United States Department of Agriculture

CHICAGO WILDERNESS REGION URBAN FOREST VULNERABILITY ASSESSMENT AND SYNTHESIS:

A Report from the Urban Forestry Climate Change Response Framework Chicago Wilderness Pilot Project

Forest Service
Northern Research Station

General Technical Report NRS-168
April 2017

ABSTRACT

The urban forest of the Chicago Wilderness region, a 7-million-acre area covering portions of Illinois, Indiana, Michigan, and Wisconsin, will face direct and indirect impacts from a changing climate over the 21st century. This assessment evaluates the vulnerability of urban trees and natural and developed landscapes within the Chicago Wilderness region to a range of future climates. We synthesized and summarized information on the contemporary landscape, provided information on past climate trends, and illustrated a range of projected future climates. We used this information to inform models of habitat suitability for trees native to the area. Projected shifts in plant hardiness and heat zones were used to understand how nonnative species and cultivars may tolerate future conditions. We also assessed the adaptability of planted and naturally occurring trees to stressors that may not be accounted for in habitat suitability models such as drought, flooding, wind damage, and air pollution.

The summary of the contemporary landscape identifies major stressors currently threatening the urban forest of the Chicago Wilderness region. Major current threats to the region's urban forest include invasive species, pests and disease, land-use change, development, and fragmentation. Observed trends in climate over the historical record from 1901 through 2011 show a temperature increase of 1 °F in the Chicago Wilderness region. Precipitation increased as well, especially during the summer. Mean annual temperature is projected to increase by 2.3 to 8.2 °F by the end of the century, with temperature increases across all seasons. Projections for precipitation show an increase in winter and spring precipitation, and summer and fall precipitation projections vary by model. Species distribution modeling for native species suggests that suitable habitat may decrease for 11 primarily northern species and increase or become newly suitable for 40 species. An analysis of tree species vulnerability that combines model projections, shifts in hardiness and heat zones, and adaptive capacity showed that 15 percent of the trees currently present in the region have either moderate-high or high vulnerability to climate change, and many of those trees with low vulnerability are invasive species.

We developed a process for self-assessment of urban forest vulnerability that was tested by urban forestry professionals from four municipalities, three park districts, and three forest preserve districts in the region. The professionals generally rated the impacts of climate change on the places they managed as moderately negative, mostly driven by the potential effects of extreme storms and heavy precipitation on trees in the area. The capacity of forests to adapt to climate change ranged widely based on economic, social, and organizational factors, as well as on the diversity of species and genotypes of trees in the area. These projected changes in climate and their associated impacts and vulnerabilities will have important implications for urban forest management, including the planting and maintenance of street and park trees, management of natural areas, and long-term planning.

Quality Assurance

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Cover Photo

Residential street trees, Chicago, IL. Photo by L. Darling, The Morton Arboretum, used with permission.

Manuscript received for publication August 2016

PUBLISHED BY:

U.S. FOREST SERVICE
11 CAMPUS BLVD., SUITE 200
NEWTOWN SQUARE, PA 19073-3294

APRIL 2017

FOR ADDITIONAL COPIES, CONTACT:

U.S. FOREST SERVICE
PUBLICATIONS DISTRIBUTION
359 MAIN ROAD
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FAX: 740-368-0152

www.nrs.fs.fed.us

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PREFACE

Context and Scope

This assessment is a fundamental component of the Urban Forestry Climate Change Response Framework project. This project builds on lessons learned from the Climate Change Response Framework: a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. Other Framework projects are currently underway, covering millions of acres of natural ecosystems or large-scale forestry plantations in the northeastern quarter of the United States. Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects. The scope of the Chicago Wilderness region assessment is the urban forest, broadly defined to include both developed and natural settings within the urban landscape.

We designed this assessment to be a synthesis of the best available scientific information. Its primary goal is to inform those who work, study, recreate in, and care about the urban forests in the Chicago Wilderness region. As new scientific information arises, we expect that new efforts will need to be undertaken to reflect that acquired knowledge and understanding. Most important, this assessment does not make recommendations about how this information should be used.

Author Contributions and Acknowledgments

Leslie Brandt developed the document structure and was the primary author of the document, with substantial input and writing from Abigail Derby Lewis, Lydia Scott, Lindsay Darling, and Robert Fahey. Danielle Shannon and Lindsay Darling conducted much of the data analysis and developed maps for Chapters 1, 2, and 4. Louis Iverson, Steve Matthews, Matthew Peters, and Anantha Prasad provided and interpreted the hardiness and heat zone projections for Chapter 2, and assisted with the data processing for the climate data presented in Chapter 4. Allison Bodine and Dave Nowak collaborated with Louis Iverson, Steve Matthews, Matthew Peters, and Anantha Prasad to provide Tree Atlas results for Chapter 3. Andrew Bell and Shannon Still provided the information on modeled cultivated species. Andrew Bell, Lydia Scott, Robert Fahey, Jason Miesbauer, and Lindsay Darling provided expert review of the modifying factor scores in Chapter 3. All authors contributed to the content and structure of the report.

We wish to thank the municipal foresters, park district representatives, and forest managers who participated in the vulnerability case studies. We also thank Elizabeth Larry, Lara Roman, Elizabeth Gibbons, and two anonymous reviewers, who provided technical reviews of the manuscript.

CONTENTS

EXECUTIVE SUMMARY

This assessment evaluates the vulnerability of urban trees and forests in the Chicago Wilderness region (whose 7 million acres cover portions of Illinois, Indiana, Michigan, and Wisconsin) to a range of future climate scenarios. This assessment is part of the Urban Forestry Climate Change Response Framework project, a collaborative approach among researchers, managers, and landowners to incorporate climate change considerations into urban 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 local knowledge and expertise, are used to develop case studies of urban forest vulnerability for municipalities, park districts, and forest preserve districts across the region. A final chapter summarizes the implications of these impacts and vulnerabilities for urban forest management across the region.

CHAPTER 1
The Contemporary Landscape

Summary

This chapter discusses the structure and function of the Chicago Wilderness regional forest, the forces that have shaped it, and stressors that currently threaten it. This information lays the foundation for understanding how shifts in climate may contribute to changes in this forest, and how climate may interact with other stressors present on the landscape.

Key Points

- Before Euro-American settlement, open oak ecosystems such as savannas and woodlands dominated the Chicago Wilderness region.
- Today, most of the natural areas have been lost to urbanization and suburban sprawl. The only remaining natural areas in the region are fragmented and are a small fraction of their original size.
- Key stressors to forests in the region include development, soil alteration, alteration of historical fire regimes, air pollution, the urban heat island effect, extreme weather events, invasive plants, insect pests, and diseases.
- Current management of natural areas in the region focuses on restoring native ecosystems and simulating past disturbance regimes.
- Selection of trees for urban plantings weighs other factors besides native status, such as tolerance of site conditions, diversity of community trees, tree height, required maintenance, and ornamental appeal.

CHAPTER 2
Climate Trends and Projections

Summary

This chapter discusses our current understanding of past and projected future changes in climate in the Chicago Wilderness region. This chapter examines how climate may change over the next century using two models representing a range of possible futures that are downscaled in order to be relevant to local decisionmaking. A review of the most recent scientific literature on local trends and projections is also included.

Key Points

- Over the past century, the Chicago Wilderness region has warmed by about 1 °F on average and has had a significant increase in precipitation, especially during the summer (3-inch increase).
- Mean annual temperature is projected to increase by 2.3 to 8.2 °F by the end of the 21st century, with temperature increases across all seasons.
- Precipitation is projected to increase in winter and spring over the 21st century, but projections for summer and fall precipitation are less clear.
- Heavy precipitation events have been increasing in number and intensity and are projected to continue to increase further, which could increase runoff and local flooding from stormwater.

- Extreme and exceptional droughts may increase in duration, frequency, and spatial extent compared to the end of the 20th century.
- Rises in temperature may lead to a shift of one to two hardiness zones and two to four heat zones.

CHAPTER 3
Climate Change Impacts and the Adaptive Capacity of the Urban Forest

Summary

This chapter synthesizes the potential impacts of climate change on urban forests in the Chicago Wilderness region, with an emphasis on changes in habitat suitability and the adaptive capacity of different species.

Key Points

- Species distribution modeling for native species suggests that suitable habitat may decrease for 11 primarily northern species, and increase or become newly suitable for 40 species.
- For species for which no model information is available (rare, nonnative, or cultivars), shifts in heat and hardiness zones could have a positive effect on about 23 percent of species that are either present in the area or considered for planting, and a negative effect on about 19 percent.
- Adaptive capacity of 179 species was evaluated by using scoring systems for planted and natural environments, with invasive species among those with the highest capacity to adapt to a range of stressors.
- An analysis of vulnerability that combines model projections, shifts in hardiness and heat zones, and adaptive capacity showed that 17 percent of the tree species currently present in the region have either moderate-high or high vulnerability to climate change, and 77 percent of individual trees with low vulnerability are invasive species.
- Key impacts to trees in the Chicago Wilderness region projected over the next century include increased drought and heat stress, increased stormwater runoff and flooding, increases in wind damage, and increases in tree pests and pathogens.

CHAPTER 4
Urban Forest Vulnerability Case Studies

Summary

This chapter focuses on the vulnerability of urban forests in the Chicago Wilderness region to climate change, describing case study examples from municipalities, park districts, and forest preserve districts.

Key Points

- We developed a process for municipalities, park districts, and forest preserve districts to assess their vulnerability to climate change based on impacts and adaptive capacity.
- Ten case studies were developed in the Chicago Wilderness region using this approach.
- Most of the variation in vulnerability among case studies was in adaptive capacity, driven by differences in biological, organizational, economic, and social factors among communities.

CHAPTER 5
Management Considerations

Summary

This chapter provides an overview of climate change impacts on decisionmaking, management practices, and other issues related to urban and community forestry in the Chicago Wilderness region. The management of natural areas, street trees, and landscaped parks may become more challenging due to more-severe storms and changes in habitat suitability for dominant trees. Greater financial investments may be required in the short term to maintain the urban forest so it can continue to provide benefits to the community, such as clean air, reduced heat island effects, and stormwater management, in the long term. At the same time, confronting the challenge of climate change also presents opportunities for managers and other decisionmakers to protect their investments by planning ahead, building resilient landscapes, expanding their volunteer base, and engaging with their communities to adapt to future change.

INTRODUCTION

Context

This assessment is a fundamental component of the Urban Forestry Climate Change Response Framework project (www.forestadaptation.org/urban). This project builds on lessons learned from the Climate Change Response Framework: a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. Five broader projects are currently underway, covering millions of acres in the northeastern quarter of the United States: Northwoods, Central Appalachians, Central Hardwoods, Mid-Atlantic, and New England. Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects (Fig. 1). The Chicago Wilderness region assessment is the first to focus on urban trees in a developed setting. Vulnerability assessments for the other five project areas focus on natural ecosystems or large-scale forestry plantations within a specific ecoregion.

The overarching goal of all Framework projects is to incorporate climate change considerations into forest management. The overall goal of the Urban project is to ensure that urban forests will continue to provide benefits to the people who live in urban communities as the climate changes. We define the urban forest as all publicly and privately owned trees within an urban area—including individual trees along streets and in backyards—as well as stands of remnant forest. The Urban project works across public and private organizations toward this goal by accomplishing the following objectives:

- Engage with communities across the Northeast, Mid-Atlantic, and Midwest that are interested in adapting their urban forest management to climate change
- Work with these communities to assess the vulnerability of their urban forests to climate change
- Identify and develop tools to aid adaptation of urban forests to climate change
- Develop real-world examples of climate-informed management of urban forests.

Figure 1.—Climate Change Response Framework components.

