | 57% | 1.1 | 0% | 1.0 | -9% |
| | M221A | 2.9 | 2.8 | -3% | 3.0 | 7% | 3.0 | 7% | 10.3 | 4.8 | -53% | 6.1 | 27% | 6.9 | 44% |
| | M221B | 2.9 | 3.3 | 14% | 3.4 | 3% | 3.4 | 3% | 9.8 | 7.1 | -28% | 7.4 | 4% | 7.9 | 11% |
| | M221C | 3.0 | 3.2 | 7% | 3.2 | 0% | 3.1 | -3% | 7.6 | 5.9 | -22% | 6.1 | 3% | 6.0 | 2% |
| Red maple | Assessment area | 16.0 | 30.0 | 88% | 30.5 | 2% | 30.3 | 1% | 77.4 | 66.9 | -13% | 70.3 | 5% | 74.5 | 11% |
| | 221E | 13.8 | 30.1 | 118% | 30.4 | 1% | 29.9 | -1% | 72.7 | 66.2 | -9% | 68.7 | 4% | 70.6 | 7% |
| | 221F | 23.6 | 40.0 | 69% | 40.3 | 1% | 40.6 | 2% | 81.6 | 143.5 | 76% | 145.9 | 2% | 160.7 | 12% |
| | M221A | 18.0 | 25.2 | 40% | 27.5 | 9% | 27.1 | 8% | 66.8 | 63.4 | -5% | 75.9 | 20% | 81.8 | 29% |
| | M221B | 17.5 | 26.8 | 53% | 27.0 | 1% | 27.7 | 3% | 77.0 | 48.5 | -37% | 50.6 | 4% | 56.6 | 17% |
| | M221C | 15.5 | 30.9 | 99% | 31.3 | 1% | 30.6 | -1% | 97.2 | 50.4 | -48% | 52.8 | 5% | 55.1 | 9% |
| Red spruce | Assessment area | 1.0 | 0.3 | -67% | 0.3 | 0% | 0.3 | 0% | 5.1 | 0.4 | -92% | 0.4 | 0% | 0.2 | 0% |
| | 221E | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 1.7 | 0.0 | -100% | 0.0 | 0% | 0.0 | 0% |
| | 221F | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% | 0.0 | 0.0 | 0% | 0.0 | 0% | 0.0 | 0% |
| | M221A | 3.4 | 1.0 | -71% | 1.0 | 0% | 1.0 | 0% | 17.0 | 0.7 | -96% | 0.7 | 0% | 0.7 | 0% |
| | M221B | 2.5 | 0.9 | -64% | 0.9 | 0% | 0.9 | 0% | 13.0 | 1.7 | -87% | 1.6 | -6% | 0.9 | -47% |
| | M221C | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 1.4 | 0.1 | -93% | 0.0 | -100% | 0.0 | -100% |

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**Table 42 (continued).**

| | | Current climate | | | PCM B1 | | GFDL A1FI | | Current climate | | | PCM B1 | | GFDL A1FI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tree species** | **Section**[a] | **BA in 2009** | **BA in 2100** | **Change from 2009**[b] | **BA in 2100** | **Change from current climate**[c] | **BA in 2100** | **Change from current climate**[c] | **TPA in 2009** | **TPA in 2100** | **Change from 2009**[b] | **TPA in 2100** | **Change from current climate**[c] | **TPA in 2100** | **Change from current climate**[c] |
| Scarlet oak | Assessment area | 4.8 | 0.7 | -86% | 0.7 | 8% | 0.7 | -2% | 4.0 | 1.1 | -72% | 1.2 | 3% | 0.9 | -17% |
| | 221E | 3.4 | 0.4 | -88% | 0.5 | 25% | 0.4 | 0% | 2.5 | 0.7 | -72% | 0.7 | 0% | 0.5 | -29% |
| | 221F | 0.3 | 0.1 | -67% | 0.1 | 0% | 0.1 | 0% | 0.5 | 0.3 | -40% | 0.3 | 0% | 0.2 | -33% |
| | M221A | 6.7 | 1.0 | -85% | 1.1 | 10% | 1.0 | 0% | 6.4 | 1.5 | -77% | 1.8 | 20% | 1.3 | -13% |
| | M221B | 7.4 | 1.2 | -84% | 1.2 | 0% | 1.2 | 0% | 6.7 | 2.0 | -70% | 2.0 | 0% | 2.0 | 0% |
| | M221C | 7.8 | 1.1 | -86% | 1.1 | 0% | 1.0 | -9% | 6.2 | 1.8 | -71% | 1.8 | 0% | 1.3 | -28% |
| Sugar maple | Assessment area | 6.1 | 8.0 | 30% | 8.0 | 0% | 7.3 | -9% | 54.1 | 53.6 | -1% | 50.8 | -5% | 23.4 | -56% |
| | 221E | 5.9 | 8.0 | 36% | 8.0 | 0% | 7.2 | -10% | 53.4 | 47.7 | -11% | 44.9 | -6% | 18.3 | -62% |
| | 221F | 7.0 | 8.3 | 19% | 8.3 | 0% | 7.7 | -7% | 73.8 | 43.4 | -41% | 42.6 | -2% | 16.7 | -62% |
| | M221A | 6.8 | 9.2 | 35% | 9.5 | 3% | 8.0 | -13% | 47.2 | 91.4 | 94% | 88.0 | -4% | 27.4 | -70% |
| | M221B | 6.4 | 8.0 | 25% | 8.0 | 0% | 7.8 | -3% | 49.9 | 59.9 | 20% | 57.3 | -4% | 43.5 | -27% |
| | M221C | 5.5 | 6.8 | 24% | 6.7 | -1% | 6.1 | -10% | 54.7 | 46.3 | -15% | 43.0 | -7% | 16.8 | -64% |
| Tulip tree | Assessment area | 6.5 | 10.5 | 62% | 10.8 | 3% | 10.8 | 3% | 22.9 | 104.3 | 356% | 112.1 | 8% | 114.8 | 10% |
| | 221E | 6.6 | 11.1 | 68% | 11.5 | 4% | 11.3 | 2% | 25.0 | 113.0 | 352% | 123.8 | 10% | 123.3 | 9% |
| | 221F | 2.1 | 7.0 | 233% | 6.9 | -1% | 7.1 | 1% | 9.5 | 123.3 | 1198% | 127.2 | 3% | 128.1 | 4% |
| | M221A | 5.8 | 4.6 | -21% | 5.1 | 11% | 5.6 | 22% | 14.1 | 19.3 | 37% | 27.7 | 44% | 39.6 | 105% |
| | M221B | 5.7 | 9.6 | 68% | 9.7 | 1% | 9.9 | 3% | 16.9 | 95.2 | 463% | 97.6 | 3% | 105.3 | 11% |
| | M221C | 9.9 | 15.5 | 57% | 15.8 | 2% | 15.6 | 1% | 36.6 | 130.7 | 257% | 137.4 | 5% | 139.3 | 7% |
| White ash | Assessment area | 2.5 | 2.9 | 18% | 3.0 | 4% | 2.9 | 0% | 11.9 | 7.3 | -39% | 7.9 | 8% | 6.8 | -7% |
| | 221E | 2.7 | 3.2 | 19% | 3.4 | 6% | 3.2 | 0% | 14.0 | 6.4 | -54% | 7.5 | 17% | 5.3 | -17% |
| | 221F | 4.8 | 4.6 | -4% | 4.7 | 2% | 4.5 | -2% | 19.5 | 25.1 | 29% | 24.4 | -3% | 24.3 | -3% |
| | M221A | 1.9 | 2.1 | 11% | 2.1 | 0% | 2.1 | 0% | 8.1 | 1.4 | -83% | 1.6 | 14% | 1.7 | 21% |
| | M221B | 1.7 | 2.4 | 41% | 2.4 | 0% | 2.5 | 4% | 8.0 | 7.2 | -10% | 7.3 | 1% | 7.7 | 7% |
| | M221C | 1.7 | 2.2 | 29% | 2.2 | 0% | 2.2 | 0% | 8.0 | 4.0 | -50% | 4.4 | 10% | 4.0 | 0% |
| White oak | Assessment area | 5.7 | 8.4 | 46% | 8.6 | 2% | 8.3 | -1% | 12.8 | 57.7 | 349% | 60.9 | 6% | 60.8 | 5% |
| | 221E | 6.6 | 9.5 | 44% | 9.7 | 2% | 9.2 | -3% | 15.0 | 64.3 | 329% | 68.1 | 6% | 65.8 | 2% |
| | 221F | 1.1 | 1.9 | 73% | 1.9 | 0% | 1.9 | 0% | 2.9 | 20.8 | 617% | 22.2 | 7% | 21.5 | 3% |
| | M221A | 5.6 | 7.8 | 39% | 8.4 | 8% | 8.4 | 8% | 12.8 | 50.0 | 291% | 56.1 | 12% | 61.0 | 22% |
| | M221B | 5.6 | 8.5 | 52% | 8.6 | 1% | 8.8 | 4% | 12.3 | 60.6 | 393% | 61.7 | 2% | 65.1 | 7% |
| | M221C | 5.7 | 8.5 | 49% | 8.7 | 2% | 8.4 | -1% | 12.2 | 58.7 | 381% | 61.8 | 5% | 61.7 | 5% |