The tools and approaches developed in the Urban project are designed to be applied to any urban, suburban, or other developed area in the Midwest and Northeast. The Chicago Wilderness region was chosen as a pilot area to test these ideas, with the intention of applying lessons learned to other metropolitan regions and municipalities in the future.

The Chicago Wilderness region pilot of the Urban project is a collaborative effort among the U.S. Forest Service and other organizations. Current partners in the effort include:

- Northern Institute of Applied Climate Science
- U.S. Forest Service
  - Eastern Region
  - Northern Research Station
  - Northeastern Area (State & Private Forestry)
- Chicago Region Trees Initiative
- The Morton Arboretum
- Chicago Wilderness
- The Field Museum
- The Chicago Botanic Garden

Scope and Goals

The primary goal of this assessment is to summarize potential changes to the urban forest of the Chicago Wilderness region under a range of future climates, and determine the vulnerability of trees and developed and natural landscapes to those changes. The assessment also includes 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 the urban forest of the Chicago Wilderness region, an area of about 7 million acres that stretches from southwestern Michigan to southern Wisconsin, reaching through northwestern Indiana and northern Illinois (Fig. 2). Chicago Wilderness is a regional alliance of more than 200 organizations that work together to improve the quality of life of the humans and the many other species living in the Chicago area. This region includes 38 counties, over 500 municipalities, and a population of more than 10 million people.

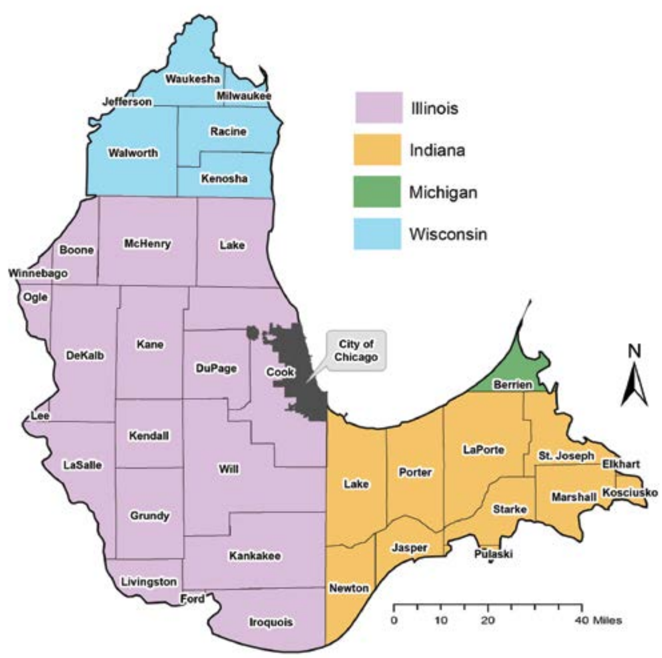


Figure 2.—Chicago Wilderness region.

The boundaries of the Chicago Wilderness region encompass several rare ecosystem types that support a high diversity of species. Boundaries of the watersheds containing the natural communities helped to define the region, as did the large concentration of natural preserves in the metropolitan area (Chicago Wilderness 1999).

Assessment Chapters

This assessment comprises the following chapters:

Chapter 1: The Contemporary Landscape describes existing conditions, providing background on the physical environment, ecological character, and current management of urban forests of the Chicago Wilderness region.

Chapter 2: Climate Trends and Projections discusses our current understanding of past and projected future changes in climate in the Chicago Wilderness region.

Chapter 3: Climate Change Impacts and the Adaptive Capacity of the Urban Forest synthesizes the potential impacts of climate change on urban forests in the Chicago Wilderness region, with an emphasis on changes in habitat suitability and the adaptive capacity of different species.

Chapter 4: Urban Forest Vulnerability Case Studies presents case study vulnerability assessments for municipalities, park districts, and forest preserve districts in the Chicago Wilderness region.

Chapter 5: Management Considerations provides an overview of climate change impacts on decisionmaking, management practices, and other issues related to urban and community forestry in the Chicago Wilderness region.

CHAPTER 1

THE CONTEMPORARY LANDSCAPE

The urban forest is defined as all publicly and privately owned trees within an urban area—including individual trees along streets and in backyards—as well as stands of remnant forest (Nowak et al. 2001). The urban forest of the Chicago Wilderness region, a 7-million-acre area in portions of Illinois, Indiana, Michigan, and Wisconsin, can be viewed as two separate but interconnected entities: natural areas and developed sites. These areas are managed and maintained in vastly different ways and by different stakeholder groups. The urban forest is shaped by current land use and development imposed upon the ecosystems, landforms, and environmental gradients that existed before Euro-American settlement. Historically, the region was a mosaic of prairies, dunes, wetlands, and wooded ecosystems, but most of these natural areas have been developed for agricultural, urban, and suburban land uses. Even though much of the region has been developed, its natural history still influences current forest composition. In this chapter we describe the structure and function of the urban forest of the Chicago Wilderness region, the forces that have shaped it, and stressors that currently threaten it. This information lays the foundation for understanding how shifts in climate may contribute to changes in the urban forest of the Chicago Wilderness region, and how climate may interact with other stressors present on the landscape.

Landscape Setting

This assessment covers the urban forest of the Chicago Wilderness region, which lies within parts of Ecological Provinces 221 and 251 (Midwest Broadleaf Forest and Prairie Parkland; Cleland et al. 2007) (Fig. 3). Provinces, and sections within them, are distinguished by differences in geologic parent material, elevation, plant distribution, and regional climate and are based on the U.S. Forest Service National Hierarchical Framework of Ecological Units (McNab and Avers 1994, McNab et al. 2007). Following is a brief overview of the landscape setting. Additional descriptions of the landscape setting can be found in the resources listed in the sidebar.

More Information on Forests in the Chicago Wilderness Region

Origins of the Chicago Urban Forest: Composition and Structure in Relation to Pre-settlement Vegetation and Modern Land-use (Fahey et al. 2012)—Analyzes the effect of pre-urban ecosystem conditions on modern urban forest composition and structure.

Sustaining our Oaks: a Vision for the Future of Oak Ecosystems in the Chicago Wilderness Region (Fahey et al. 2015)—Provides detailed information on the distribution of remnant wooded ecosystems across the Chicago Wilderness region and outlines a strategy for promoting continued oak dominance in the region across land-use categories and stakeholder groups.

Vegetation of the Chicago Region as Mapped by the Public Land Survey 1821–1845. Interactive Maps and Reports (McBride and Bowles 2007b)—Provides data, summary reports, and interactive maps focused on the distribution, structure, and composition of ecosystems in the pre-urban Chicago region.

Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project (McPherson et al. 1994)—Summarizes a 3-year study to quantify the effects of urban vegetation on the local environment and help city planning and management organizations increase the net environmental benefits from Chicago's urban forest.

Urban Trees and Forests of the Chicago Region (Nowak et al. 2013)—Provides a quantitative assessment of the current composition of trees in the region along with their ecosystem service values.

Chicago Wilderness: an Atlas of Biodiversity (Sullivan 2011)—Describes the geologic history and natural communities in the area.

(see the Literature Cited section starting on p. 76 for complete citations)

Landform, Soils, and Hydrology

The topography and soils of the Chicago Wilderness region were shaped by glaciers that advanced and retreated across the region from 85,000 to 10,000 years before present. These ice sheets were massive: some were more than a quarter of a mile thick (Sullivan 2011). The glaciers flattened most of the land, but they also carved the rivers and lakes that dot the region (Bowles and Jones 2007). Additionally they created a series of swells (low-relief undulations in the landscape) that run through the area, leading to occasional glacial features such as eskers, kames, and moraines (Pielou 2008).

Glaciers formed the foundation for soils in the Chicago Wilderness region. As the glaciers advanced across the region's limestone bedrock, they gathered and carried large amounts of earth with them, leaving behind large rocks, finer pebbles, sand, clay, and silt as they receded. This material makes up the mineral components of the soils in the region (Bretz 1955). Topsoil tends to be quite sandy near Lake Michigan, and was primarily formed on beach deposits from the lake. Areas farther from the lake are formed primarily on glacial outwash and till, and have more silt and clay. Much of the region has a heavy clay layer a few feet below the topsoil. In the thousands of years since the final retreat of the glaciers, this soil has changed into its current state. Erosion moved some of the soil and deposited it in new places, and organic matter has been added to the soils by generations of plants and animals (Sullivan 2011). More recently, agriculture and development substantially altered the soils in the area from their original state, leading to heavy compaction, altered nutrient levels, and the presence of non-soil materials in the profile (Gregory and Dukes 2006) (see subsection on Major Stressors and Threats to the Urban Forest).

Agricultural and urban development has changed the hydrology of the area (Fitzpatrick et al. 2005). By the late 1970s, peak flood levels in northeastern Illinois had tripled over the historical record, an increase believed to be driven by urbanization (Allen and Bejcek 1979). The relative effect of urbanization depends in part on factors such as watershed slope, percentage of clayey surficial deposits, reach (the length of a river), glacial landforms, hydrologic alterations (e.g., stormwater management practices and point sources), and historical and present channel alterations (Fitzpatrick et al. 2005).

Natural Communities

Before Euro-American settlement, the Chicago Wilderness region had many natural community types, though few remnants persist. Community types include dunes, wetlands, prairies, shrublands/barrens, woodlands, and forested ecosystems (Fig. 4). Landscape features such as soil texture, depth, and drainage; rainfall; slope and aspect; and hydrology determine what

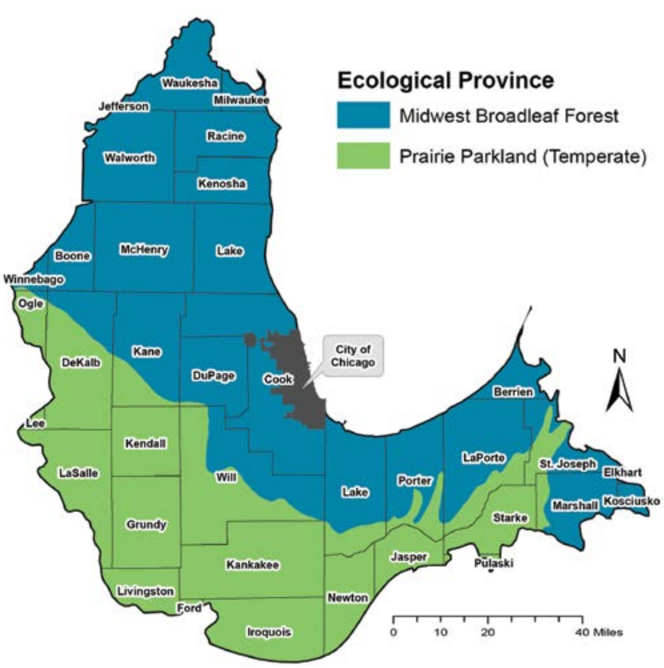


Figure 3.—Ecological provinces in the Chicago Wilderness region. Source: Cleland et al. (2007).

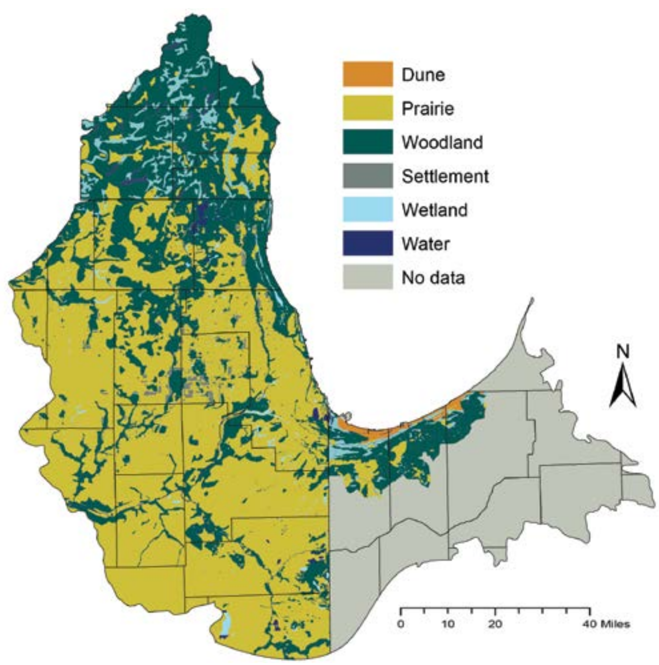


Figure 4.—Distribution of natural community types across the Chicago Wilderness region prior to Euro-American settlement. Source: Chicago Metropolitan Agency for Planning (2015).

groups of species are suited to a given site (Leitner et al. 1991). Prairies formed in many sites, including those with poor or shallow soils, those with south-facing aspects, and areas that experienced frequent fire disturbance. Woodlands and forests formed where the soil was deeper and where firebreaks reduced disturbance frequency and severity (Sullivan 2011). The formation of fens, marshes, bogs, and swamps depends on the hydrology and pH of the waters.

Hydrology, landscape features, and soils played only a part in determining ecosystem distributions; disturbance heavily influenced the ecology of the Chicago Wilderness region for thousands of years (Abrams 1992, Leitner et al. 1991, Nowacki and Abrams 2008). Much of the region has suitable soil and hydrologic characteristics to support forests, but disturbance from fire and grazing limited their distribution. Prior to Euro-American settlement, fires were frequent and widespread across much of the area because of the region's flat topography and few firebreaks (Anderson 1991, Bowles et al. 1994). The fires affected the distribution, structure, and species composition of the area's ecosystems. Forests were present only in sites that were protected from fires: primarily along the east side of rivers (Bowles et al. 1994).

Disturbance not only limited the extent of woody ecosystems, but also influenced their structure and function. Woodlands were relatively open, with a low number of trees per acre, and they were dominated by fire-tolerant trees such as oaks and hickories (Fig. 5). Before Euro-American settlement, oaks were the most abundant species in the Chicago Wilderness region, making up more than 65 percent of the regional forest by basal area (Fahey et al. 2012). Less fire-tolerant species, such as maples and American basswood, were not abundant, and existed only in areas with firebreaks (McBride and Bowles 2007a). For lists of the common and scientific names of species mentioned in this report, see Appendix 1.

The variety of ecosystem types in the region has resulted in a diverse assemblage of plant and animal species. The region is home to approximately 1,650 native plant species. In the Indiana Dunes National Lake Shore, for example, there are 1,300 native plant species, the third highest number of species in the U.S. National Park

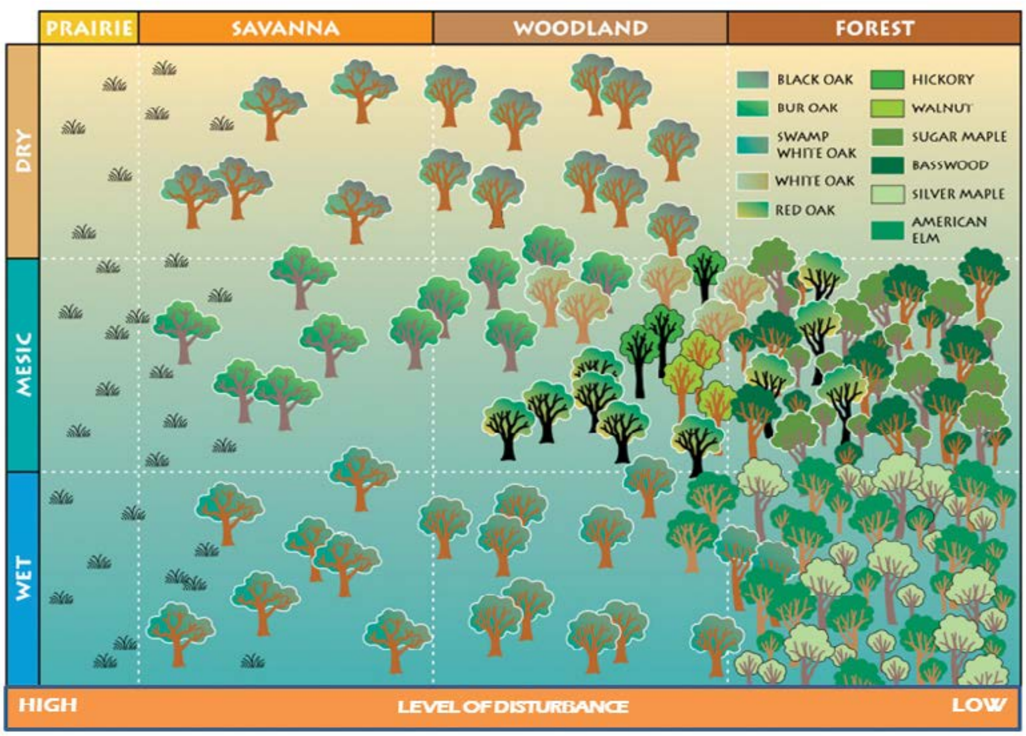


Figure 5.—This diagram arranges the pre-settlement wooded communities of this region on two axes. One separates them according to soil moisture from wet to dry and the other according to the density of the tree canopy. This density gradient is also a fire gradient. Fires burned hotter and more often in the communities to the left of the diagram. Communities to the right saw fewer fires. Reproduced with permission from Sullivan (2011).

System (Sullivan 2011). Hundreds of species of birds use forests in the Chicago Wilderness region to nest, overwinter, or rest during migration. Nearly 100 species of reptiles and amphibians are also present. More detail on the biodiversity of the Chicago region can be found in Sullivan (2011).

Human Influences

Humans have strongly influenced the area for thousands of years for different purposes. Native Americans colonized the Chicago Wilderness region soon after the final glacial retreat (Hicks 2000). More recently, Euro-American settlement dramatically transformed the landscape through agriculture, development, hunting, and horticulture.

Native American Influence

Native Americans were present in the area for thousands of years and primarily used fire to manipulate the landscape (Lesser 1993, MacCleery 2011). They lit fires to clear land for dwellings and fields, to control vegetation, and to flush wildlife from forested areas while hunting (Pyne 1982). The long-term and wide-ranging use of fire by Native Americans and the presence of grazing animals created ecosystems that were adapted to live with these disturbances (Curtis and McIntosh 1951). Native American practices created open woodlands and savannas. These activities tended to favor oaks and other fire-tolerant species and disfavor more fire-sensitive species.

Early Euro-American Settlement

Extensive Euro-American settlement began in the early to mid-19th century. Soon thereafter, settlers plowed many prairies and savannas to establish vast agricultural lands (Hicks 2000). Many of the region's natural areas and numerous large trees were lost. Euro-Americans also suppressed fire in the remaining natural areas. Fire-intolerant species became established in areas where they had previously been precluded.

Euro-American Influence Through Present Day

As Euro-Americans continued to settle in the region, agricultural use intensified; farmers plowed most of the prairies and savannas in the outer counties of the Chicago Wilderness region. Closer to the City of Chicago, most of the natural areas have been lost to urbanization and suburban sprawl. The only remaining natural areas in the region are fragmented and are a small fraction of their original size (Mankin and Warner 1997) (Fig. 6).

Many of the natural areas that still exist bear little resemblance to pre-Euro-American settlement landscapes. Although there have been recent efforts to reintroduce fire to these sites, it had largely been suppressed for the previous 100 years. Wooded ecosystems have a much higher tree density under fire suppression than was present historically. Canopy closure changed the composition of the forest: species such as oaks and hickories that were abundant before Euro-American settlement have become less common, as their seedlings require ample light to develop (Fig. 7). Shade-tolerant species have increased, including American basswood, elms, maples, and invasive species such as European buckthorn.

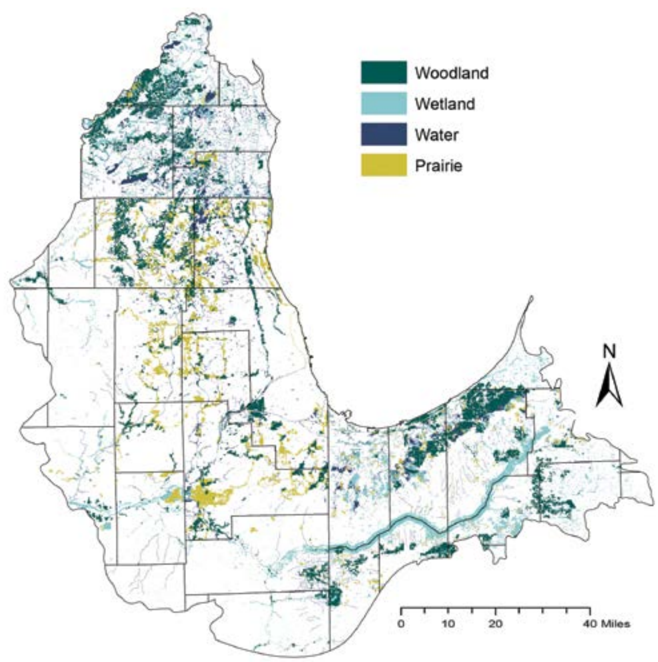


Figure 6.—Current distribution of natural areas in the Chicago Wilderness region. Source: Chicago Metropolitan Agency for Planning (2015).

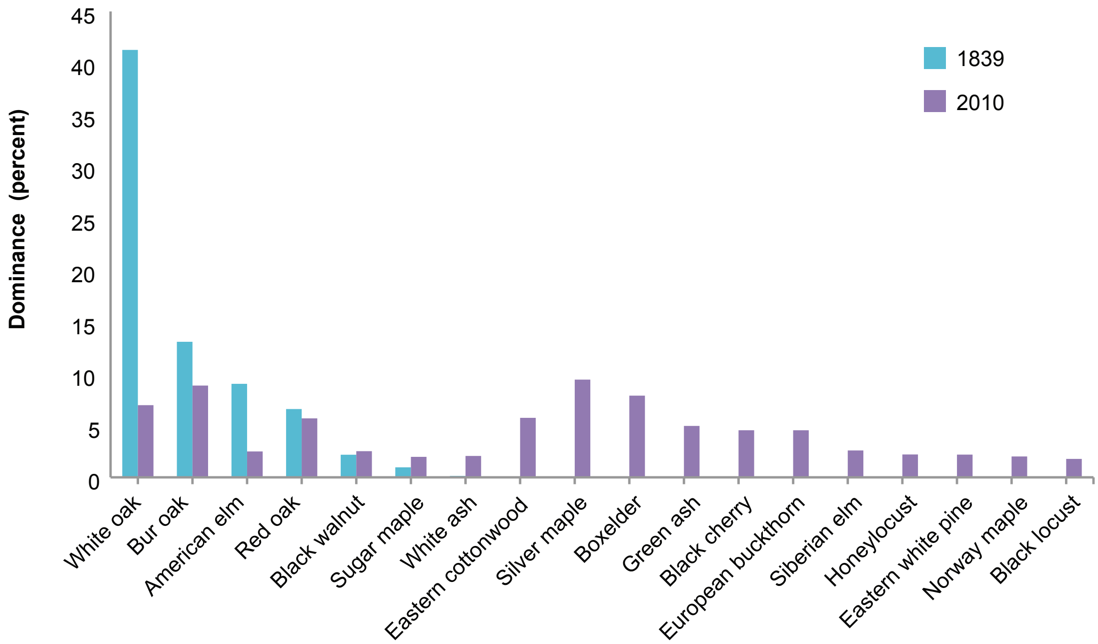


Figure 7.—Comparison of species dominance (percentage of estimated total basal area) in 1839 (based on Government Land Office Public Land Survey data) and 2010 (based on the urban tree census data) in the Chicago Wilderness region across all land-use types. Source: Fahey et al. (2012).