[a] Assessment area values were derived from the weighted average of sections.

[b] Change under current climate represents the difference from 2009 through 2100 due to succession and management, but not climate.

[c] Change from current climate for PCM B1 and GFDL A1FI represents the difference between these scenarios and current climate in 2100 and represents the potential change due to climate change.

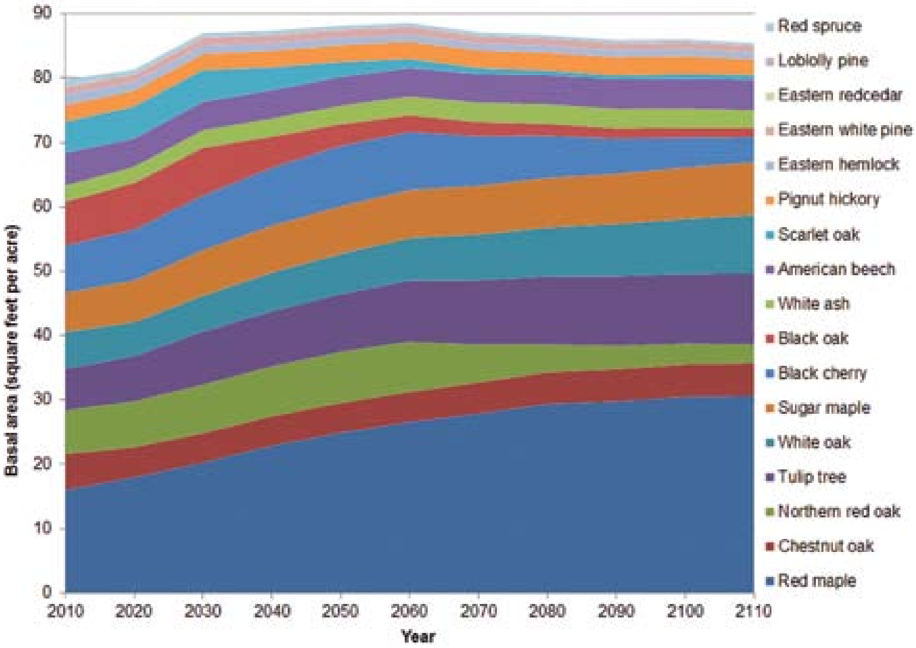


Figure 61.—Projected changes in basal area for 17 species across the assessment area for PCM B1. Assessment area values were derived from the weighted average of sections. The width of the colored line represents the basal area for each species at various points through time. For example, red maple had the highest basal area in 2010, and basal area is projected to increase by 2 percent for the PCM B1 scenario, in addition to the projected 88-percent increase due to natural succession and management (see also Table 42).

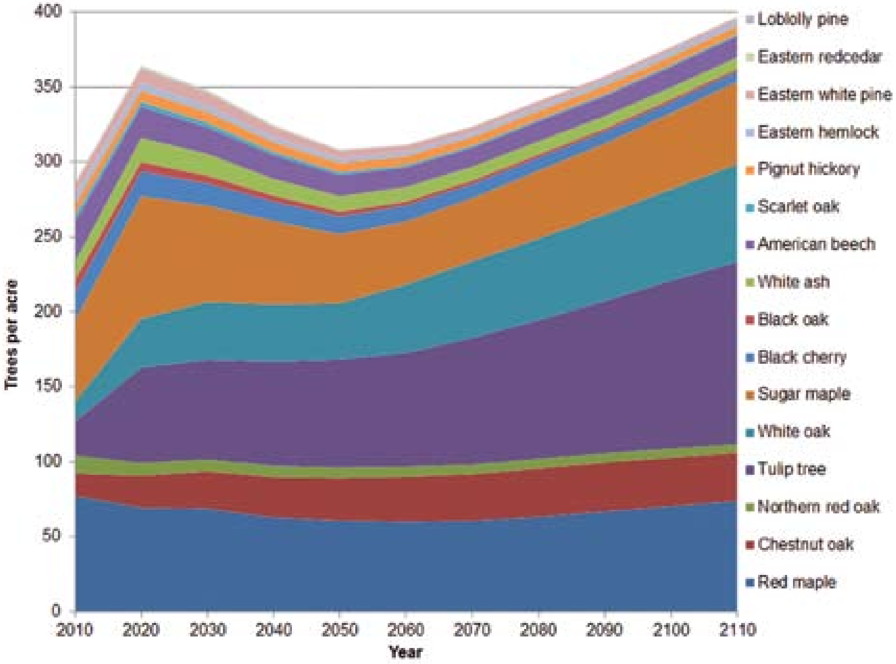


Figure 62.—Projected changes in trees per acre for 17 species across the assessment area for PCM B1. Assessment area values were derived from the weighted average of sections. The width of the colored line represents trees per acre for each species at various points through time. For example, red maple had the highest trees per acre in 2010, and the number of trees per acre is projected to increase by 5 percent for the PCM B1 scenario, partially offsetting the projected 13-percent decrease due to natural succession and management (see also Table 42).