Current Conditions in the Chicago Wilderness Area

Land Use

Like its historical predecessor, the current landscape is heterogeneous; but instead of containing many natural ecosystem types, it varies by land use and ownership and across a gradient in density from urban to suburban to rural. Trees and forests are arrayed across land use types, from privately owned residential, commercial, and agricultural sites, and publicly owned parks, transit ways, and forest preserves to golf courses, cemeteries, and university campuses. Patterns of land use vary greatly from the urban core in the City of Chicago to the seven exurban and rural collar counties (Fig. 8). In the City of Chicago, the vast majority of land is residential and commercial. In Cook, DuPage, and Lake Counties residential, transit, and open space are the most abundant land-use types. Across the Chicago Wilderness region, open spaces are more common. Open spaces such as parks, forest preserves, and vacant lots make up almost one-quarter of the land. Residential areas account for nearly one-third. Although agriculture is virtually nonexistent in the City of Chicago, it is abundant in the outer counties, and makes up one-third of the land in the region.

Species Composition Patterns

The forest of the Chicago Wilderness region is a mixture of remnant (pre-Euro-American settlement) trees, planted trees, and spontaneous recruitment from both sources. The proportion of remnant to planted trees varies from site to site. Some parts of the region still have a greater proportion of remnant trees and their offspring; other areas are dominated by newly planted and often nonnative species (Fahey et al. 2012, Nowak 2012). The ratio depends on the natural history and ecology, development history, and the land use and ownership of a particular site. Areas that were historically wooded often retain that legacy. Individual remnant trees can be seen not only in natural areas across the region, but even in some developed areas such as the Villages of Oak Park and Riverside. In these communities, 200-year-old trees stand in the parks and boulevards alongside newly planted trees. Parts of the region that were historically prairies lack these remnant trees, and a greater proportion of the trees at these sites were planted or spontaneously regenerated more recently (Fahey et al. 2012).

The current composition at a site also depends on ownership and management. In most areas there is a mix of both native and planted trees. For example, in golf courses and cemeteries, many remnant trees and their offspring grow next to recently planted trees that

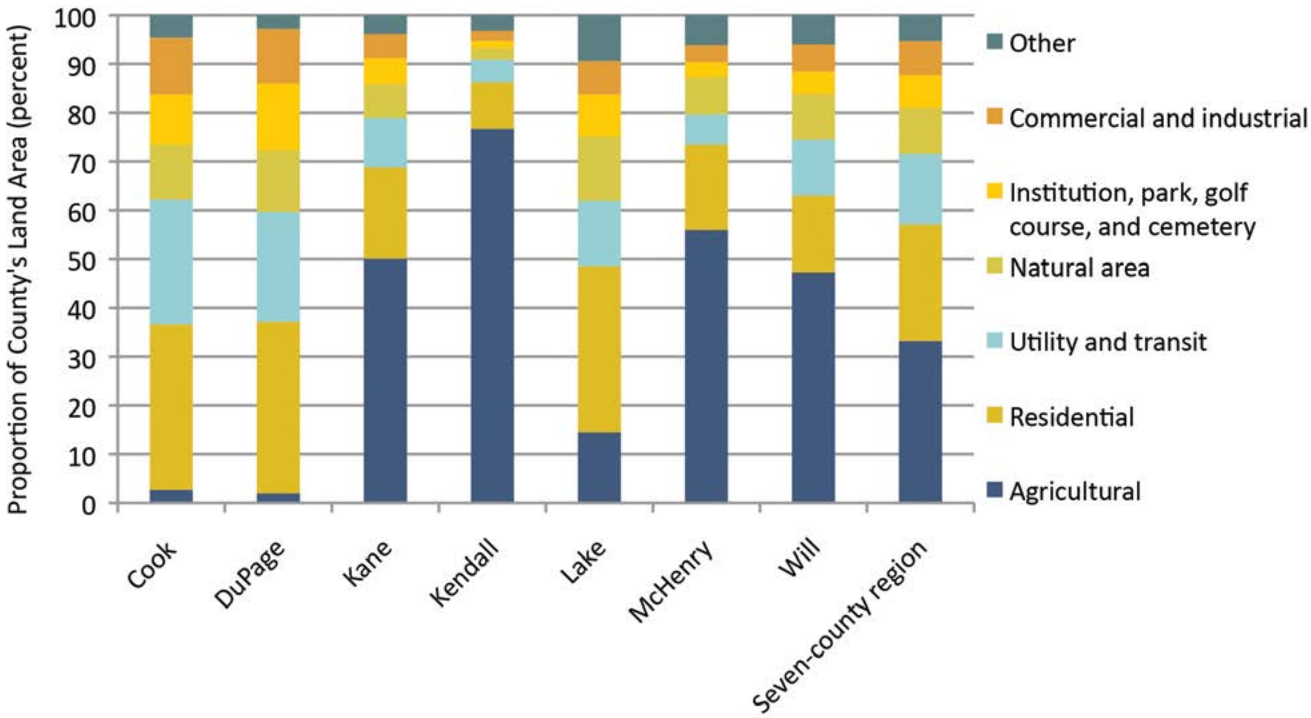


Figure 8.—Land-use type by county. Source: Chicago Metropolitan Agency for Planning (2010).

are often nonnative. Parks, natural areas, and other open spaces tend to have a higher proportion of remnant vegetation. In areas where the original forest was cleared for agriculture or urban development, the current forest has a much higher proportion of planted and nonnative trees (Fahey et al. 2012). In residential and commercial sites many new trees have been planted, and these trees often bear little resemblance to what originally existed in the Chicago Wilderness region. Most trees have been removed from agricultural sites, but those that remain are generally not planted, and are more likely to be native, to have sprouted spontaneously, or both.

Major Stressors and Threats to the Urban Forest

Land-use change, development, and fragmentation

Development is the major driver of forest change in the Chicago Wilderness region; it has altered species composition, as described earlier, and increased fragmentation among native populations. Fragmentation of natural landscapes leads to the creation of isolated populations that are unable to migrate easily and exchange genetic material. Consequently, biological and genetic diversity may be reduced (Fahrig 2003, Harrison and Bruna 1999, Robinson et al. 1995). In the Chicago Wilderness region, the number of parcels of remnant oak ecosystems greater than 500 acres has been reduced from 26 in 1939 to just 6 in 2010 (Fahey et al. 2015). Fragmentation has resulted in the near extinction of the lakeside daisy (DeMauro 1993) and in severe population losses for many reptiles and amphibians (Cushman 2006). Fragmentation not only decreases connectivity among natural areas but also changes the structure of existing sites. As sites become fragmented and the amount of core ecosystem space is reduced, many plants and animals that rely on core habitat may be extirpated from the region (Saunders et al. 1991). Additionally, habitat edges are more likely to be affected by pollution runoff from nearby roads and industry, and are more likely to contain invasive species. As a result, they tend to be less biologically diverse than core areas, and offer less useful habitat for wildlife (Saunders et al. 1991).

Alteration of soil

Changes in land use have altered soils in the region. Levels of nitrogen and phosphorus tend to be higher across the Midwest than historical levels due to application of fertilizers and heavy planting of leguminous, nitrogen-fixing crops (Vitousek et al. 1997). Although little research is available specific to the Chicago Wilderness region, studies from other urban areas can shed light on likely impacts. In other areas, atmospheric deposition of nitrate, ammonium,

A work in progress: shoreline of Jackson Park, on Chicago's South Side. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

calcium, and sulfate ions has been detected in areas nearly 30 miles from the urban core (Lovett et al. 2000). In heavily urbanized sites, soils tend to be compacted, which can decrease the rate at which water enters the soil, increasing rainwater runoff and making it more difficult for trees to grow (Gregory and Dukes 2006). Development and industrialization have caused the deposition of heavy metals such as lead, copper, and nickel (Pouyat et al. 1995). Heavy metals are more abundant in dense urban cores and are associated with industrial areas, but are also deposited near roadways (Helmreich et al. 2010). Salt loads (from both mineral salt and salt spray) are also heavy along roads and in parking lots. Runoff from limestone and concrete causes many urban soils to be more alkaline than is found in most natural areas (Ware 1990). The most severely altered soil conditions occur in tree pits: cutouts in sidewalks or along roads where trees are planted. Tree pits are often nutrient-deficient and heavily compacted, and have some of the highest salt inputs (Craul 1999).

Shifts in fire regime

Fire suppression since Euro-American settlement has altered the structure and composition of the vegetation in the region. The number of mesic species, such as American basswood and maple, has increased, and the number of oak and hickory species has decreased (Fahey et al. 2012). More recently, managers of natural areas in the region are reintroducing fire through prescribed burning. However, the fragmentation of the landscape along with the high density of homes limits the use of fire in the region. In addition, the changes to the structure and composition of the forest (sometimes termed "mesophication") have made the landscape less prone to fire and harder to manage effectively by using prescribed fire alone (Nowacki and Abrams 2008).

Invasive plant species

Invasive plant species such as European buckthorn and Amur honeysuckle strongly influence the structure, composition, and functioning of forests in the area. In fact, European buckthorn is the most abundant tree species currently in the Chicago Wilderness region, accounting for 28 percent of the total urban tree population (Nowak et al. 2013). Invasive plants create a dense shrub layer in woody ecosystems under which native forbs and trees are unable to grow (Heneghan et al. 2006, Knight et al. 2007, Olden 2006). They can also affect soil conditions such as nutrient cycling (Heneghan et al. 2006). Other problematic woody species include multiflora rose and Oriental bittersweet. Herbaceous invaders include garlic mustard, Japanese stiltgrass, and common reed. All of these invasive species can outcompete native species and reduce the biodiversity of the region's natural areas.

Insect pests and diseases

Some native and nonnative insect pests and diseases are dramatically affecting trees and forests, especially in developed areas. In the past, Dutch elm disease devastated the American elms that once lined city streets. A current major issue in the Chicago Wilderness region is emerald ash borer, which has the potential to eliminate all ash species in the region (MacFarlane and Meyer 2005). The emerald ash borer has killed tens of millions of ash trees in the Northeast and Midwest. This has cost municipalities, property owners, nursery operators, and forest products industries tens of millions of dollars, and the total cost of treatment across the United States is estimated to be in the tens of billions of dollars (Kovacs et al. 2010). Although currently not present, Asian longhorned beetle is another species that poses a great risk to the area as it attacks many of the most common natural and planted species.

Extreme weather events

Current climate- and weather-related events include wind disturbance, winter storms, droughts, and floods. Tornadoes, derechos, and downbursts are frequent features on the landscape, damaging trees and subsequently property and powerlines. Ice storms occur occasionally in the Chicago Wilderness region, and can cause damage to a variety of species (Hauer et al. 2006). Drought can lead to reduced growth rates as well as the secondary effects of pest and disease infestations (Fahey et al. 2013). Current and future projected impacts of extreme weather events on forests in the region are discussed in Chapter 3.

Urban heat island effect and ozone pollution

The urban heat island effect occurs when developed areas are hotter than nearby rural areas. The urban heat island effect in the Chicago Wilderness region is noticeable despite the cooling effects of Lake Michigan. Summer temperatures in Chicago are 2.2 °F (1.2 °C) warmer than the surrounding area, with an even greater effect at night: 3.4 °F (1.9 °C) warmer (Kenward et al. 2014). Elevated temperatures can lead to direct heat-related stress on urban trees and increase the rate of ground-level ozone formation (Jacob and Winner 2009). Ozone pollution can have negative effects on photosynthesis and cause damage to leaves, and some species such as black cherry and red maple are particularly sensitive (Chappelka and Samuelson 1998, Pye 1988, Reich and Amundson 1985). In addition, ozone damage can make trees more susceptible to disease, damage from insects, effects of other pollutants, competition, and harm from severe weather.