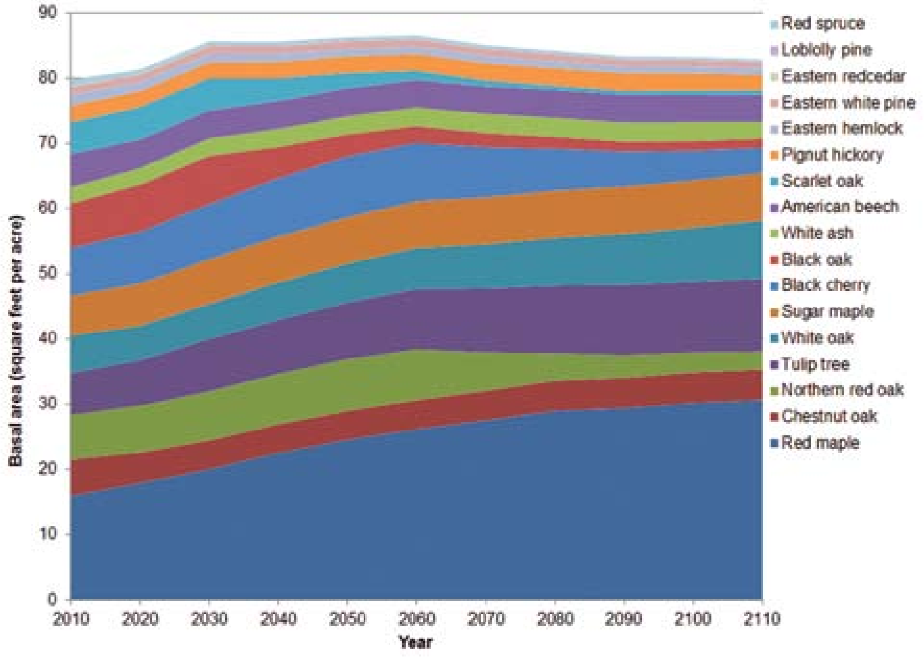


Figure 63.—Projected changes in basal area for 17 species across the assessment area for GFDL A1FI. Assessment area values were derived from the weighted average of sections. The width of the colored line represents trees per acre for each species at various points through time. For example, red maple had the highest basal area in 2010, and basal area is projected to increase by 1 percent for the GFDL A1FI scenario, in addition to the projected 88-percent increase due to natural succession and management (see also Table 42).

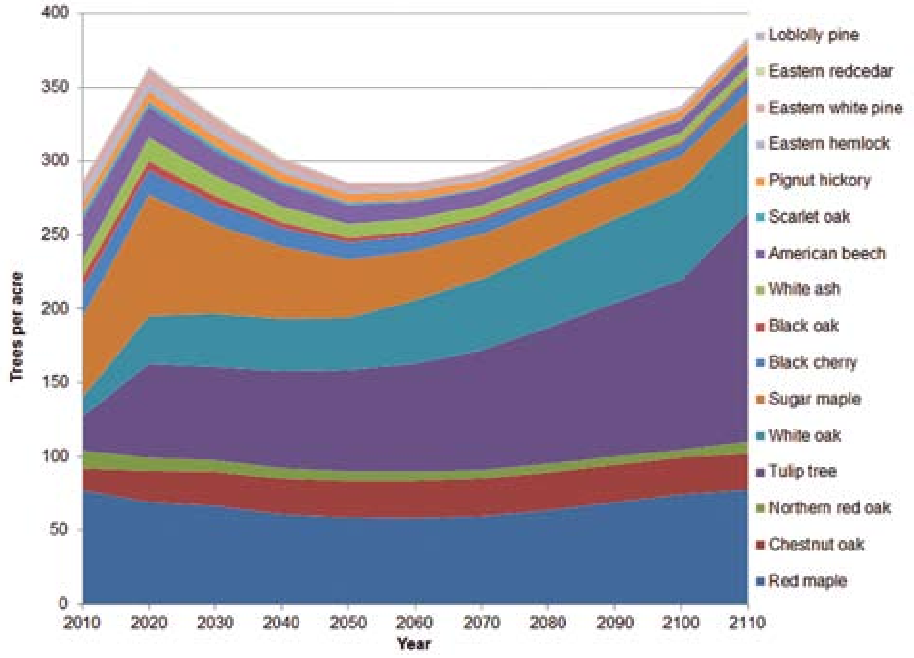


Figure 64.—Projected changes in trees per acre for 17 species across the assessment area for GFDL A1FI. Assessment area values were derived from the weighted average of sections. The width of the colored line represents trees per acre for each species at various points through time. For example, red maple had the highest trees per acre in 2010, and the number of trees per acre is projected to increase by 11 percent for the GFDL A1FI scenario, almost offsetting the projected 13-percent decrease due to natural succession and management (see also Table 42).

# APPENDIX 5: VULNERABILITY AND CONFIDENCE DETERMINATION

## EXPERT PANEL PROCESS

To assess vulnerabilities to climate change for each natural community type, we elicited input from a panel of 19 experts from a variety of land management and research organizations across the assessment area. We sought a team of panelists who would be able to contribute a diversity of subject area expertise, management history, and organizational perspectives. Most panelists had extensive knowledge about the ecology, management, and climate change impacts on forests in the assessment area. This panel was assembled at an in-person workshop in Morgantown, WV, in April 2013. Here we describe the structured discussion process that the panel used.

| Name | Organization |
|---|---|
| Jarel Bartig | Wayne National Forest |
| Scott Bearer | The Nature Conservancy - Pennsylvania |
| Steve Blatt | Wayne National Forest |
| Andrea Brandon | The Nature Conservancy - West Virginia |
| Patricia Butler* | Michigan Technological University & Northern Institute of Applied Climate Science |
| Stephanie Connolly | Monongahela National Forest |
| Tim Culbreth | Maryland Department of Natural Resources, Forest Service |
| William Dijak | U.S. Forest Service, Northern Research Station |
| Wade Dorsey | Savage River State Forest |
| Neil Gillies | Cacapon Institute |
| Louis Iverson | U.S. Forest Service, Northern Research Station |
| Maria Janowiak* | U.S. Forest Service, Northern Research Station & Northern Institute of Applied Climate Science |
| Kent Karriker | Monongahela National Forest |
| Dave Minney | Independent consultant |
| Cotton Randall | Ohio Department of Natural Resources, Division of Forestry |
| Tom Schuler | U.S. Forest Service, Fernow Experimental Forest |
| Bill Stanley | The Nature Conservancy - Ohio |
| Al Steele | U.S. Forest Service, Northeastern Area, State & Private Forestry |
| Susan Stout | U.S. Forest Service, Northern Research Station |
| Jason Teets | Natural Resources Conservation Service |
| Frank Thompson | U.S. Forest Service, Northern Research Station |

*Workshop facilitator

## FOREST SYSTEMS ASSESSED

The authors of this assessment modified and combined NatureServe (2011) ecological systems in order to describe specific forest ecosystems within the assessment area (see Chapter 1). For each forest ecosystem, we collected information related to the major system drivers, dominant species, and stressors that characterize that ecosystem from the relevant ecological literature. The panel was asked to comment on the forest ecosystem descriptions, and those comments were used to revise the descriptions in Chapter 1.

## POTENTIAL IMPACTS

To examine potential impacts, the panel was given several sources of background information on past and future climate change in the region (summarized in Chapters 3 and 4) and projected impacts on dominant tree species (summarized in Chapter 5). The panel was directed to focus on impacts to each forest ecosystem from the present through the end of the century, but more weight was given to the end-of-century period. The panel assessed impacts by considering a range of climate futures bracketed by two scenarios: GFDL A1FI and PCM B1. Panelists were then led through a structured discussion process to consider this information for each forest ecosystem in the assessment.

Potential impacts on ecosystem drivers and stressors were summarized based on climate model projections, the published literature, and insights from the panelists. Impacts on drivers were considered positive or negative if they would alter system drivers in a way that would be more or less favorable for that forest ecosystem. Impacts on stressors were considered negative if they increased the influence of that stressor or positive if they decreased the influence of that stressor on the forest ecosystem. Panelists were also asked to consider the potential for climate change to facilitate new stressors in the assessment area over the next century.

To assess potential impacts on dominant tree species, the panelists examined results from three forest impact models (Tree Atlas, LINKAGES, and LANDIS-PRO), and were asked to consider those results in addition to their knowledge of life history traits and ecology of those species. The panel evaluated how much agreement existed within the available information, between climate scenarios, and across space and time. Finally, panelists were asked to consider the potential for interactions among anticipated climate trends, species impacts, and stressors. Input on these future ecosystem interactions relied primarily on the panelists' expertise and judgment because there are not many examples of published literature on complex interactions, nor are future interactions accurately represented by forest impact models (Box 12).

## ADAPTIVE CAPACITY

Panelists discussed the adaptive capacity of each forest ecosystem based on their ecological knowledge and management experience. Panelists were told to focus on characteristics that would increase or decrease the adaptive capacity of that system. Factors that the panel considered included characteristics of dominant species within each forest ecosystem (e.g., dispersal ability, genetic diversity, range limits) as well as comprehensive ecosystem characteristics (e.g., functional and species diversity, tolerance to a variety of disturbances, distribution across the landscape). The panelists were directed to base their considerations on the current condition of the system given past and current management regimes, with no consideration of potential adaptation actions that could take place in the future.

### Box 12: A Note on Forest Impact Models Used in this Assessment

During the expert panel workshop, preliminary LANDIS PRO results were used that included the climate parameters based on the average climate at the center of an ecological section. This methodology was found to be less effective in areas of complex topography, where steep elevational gradients result in climatic gradients as well. The inclusion of climate data from the center of the section projected unrealistic responses for several tree species in the Allegheny Mountain and Northern Ridge and Valley sections of the assessment area. The climate value at the center of the section happened to fall on a high-elevation area, which represented the climate for the whole region as being much colder than the average climate. This was identified as an issue with the preliminary LANDIS PRO model results at the expert panel workshop, and many participants expressed their tendency to "discount" the results for black cherry and tulip tree. Following the expert panel workshop, the LANDIS PRO model was recalibrated with alternate climate data that better represent the average climate. All results summarized in Chapters 5 and 6 were vetted with the expert panelists to ensure their vulnerability rankings were still consistent with the final LANDIS PRO model results.

## VULNERABILITY

After extensive group discussion, each panelist evaluated the potential impacts to and adaptive capacity of each forest ecosystem to arrive at a vulnerability rating. Participants were provided with individual worksheets and asked to list which impacts they felt were most important to that system in addition to the major factors that would contribute to the adaptive capacity of that ecosystem (Fig. 65).

Panelists were directed to mark their rating in two-dimensional space on the individual worksheet and on a large group poster (Fig. 66a). This vulnerability figure required the participants to evaluate the degree of potential impacts related to climate change as well as the adaptive capacity of the ecosystem to tolerate those impacts (Swanston and Janowiak 2012). Individual ratings were compared and discussed and used to arrive at a group determination. In many cases, the group determination was at or near the centroid of all individual determinations. Sometimes the group determination deviated from the centroid because further discussion convinced some group members to alter their original response.

## CONFIDENCE

Panelists were also directed to give a confidence rating to each of their individual vulnerability determinations (Fig. 66b). Panelists were asked to evaluate the amount of evidence they felt was available to support their vulnerability determination and the level of agreement among the available evidence (Mastrandrea et al. 2010). Panelists evaluated confidence individually and as a group, in a similar fashion to the vulnerability determination.

### Vulnerability and Confidence Figures

For reference, figures of individual and group determinations for all nine forest ecosystems considered in this assessment are displayed in Figures 67 through 75. In each figure, individual panelist votes are indicated with a small circle and the group determination is indicated with a large square. We do not intend for direct comparison between these figures because the axes represent subjective, qualitative scales.

# Example Vulnerability Determination Worksheet

**Name:** ______________________________ **Ecosystem/Forest Type:** ____________________

**How familiar are you with this ecosystem? (circle one)**

| **Low** | **Medium** | **High** |
|---|---|---|
| I have some basic knowledge about this system and how it operates | I do some management or research in this system, or have read a lot about it. | I regularly do management or research in this system |

**What do you think are the greatest potential impacts to the ecosystem?**

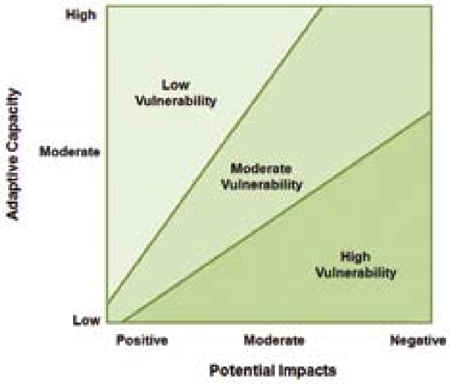
**What factors do you think contribute most to the adaptive capacity of the ecosystem?**

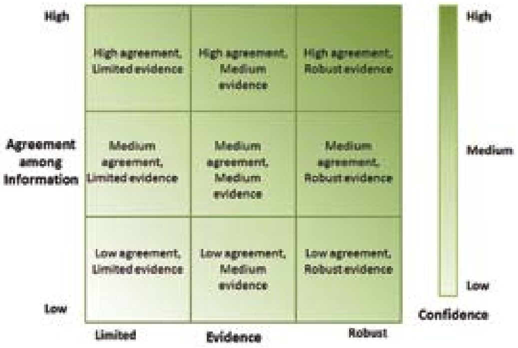
### Vulnerability Determination

Use the handout for the vulnerability determination process and the notes that you have taken to plot your assessment of vulnerability on the figure below.

### Confidence Rating

Use the handout for the confidence rating process and the notes that you have taken to rate confidence using the figure below.





| | | |
|---|---|---|
| High agreement, Limited evidence | High agreement, Medium evidence | High agreement, Robust evidence |
| Medium agreement, Limited evidence | Medium agreement, Medium evidence | Medium agreement, Robust evidence |
| Low agreement, Limited evidence | Low agreement, Medium evidence | Low agreement, Robust evidence |

**The ratings above are for the entire analysis area. Please note where you think potential impacts or adaptive capacity may vary substantially within the analysis area (e.g., forests in the eastern portion may be more prone to impact X).**

Figure 65.—Worksheet used for vulnerability and confidence determination by expert panelists, based on Swanston and Janowiak (2012).