Current Management

Management of Natural Systems in the Region

Residents of the Chicago Wilderness region recognized the rapid destruction of natural areas soon after Euro-American colonization began. In response, they created forest preserves and park districts that protected the remaining natural areas. The Chicago Park District was created in 1869, and aimed to provide ample green space for Chicago residents to enjoy (Bachrach 2001). Chicago architect Jens Jensen recognized the beauty of the Chicago region's natural areas, and foresaw the need to protect sites that were even quite distant from the City of Chicago. In 1914, the Forest Preserves of Cook County were created. The forest preserves went beyond the goal of preserving parks within the city to protecting large swaths of natural areas throughout Cook County. In the following decades other counties created forest preserve districts of their own. These preserves contain much of the region's existing natural areas, but are strongly biased toward protection of forested areas in fire-protected positions.

Management of these preserves has changed over the past century. When preserves were first created, it was considered sufficient to just preserve the land. More recently, managers have become aware of the widespread changes in structure and species composition of the natural areas relative to historical conditions. In response, management with prescribed fire and removal of invasive species have increased.

The threats posed by invasive species, lack of disturbance, overabundance of white-tailed deer, and fragmentation are an ongoing concern in the region's natural areas. Management plans such as the Biodiversity Recovery Plan (Chicago Wilderness 1999), Green Infrastructure Vision (Chicago Wilderness 2004), and the Oak Recovery Plan (Fahey et al. 2015) have been developed to address these problems. These projects outline broad strategies to improve the management of the region's natural areas so that they will continue to provide habitat for wildlife, recreation for people, and ecosystem services for generations to come.

Winnemac Park, Chicago. Photo by L. Darling, The Morton Arboretum, used with permission.

Selection and Management of Trees in Developed Sites

Trees that are planted in developed areas undergo much different stressors than trees in natural areas, and consequently their species composition and management differ as well. Trees selected for planting on streets and other developed areas need to be able to withstand challenging environmental conditions such as the urban heat island effect, air pollution, and soils with compaction, high pH, and heavy salt loads (Nowak 2012).

A survey of municipal foresters in the Chicago Wilderness region showed that although tolerance of site conditions was the most important factor that they considered when selecting a tree, they considered a variety of other factors as well (Table 1). The second most important factor that municipal foresters consider is maintaining or enhancing species diversity in their forest. Many aim to plant no more than 30 percent of a given family, 20 percent of a genus, and 10 percent of a species (Santamour 1990). However, other recent studies suggest a more nuanced approach to managing for enhanced diversity (Laćan and McBride 2008). Trees that flower and have striking fall color are often preferred, and mature height of trees is important if the trees are to be planted under powerlines or close to buildings. Many foresters are reluctant to plant trees that require regular pruning to encourage good shape or to prevent breakage; instead, they prefer trees that can withstand storms with minimal maintenance.

Based on the survey, municipal foresters in the Chicago Wilderness region are less concerned about planting trees that are native to the region or trees that offer food and shelter to wildlife. Therefore, planted species composition differs greatly from the native species assemblage.

Table 1.—Number of municipal foresters who consider each characteristic "most important" or "not important" when selecting a tree species (Source: Unpublished survey of 104 municipal foresters as part of the Chicago Region Trees Initiative, The Morton Arboretum, Lisle, IL)

Characteristic	Most important	Not important
Tolerance of site conditions	91	3
Diversity of community trees	84	9
Mature height	60	11
Required maintenance	43	8
Ornamental appeal	36	10
Native status	28	22
Wildlife services	11	53

Chicago Region Trees Initiative

Efforts are ongoing to improve the health and resilience of the natural and planted component of the Chicago regional forest. Pests such as the emerald ash borer have caused massive destruction in the region, and there is broad recognition that invasive species, pests, and climate change could further deteriorate the regional

A municipal park in Glencoe, IL. Photo by T. McDonald, Glencoe Park District, used with permission.

forest. In response, the Chicago Region Trees Initiative has been developed to improve management of the region's trees (The Morton Arboretum 2015). This initiative aims to improve management of individual trees by promoting proper species selection, planting, watering, and pruning of trees. It also strives to increase managers' capacity to care for their trees by offering training. Ultimately, the Chicago Region Trees Initiative aims to increase canopy cover in the region, and to increase the resilience of the regional forest by planting an appropriate diversity of tree species.

Summary

The Chicago Wilderness region has been heavily shaped by agriculture and urban development for more than 150 years, which has resulted in dramatic changes in the landscape from its previous condition. The area was once dominated by open, fire-adapted systems such as savannas, prairies, and oak woodlands. Now it is a mosaic of land uses with a mix of native and nonnative species that are less fire-tolerant. Human land use has dramatically altered the soils in the region, and created an environment where many nonnative invasive species and forest pests and pathogens can thrive. Foresters and other natural resource managers in the area are balancing many needs as they work to select tree species that are able to cope with the realities of the harsh urban environment.

Key Points

- Before Euro-American settlement, open oak ecosystems such as savannas and woodlands dominated the Chicago Wilderness region.
- Today, most of the natural areas have been lost to urbanization and suburban sprawl. The only remaining natural areas in the region are fragmented and are a small fraction of their original size.
- Key stressors to forests in the region include development, soil alteration, alteration of historical fire regimes, air pollution, the urban heat island effect, extreme weather events, invasive plants, insect pests, and diseases.
- Current management of natural areas in the region focuses on restoring native ecosystems and simulating past disturbance regimes.
- Selection of trees for urban plantings weighs other factors besides native status, such as tolerance of site conditions, diversity of community trees, tree height, required maintenance, and ornamental appeal.

CHAPTER 2

CLIMATE TRENDS AND PROJECTIONS

Climate, the long-term average weather for a particular place, can change dramatically on the scale of thousands of years. After the last ice age about 10,000 years ago, the climate in the Chicago Wilderness region shifted from cool and moist to hot and dry, before eventually becoming what we are familiar with today. Although the climate of the area has changed in the past, it is the rate of change that is of primary concern today. Temperature and precipitation are changing rapidly at a global scale and are projected to change at an even faster rate in the coming decades (Intergovernmental Panel on Climate Change [IPCC] 2014). These changes will manifest themselves differently in different areas and need to be summarized at a local level to be relevant for decisionmaking. To aid in evaluating these local changes, this chapter discusses our current understanding of past and projected future changes in climate in the Chicago Wilderness region.

Temperature and Precipitation Trends

Measurements of temperature and precipitation at weather stations in the area have been recorded for a little over 100 years. We used the ClimateWizard Custom Analysis tool to present the changes in temperature and precipitation across the Chicago Wilderness region (ClimateWizard 2011, 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. We examined long-term (1901 through 2011) trends for annual, seasonal, and monthly temperature (mean, mean minimum, and mean maximum) and total precipitation within the Chicago Wilderness region. 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 high confidence that they did not occur by chance. For more precise information about how these trends were calculated, levels of confidence, and caveats related to the data presented, refer to Appendix 2. Please note that the information presented here is meant to give the reader a general overview of regional trends in climate and is not intended for interpretation at a particular location. More information on historical trends in climate for specific weather stations can be found online (see the "More Climate Information" box on the next page).

Temperature

The Chicago Wilderness region has gotten warmer over the past century. From 1901 through 2011, mean annual temperatures increased by about 1 °F (0.6 °C) across the region (Fig. 9). Increases were larger around Lake Michigan and more pronounced in spring and summer. Increases were especially pronounced in nighttime minimum temperatures across all seasons. Summer minimum temperatures increased by 2.5 °F (1.4 °C) on average across the region. Changes in summer maximum temperatures differed geographically, with increases around the City of Chicago and several other areas along the shore of Lake Michigan and decreases throughout the southern part of the region, away from the lake. Winters have also become slightly milder, especially minimum temperatures in the area directly adjacent to Lake Michigan.

Precipitation

Precipitation has also increased across the region on average (Fig. 10). The greatest increases were around the City of Chicago and around southwestern McHenry County, IL. Across the entire area, increases were greatest in summer (3 inches). Spatial patterns in precipitation varied by season. Spring increases were primarily in southeastern Wisconsin and Lake and McHenry Counties, IL. Fall increases were primarily in Indiana along the Lake Michigan shore. The "Changes in Climate" sidebar on page 14 discusses changes in regional temperature and precipitation in the early 21st century.

More Climate Information

Chicago Climate Action Plan

To assess the impacts of climate change and to develop a plan for the future, the City of Chicago consulted leading scientists to describe various scenarios for Chicago's climate future and how the scenarios would affect life in the city. This effort resulted in the Chicago Climate Action Plan (*www.chicagoclimateaction.org*) and the report Climate Change and Chicago: Projections and Potential Impacts (Hayhoe et al. 2008).

Chapter 2 of the report summarizes past and projected changes in climate: *www.chicagoclimateaction.org/filebin/pdf/report/Chicago_climate_impacts_report_Chapter_Two_Climate.pdf*

Chapter 3 summarizes past and projected changes in water cycling: *www.chicagoclimateaction.org/filebin/pdf/report/Chicago_climate_impacts_report_Chapter_Three_Water.pdf*

Climate Adaptation Toolkit

The Chicago Metropolitan Agency for Planning developed the Climate Adaptation Toolkit for communities interested in adapting their planning and investment decisions to a changing climate. Appendix A of this toolkit, "Primary Impacts of Climate Change in the Chicago Region," summarizes past and projected changes in temperature and precipitation: *www.cmap.illinois.gov/livability/sustainability-climate-change/climate-adaptation-toolkit*

State Climatologists

State climatologists provide information about current and historical trends in climate throughout their states. The state climatologists for each of the four states within the Chicago Wilderness region have a wealth of information on trends in climate for their state:

- **Illinois:** *www.isws.illinois.edu/atmos/statecli/index.htm*
- **Indiana:** *climate.agry.purdue.edu/climate/index.asp*
- **Michigan:** *climate.geo.msu.edu*
- **Wisconsin:** *www.aos.wisc.edu/~sco*

Midwestern Regional Climate Center

The Midwestern Regional Climate Center (MRCC) is a cooperative program between the National Centers for Environmental Information (formerly the National Climatic Data Center) and the Illinois State Water Survey. The MRCC serves the nine-state Midwest region (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin). It provides high-quality climate data, derived information, and data summaries for the Midwest: *mrcc.isws.illinois.edu*

Great Lakes Integrated Sciences and Assessments

Great Lakes Integrated Sciences and Assessments (GLISA) integrates information from a wide array of scientific fields, develops collaborations between entities with similar goals, and helps inform decisionmakers throughout the region with sound science. GLISA offers a unique approach to building climate literacy and long-term sustainability, and facilitating smart decisionmaking across the eight Great Lakes states (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin) and the province of Ontario: *glisa.umich.edu*

Scenarios for Climate Assessment and Adaptation

This Web site contains a suite of climate and other scenarios produced as input to the U.S. National Climate Assessment. There are documents, graphics, references to datasets, and other resources that have been prepared to depict a range of plausible future conditions against which risks, vulnerability, and opportunities can be assessed at regional and national scales. For Midwest reports and graphics: *scenarios.globalchange.gov/regions/Midwest*

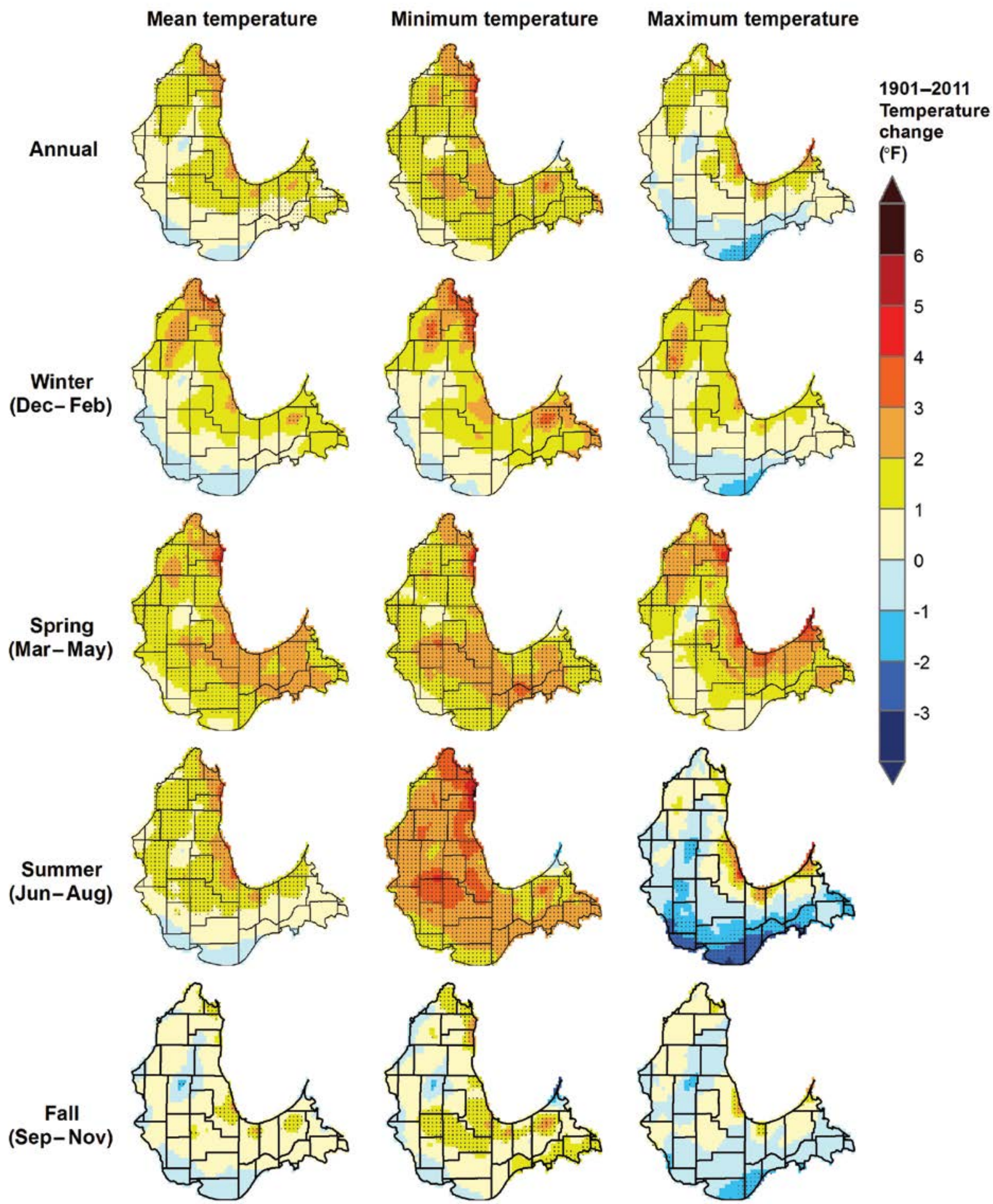


Figure 9.—Change in annual and seasonal mean daily mean, daily minimum, and daily maximum temperature (°F) in the Chicago Wilderness region from 1901 through 2011. Stippling indicates there is less than 10-percent probability that the trend could have occurred by chance alone. Source: ClimateWizard (2011).

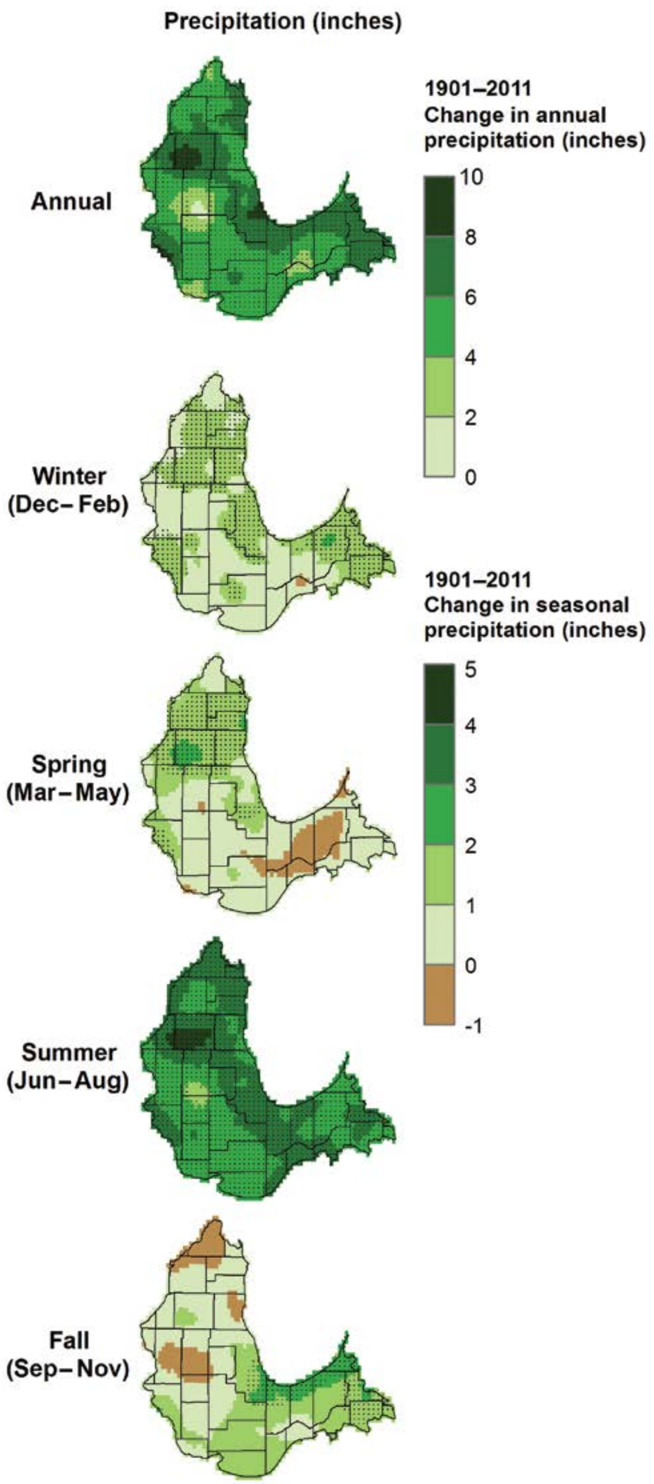


Figure 10.—Change in annual and seasonal precipitation (inches) in the Chicago Wilderness region from 1901 through 2011. Stippling indicates there is less than 10-percent probability that the trend could have occurred by chance alone. Source: ClimateWizard (2011).

Early 21st-Century Changes in Climate

Although weather fluctuates from year to year, temperatures in the early 21st century have continued to rise. The decade from 2001 through 2010 was the warmest on record both globally and averaged across North America (World Meteorological Organization 2012). In the Chicago Wilderness region, temperatures were also generally higher than average between 2001 and 2012. In fact, the year 2012 was the warmest on record for Illinois and Wisconsin, and the second warmest for Indiana (National Oceanic and Atmospheric Administration [NOAA] National Climatic Data Center [NCDC] 2013).

The winter of 2013–2014 was a newsworthy event that introduced many people to the concept of the polar vortex, a large pocket of very cold air that typically sits over the polar regions during the winter season. That winter, however, the polar vortex shifted over the eastern United States, sending temperatures plummeting. Snowfall in Chicago was the third highest and temperatures were the third coldest on record for the December to February period (NOAA National Weather Service 2015b, 2015c). Similar cold periods were experienced during the winter of 2014–2015. Despite these cold winters, the overall trend has been toward increasing winter temperatures in the area.

Trends in precipitation from 2000 to the present across the assessment area indicate a continuing pattern toward wetter conditions. The year 2012 was an exception, with the area experiencing drought conditions that had not occurred in the region for many decades (NOAA NCDC 2013). However, the trend of rising precipitation could be seen again in spring 2013, when precipitation was 6 inches higher than the 1971 through 2000 seasonal average (NOAA National Weather Service 2015a).

These recent climatic events point to the fact that seasonal and year-to-year variability will continue to be important. Thus, examining a range of potential futures will be key when assessing future vulnerability to climate change.

Temperature and Precipitation Projections

Models that are used to simulate climate projections are called general circulation models (GCMs). These models simulate physical processes in the Earth's surface, oceans, and atmosphere through time using mathematical equations in three-dimensional space. GCMs require information about changes in greenhouse gas concentrations to project future climates, and these changes must be estimated. The IPCC set of standard emissions scenarios has been widely used to estimate future greenhouse gas emissions under a range of potential futures (IPCC 2007). Throughout this document, we report climate projections for two model-emissions scenario combinations—GFDL A1FI and PCM B1 (unless otherwise noted)—that were used in the IPCC Fourth Assessment (IPCC 2007). The GFDL A1FI model-scenario combination represents a higher-end projection for future temperature increases, and the PCM B1 represents a lower end (see the sidebar). It is possible that actual emissions and temperature increases could be lower or higher than either of these projections. Based on current trends, however, the GFDL A1FI scenario represents a more likely projection of future greenhouse gas emissions and temperature increases. The future is likely to be different from any of the developed scenarios, and therefore we encourage readers to consider the range of possible climate conditions over the coming decades rather than one particular scenario. In addition, model projections change as new information becomes available and new greenhouse gas emissions scenarios are developed.

General circulation models simulate climate conditions at relatively coarse resolutions. One pixel in a GCM can cover a large portion of a state, which is not very useful for making local decisions. One method of projecting climate at finer resolutions is statistical downscaling, a technique by which statistical relationships between GCM model outputs and on-the-ground measurements are derived for the past and used to adjust large-scale GCM simulations of the future for much finer spatial scales. Downscaling can help with visualizing local variability in climate projections due to differences in topography or proximity to large bodies of water. Although downscaling can be a useful tool, it is important to keep in mind that this additional layer of analysis can add uncertainty and error to climate projections and give a false impression that the accuracy

Models and Scenarios Used in this Report

This assessment uses two model-scenario combinations from the IPCC Fourth Assessment Report (AR4; IPCC 2007). We chose to use these models and scenarios instead of the newer model results from the IPCC Fifth Assessment Report (AR5; IPCC 2013) because (1) the habitat suitability and hardiness and heat zone projections were available only for the older dataset and (2) the downscaled projections were not widely available when we started this assessment. We also chose to use this dataset for consistency with other vulnerability assessments that we performed using similar methods (e.g., Brandt et al. 2014).