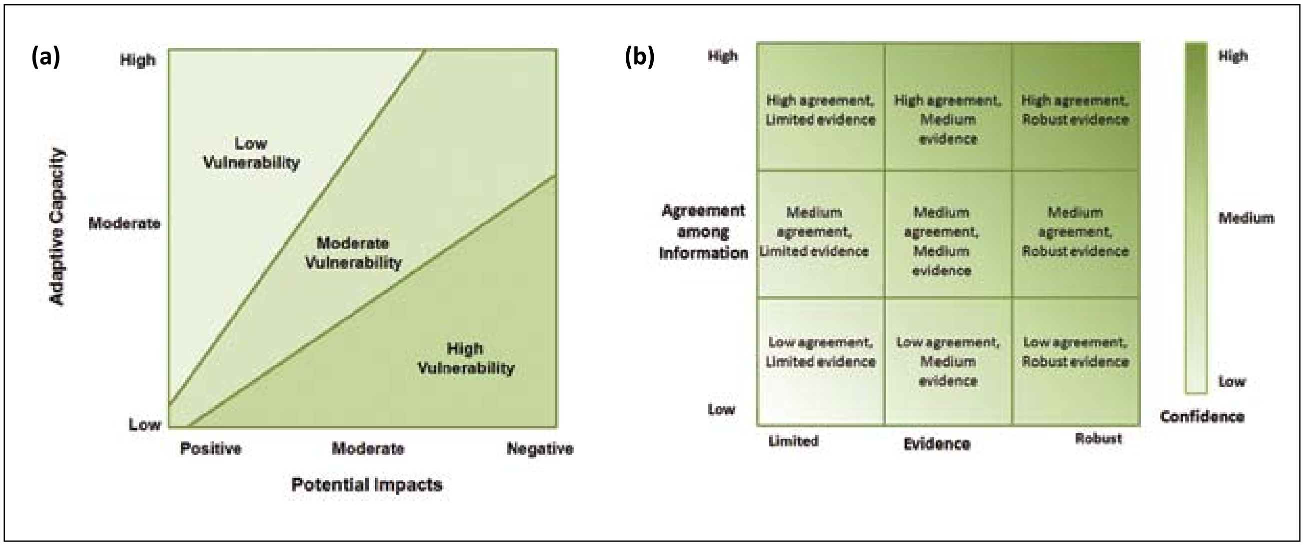


Figure 66.—Figure used for (a) vulnerability determination by expert panelists, based on Swanston and Janowiak (2012), and (b) confidence rating among expert panelists, adapted from Mastrandrea et al. (2010).

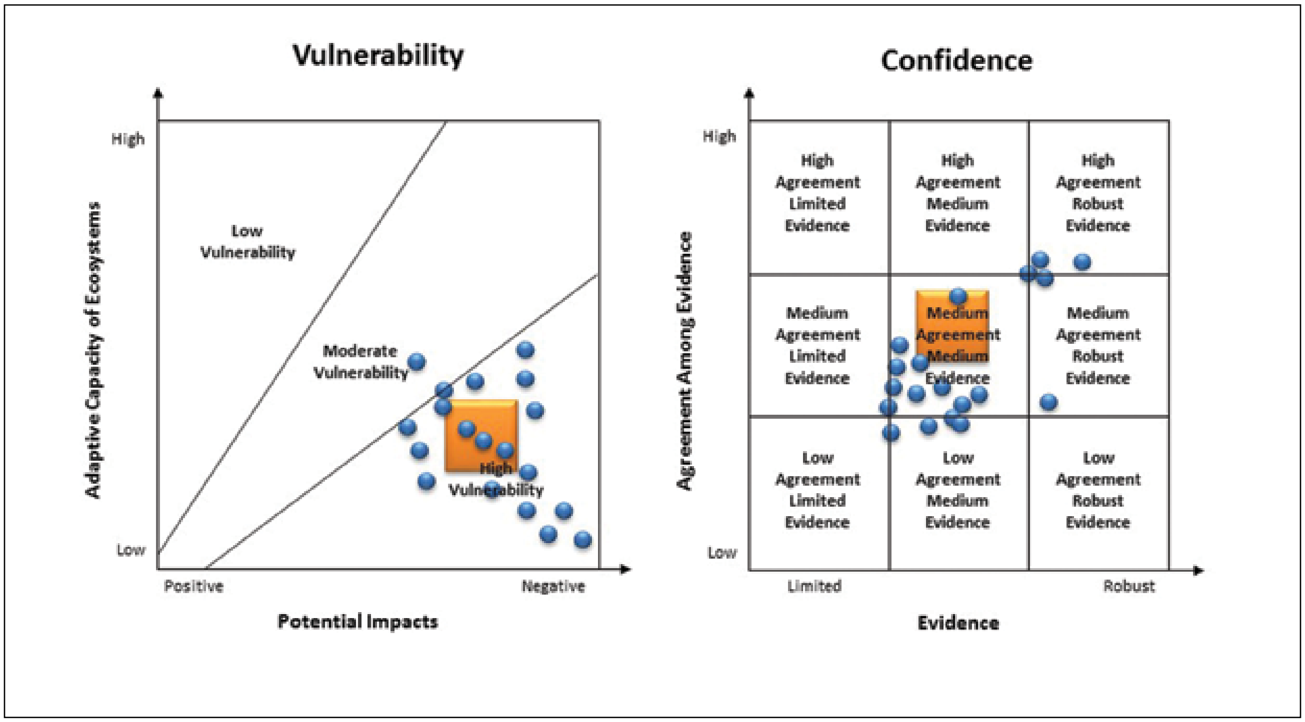


Figure 67.—Vulnerability and confidence determinations for Appalachian (hemlock)/northern hardwood forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

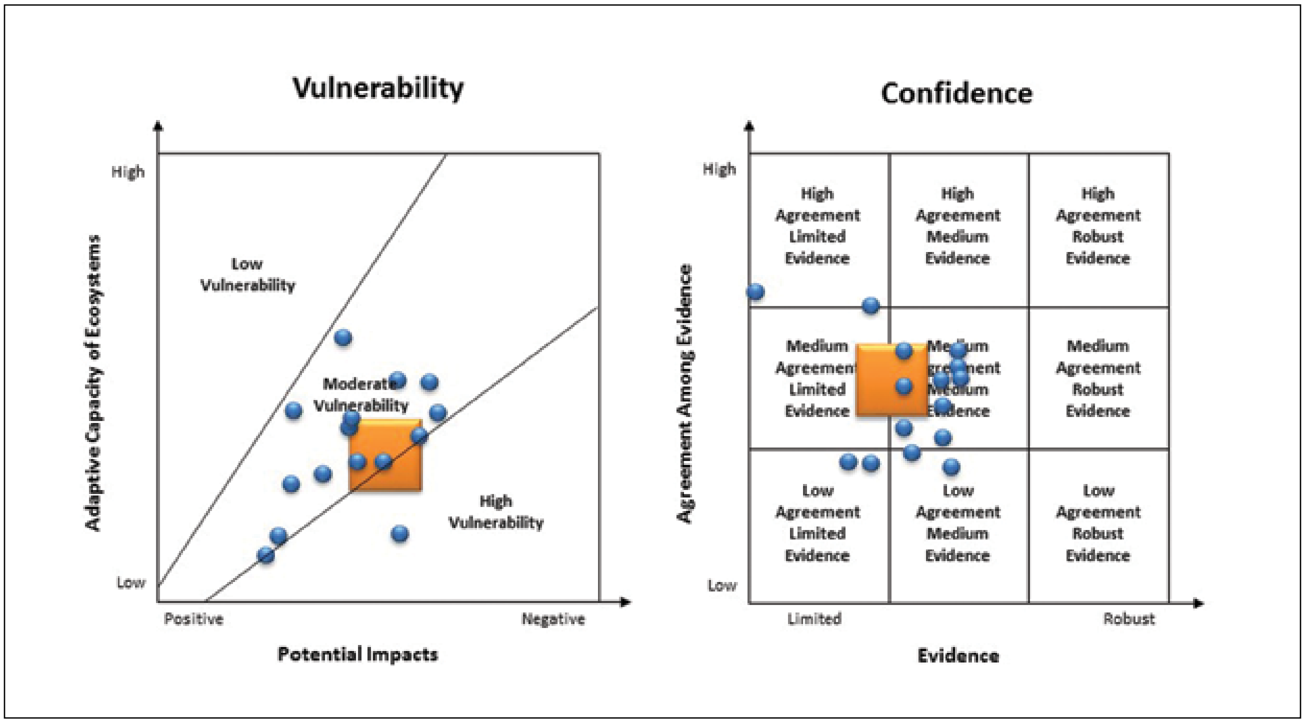


Figure 68.—Vulnerability and confidence determinations for dry calcareous forest, woodland, and glade. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

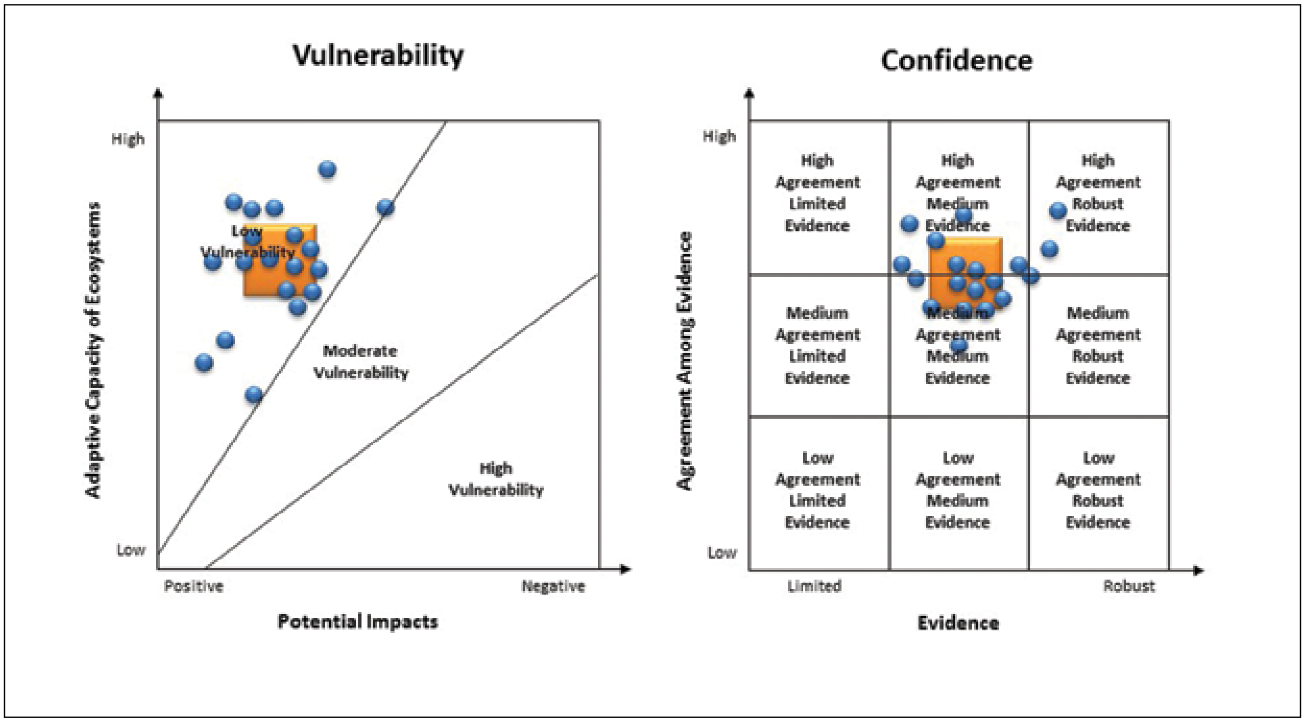


Figure 69.—Vulnerability and confidence determinations for dry oak and oak/pine forest and woodland. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

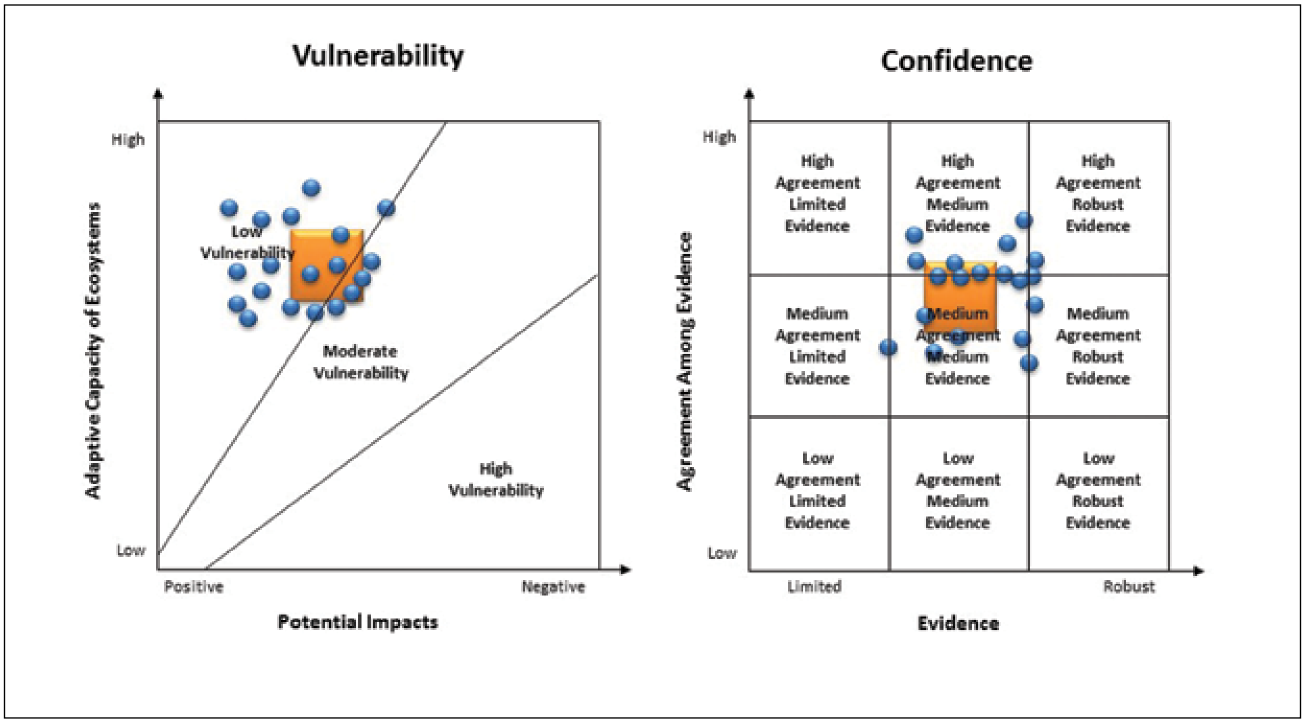


Figure 70.—Vulnerability and confidence determinations for dry/mesic oak forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