There are some minor differences in the projections between AR4 and AR5. AR4 used emissions scenarios, and AR5 used resource concentration pathways (RCPs). Although the assumptions behind AR4 and AR5 are different, projections of greenhouse gas concentrations and global temperature are similar between the A1FI emissions scenario and RCP 8.5. Greenhouse gas concentrations are also similar between the B1 emissions scenario and RCP 4.5 at the end of the century, though the concentrations at mid-century are higher for RCP 4.5. Besides changes in emissions scenarios, models were also updated to reflect better understanding of the Earth's physical processes and often perform at a finer spatial resolution than AR4. The overall magnitude and direction of change are generally similar in the Chicago Wilderness region between the two IPCC datasets, especially when comparing within models and analogous scenarios (Sun et al. 2015). Thus, we have high confidence that the changes projected using the earlier scenario-model combinations are representative of our current understanding of projected climate changes in the Midwest.

Downed trees being harvested for reuse after a storm in a Chicago park. Photo by J. Scott, Chicago Park District, used with permission.

of climate projections is greater than it actually is (Daniels et al. 2012).

In this assessment, daily mean, minimum, and maximum temperature and total daily precipitation data were downscaled to an approximately 7.5-mile grid scale across the United States and then visualized and summarized for the Chicago Wilderness region (Hayhoe 2010, Stoner et al. 2013). To visualize changes, we calculated the average daily mean, minimum, and maximum temperature for each season and the entire year for three 30-year time periods (2010 through 2039, 2040 through 2069, 2070 through 2099). Daily precipitation values were summed by year and season, and 30-year means were calculated. We subtracted temperature and precipitation values from the mean values for 1971 through 2000 as a baseline to determine the departure from current climate conditions. Historical climate data used for the departure analysis were taken from ClimateWizard based on the PRISM dataset (Girvetz et al. 2009) (see Appendix 2). Results for the end of the century (2070 through 2099) are reported in this chapter; results for early and mid-century are available in Appendix 3.

Temperature

There is general agreement among models that temperatures will increase, and at a faster rate than what has been experienced over the 20th and early 21st century. Both models project increases in mean, minimum, and maximum temperatures across all time periods and for all seasons. Mean annual daily temperature across the region is projected to increase by 8.2 °F (4.5 °C) under the GFDL A1FI scenario and 2.3 °F (1.2 °C) under PCM B1 for the final 30 years of the 21st century (Fig. 11) (see also Appendix 3) compared to the 1971 through 2000 baseline. The most dramatic increase in temperature is projected to be in summer for the GFDL A1FI scenario and in winter for the PCM B1 scenario. No spatial variation in temperature changes is discernable. Increases are projected to be slightly greater in minimum temperatures than maximum temperatures, with the exception of summer for the GFDL A1FI scenario (Figs. 11–13).

Precipitation

There is less certainty about how precipitation patterns may change in the future. The magnitude and seasonal direction of projected changes in precipitation are not consistent between the two models presented. Mean annual precipitation is projected to increase by only 0.7 inches under the GFDL A1FI scenario for the final 30 years of the 21st century (Fig. 14) (see also Appendix 3) compared to the 1971 through 2000 baseline. In contrast, annual precipitation is projected to increase by an average of 3.8 inches for the PCM B1 scenario.

Changes in precipitation are projected to vary greatly by season. Both models project an increase in precipitation in winter and spring. They differ in projections for summer and fall. PCM projects an increase of 1.8 inches, whereas GFDL projects a decrease of 5.8 inches

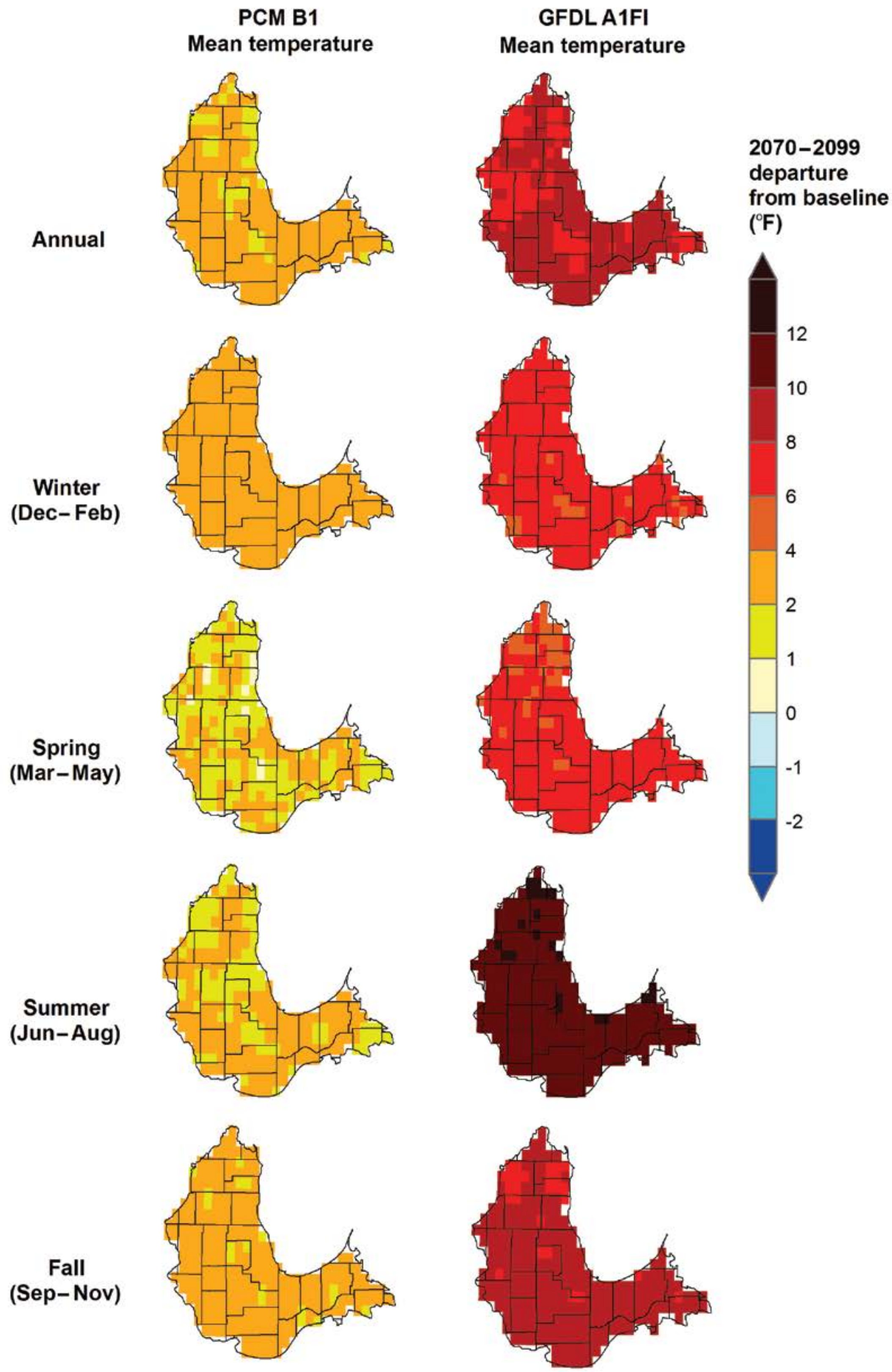


Figure 11.—Projected difference in mean daily mean temperature (°F) in the Chicago Wilderness region at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

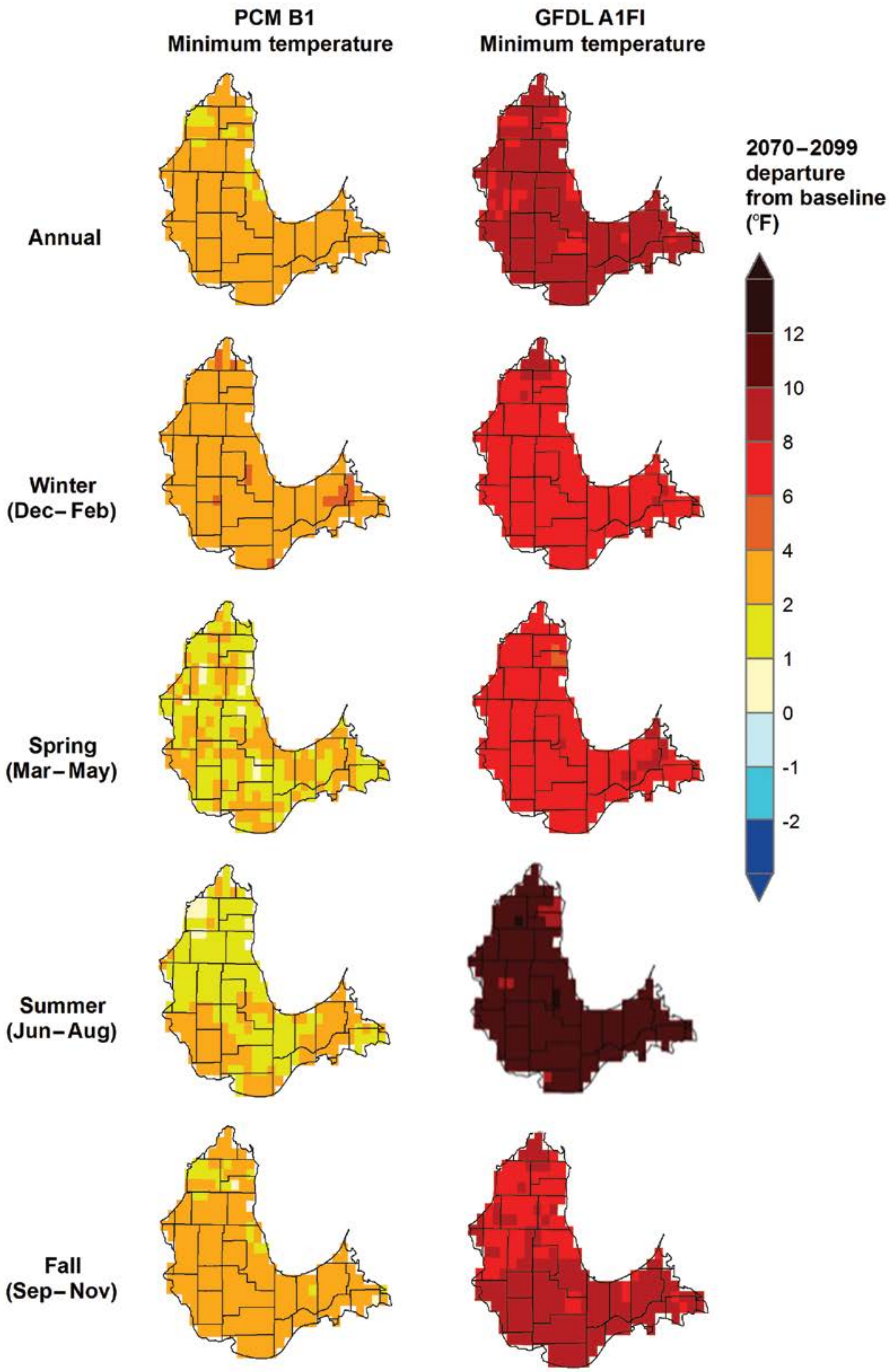


Figure 12.—Projected difference in mean daily minimum temperature (°F) in the Chicago Wilderness region at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