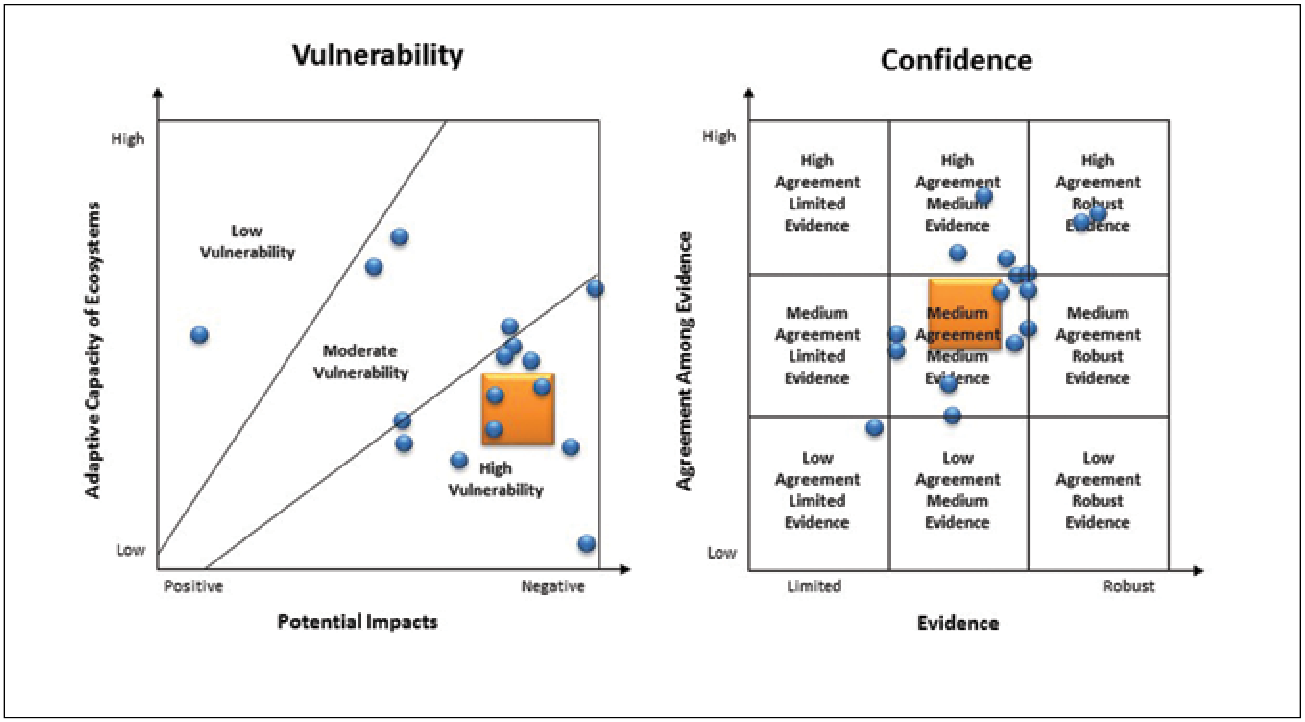


Figure 71.—Vulnerability and confidence determinations for large stream floodplain and riparian forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

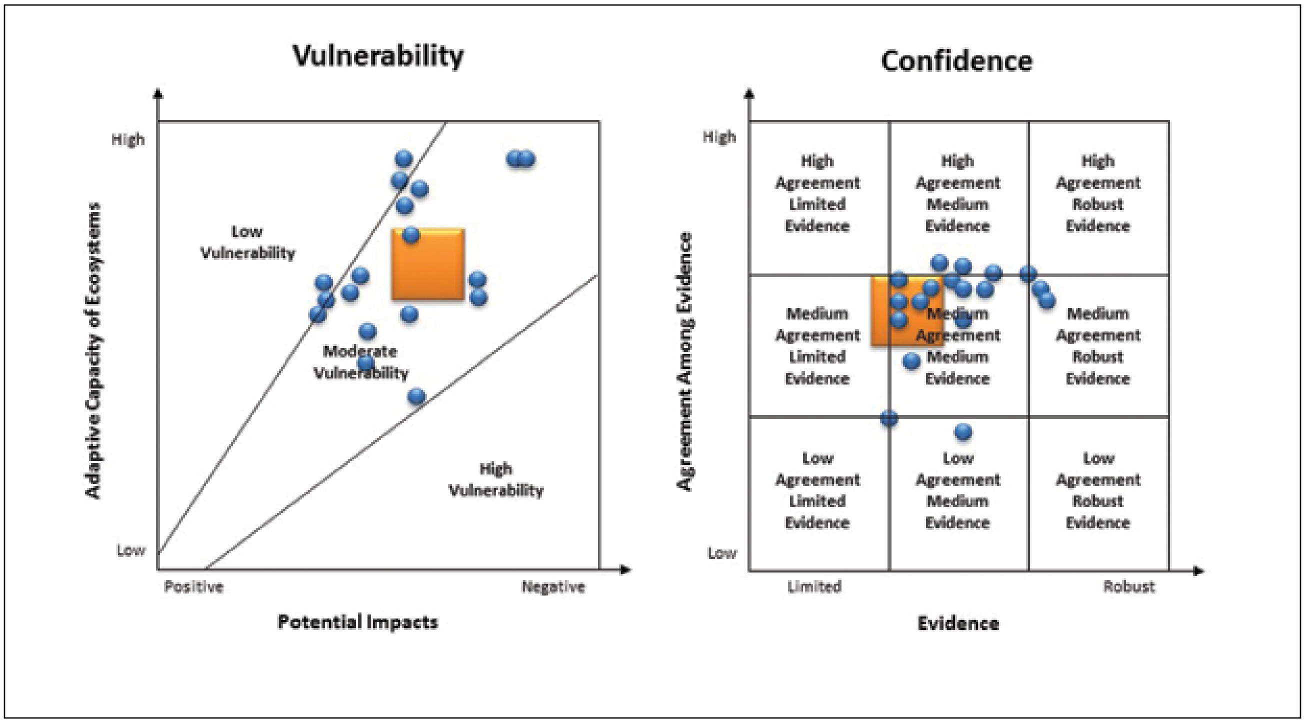


Figure 72.—Vulnerability and confidence determinations for mixed mesophytic and cove forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

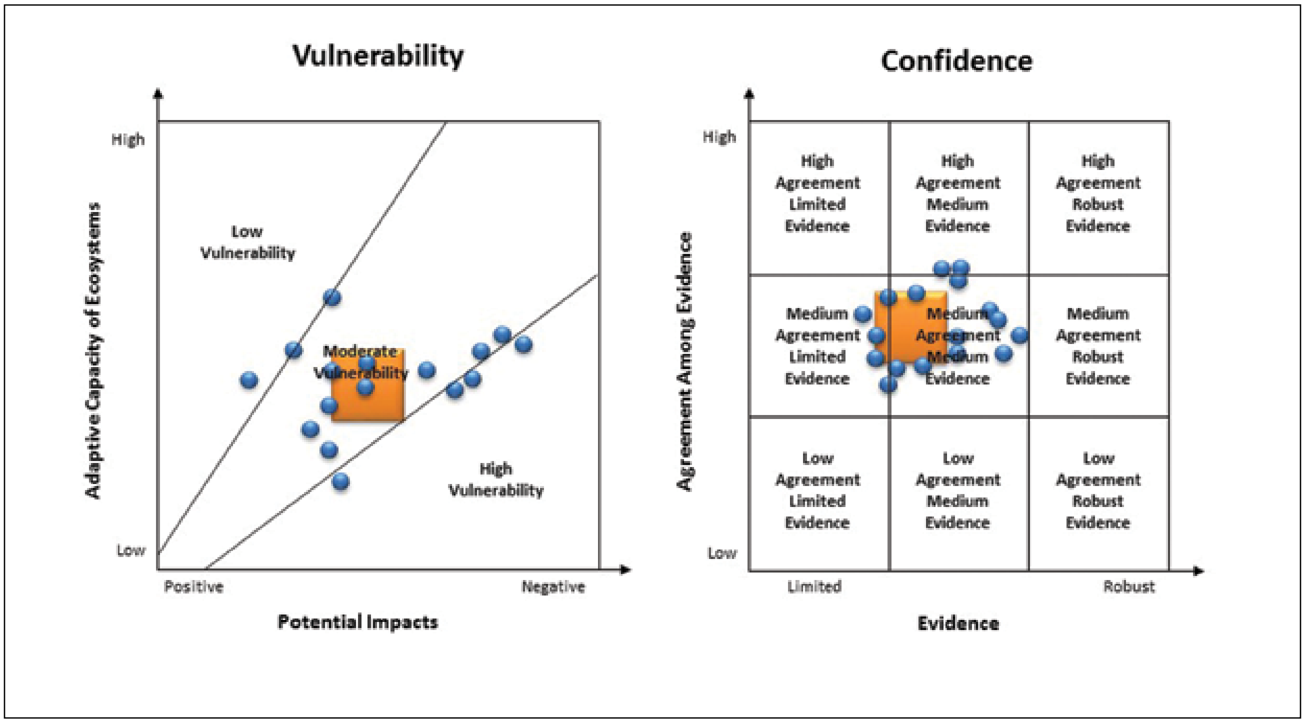


Figure 73.—Vulnerability and confidence determinations for north-central interior maple/beech forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

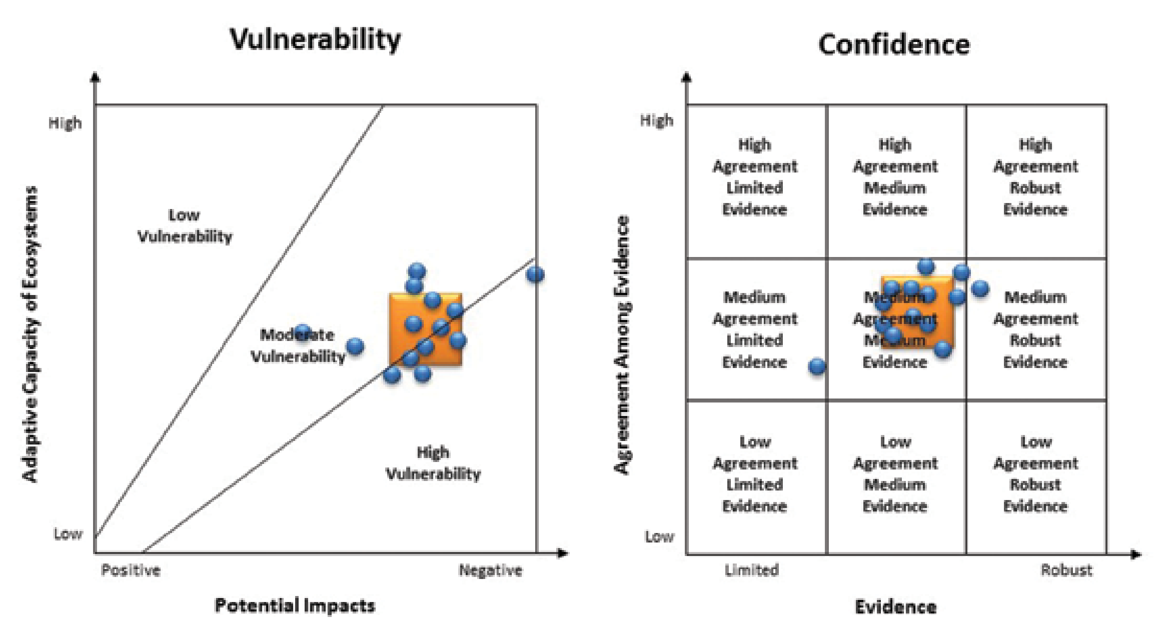


Figure 74.—Vulnerability and confidence determinations for small stream riparian forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

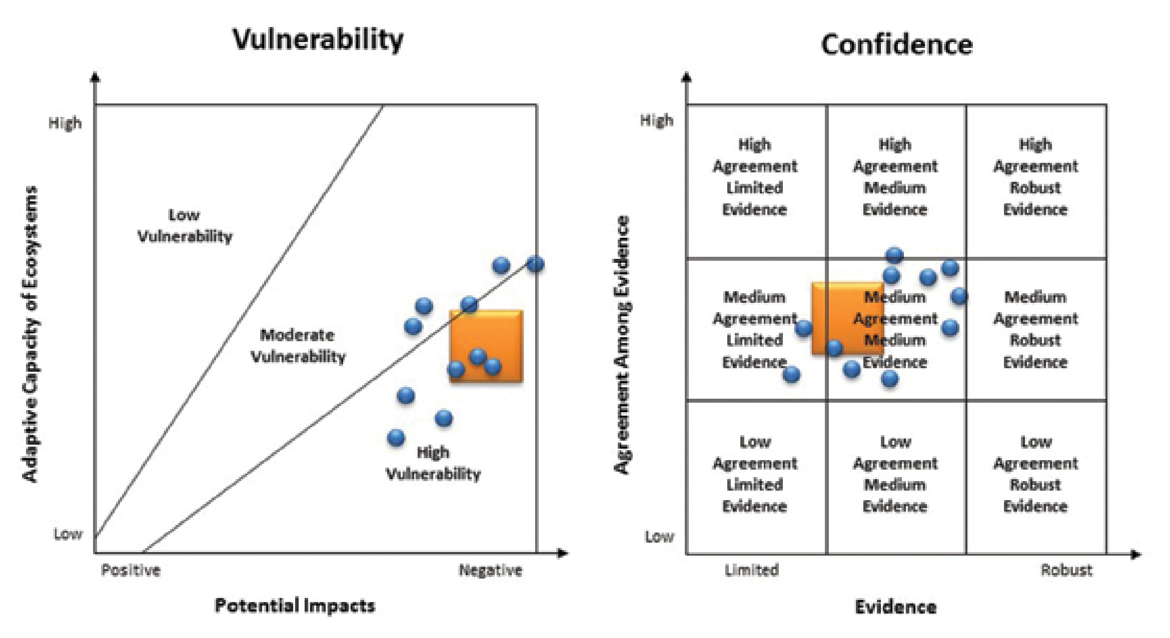


Figure 75.—Vulnerability and confidence determinations for spruce/fir forest. Circles indicate individual determinations by each panelist and squares indicate the group determination after consensus was reached.

## VULNERABILITY STATEMENTS

Recurring themes and patterns that transcended individual forest ecosystems were identified and developed into the vulnerability statements in boldface and supporting text in Chapter 6. The lead author developed the statements and supporting text based on workshop notes and literature pertinent to each statement. An initial confidence determination (evidence and agreement) was assigned based on the lead author's interpretation of the amount of information available to support each statement and the extent to which the information agreed. Each statement and its supporting literature discussion were sent to the expert panel for review. Panelists were asked to review each statement for accuracy, whether the confidence determination should be raised or lowered, if there was additional literature that was overlooked, and if there were any additional statements that needed to be made. Any changes that were suggested by a single panelist were brought forth for discussion and approved by the entire panel.

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Forest ecosystems in the Central Appalachians will be affected directly and indirectly by a changing climate over the 21st century. This assessment evaluates the vulnerability of forest ecosystems in the Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow and Eastern Broadleaf Forest Provinces of Ohio, West Virginia, and Maryland for a range of future climates. Information on current forest conditions, observed climate trends, projected climate changes, and impacts on forest ecosystems was considered by a multidisciplinary panel of scientists, land managers, and academics in order to assess ecosystem vulnerability to climate change. Appalachian (hemlock)/northern hardwood forests, large stream floodplain and riparian forests, small stream riparian forests, and spruce/fir forests were determined to be the most vulnerable. Dry/mesic oak forests and dry oak and oak/pine forests and woodlands were determined to be least vulnerable. Projected changes in climate and the associated impacts and vulnerabilities will have important implications for economically valuable timber species, forest-dependent wildlife and plants, recreation, and long-term natural resource planning.

KEY WORDS: climate change, vulnerability, adaptive capacity, forests, Climate Change Tree Atlas, DISTRIB, LANDIS PRO, LINKAGES, expert elicitation, climate projections, impacts

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