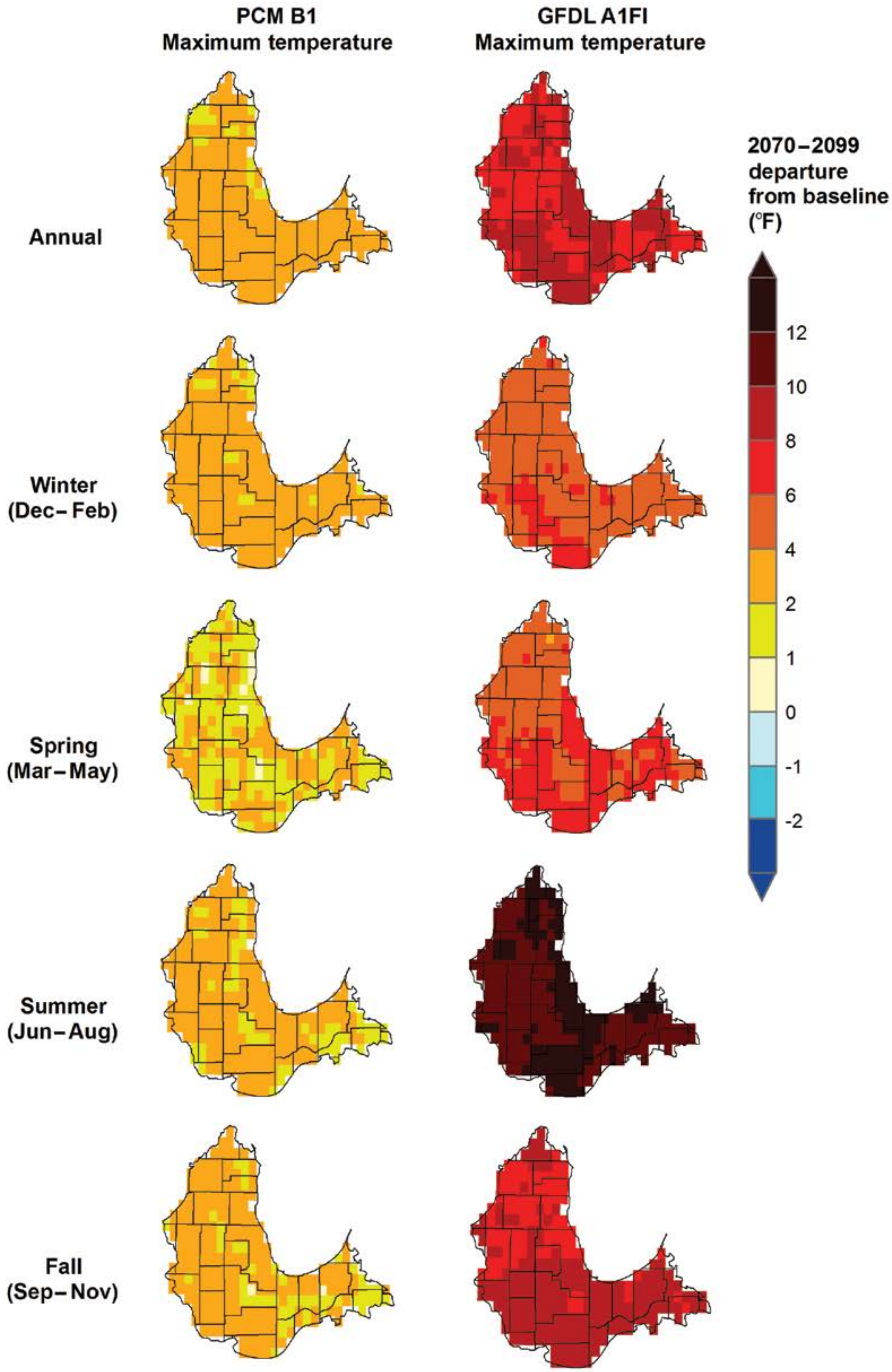


Figure 13.—Projected difference in mean daily maximum temperature (°F) in the Chicago Wilderness region at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

in summer. In the fall, PCM projects a decrease of 0.9 inches, but GFDL projects an increase of 1.4 inches.

Trends and Projections in Extreme Weather Events

Extreme weather events, such as extreme temperatures, high winds (e.g., derechos), tornadoes, thunderstorms, and winter ice storms and snowstorms are important disturbance agents to trees in both urban and natural areas. Some evidence suggests that extreme events have been increasing across the United States and globally over recent decades, and this increase is consistent with global climate change (Coumou and Rahmstorf 2012, Kunkel et al. 2008, Peterson et al. 2013). The next subsections summarize how these extreme events have changed during the historical record and are projected to change over the next century based on models.

Temperature Extremes

In addition to changes in means, temperature extremes are also likely to shift across the region. Increases in consecutive days with extremely high temperatures (heat waves) are a major concern in urban areas, where the urban heat island effect can make temperatures even more severe. The heat wave in July 1995 in Chicago, for example, was one of the worst weather-related disasters in Illinois history with more than 700 deaths over a 5-day period (Changnon et al. 1996, Kunkel et al. 1996). Extreme heat can also have negative effects on trees, leading to leaf scorch, root damage, and mortality. Today, Chicago experiences on average one more 3-day or greater heat wave per year than in the mid-20th century, leading to devastating effects on people and the environment (Perera et al. 2012). Despite the rising trend, extreme heat was more prominent in the early part of the 20th century (especially during the Dust Bowl era of the 1930s) than it has been in the past several decades (Kunkel et al. 2013). Although daytime maximum temperatures have not increased as much, there has been a significant increase in the nighttime minimum temperatures during heat wave events (Kunkel et al. 2013, Perera et al. 2012). High nighttime temperature can lead to water loss in trees and other vegetation, which could be especially harmful if summers are also drier (Zeppel et al. 2012).

Studies from across the Midwest indicate that there will be more days per year that are warmer than 95 °F (35 °C) and a greater frequency of multi-day heat waves over the 21st century (Diffenbaugh et al. 2005, Kunkel et al. 2013, Winkler et al. 2012). Under a high emissions scenario, the Chicago region could experience more than 30 heat waves like the one in 1995 (which was characterized as more than 7 consecutive days with a maximum daily temperature of greater than 90 °F, or 32 °C, and nighttime minimum of greater than 70 °F, or 21 °C) in the last 10 years of the 21st century (Hayhoe et al. 2008). In addition, there could be more than 70 days per year warmer than 90 °F by the end of the century. The high humidity in the area is also projected to worsen, leading to a higher heat index and making temperatures feel even hotter (Vavrus and Van Dorn 2010). This could have negative effects on human health and mortality, and heighten the need for cooling measures such as increased tree canopy.

Extreme cold can be damaging to trees, and is the foundation for northern range limits of many species. It can also be a limiting range factor for tree pests such as the emerald ash borer (DeSantis et al. 2013). Despite the extreme cold during the winter of 2013–2014, the frequency and intensity of periods of extremely cold days (cold waves) in the Midwest have been decreasing, although there is no statistically significant trend (Kunkel et al. 2013). Extremely cold days that are less than 10 °F (-12 °C) are projected to decrease in the area by 15 to 20 days by mid-century compared to the average for 1980 through 2000 (Kunkel et al. 2013). One study for the Chicago area suggests that the lowest temperature of the year may increase at nearly double the rate of average winter temperatures and the frequency of nights less than 0 °F (-18 °C) may decline by 50 to 90 percent (Vavrus and Van Dorn 2010). Despite an overall decreasing trend, extremely cold winters, like the one experienced in 2013–2014, may potentially continue to occur in the future. Some research indicates that the 2013–2014 cold wave was due to a weakened polar vortex that may have been driven by human-induced warming (Wang et al. 2014). This is still an active area of research, and more research is needed before we can understand the long-term implications of this phenomenon for the Midwest.

Heavy Precipitation Events

Heavy precipitation events are a particular issue in urban areas, where stormwater runoff can overwhelm sewer systems and lead to local flooding. Studies suggest that heavy precipitation has become more frequent and intense in the United States over the past several decades (Groisman et al. 2012, Kunkel et al. 2008). Across the central United States, very heavy (greater than 3 inches

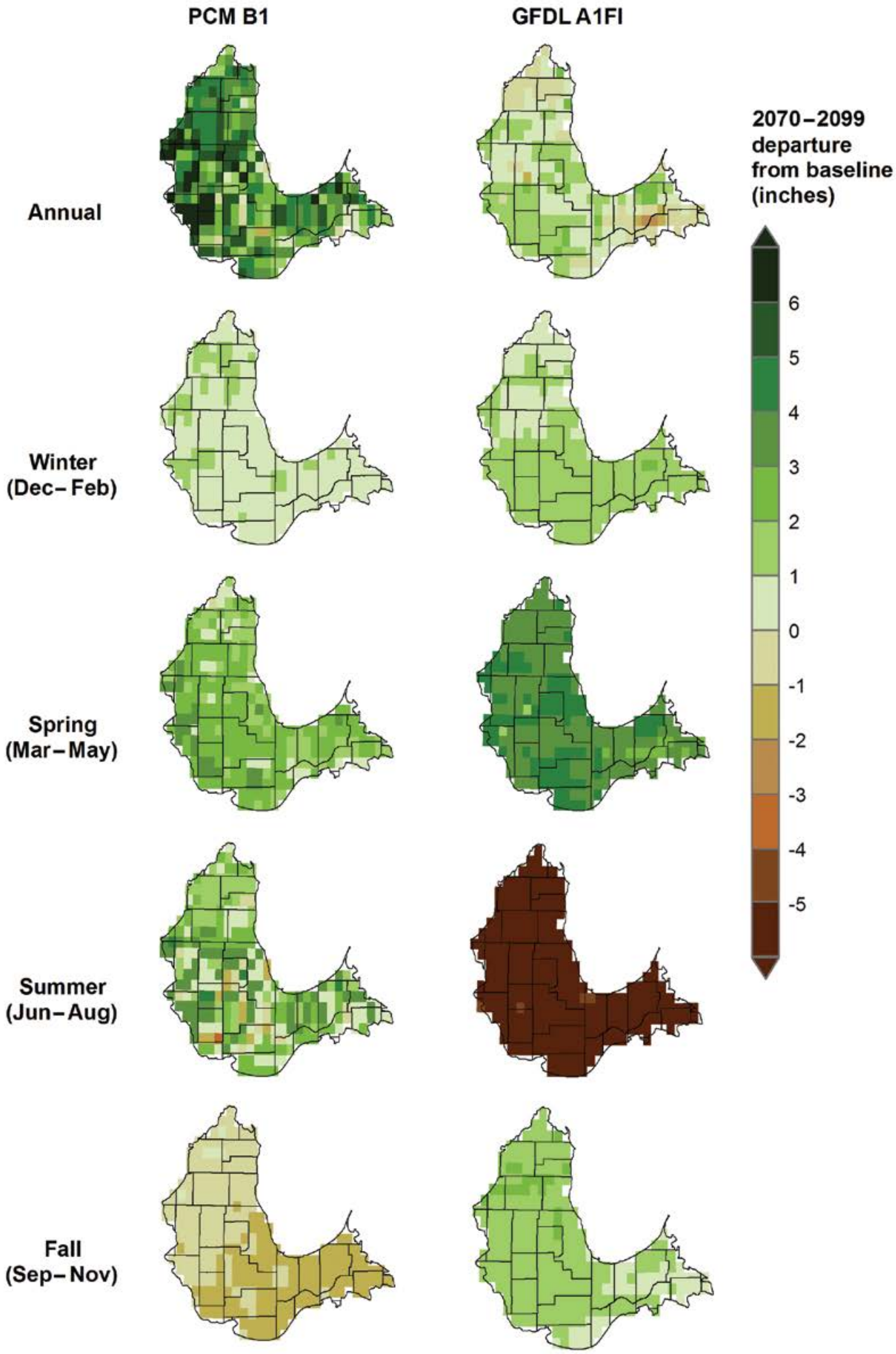


Figure 14.—Projected difference in mean annual and seasonal precipitation (inches) in the Chicago Wilderness region at the end of the century (2070 through 2099) compared to baseline (1971 through 2000) for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

Flooded open land, Hazel Crest, IL. Photo by K. Persons, Village of Hazel Crest Open Lands Commission, used with permission.

per day) and extreme (greater than 6 inches per day) precipitation events increased in the period from 1979 to 2009 compared to the 1948 to 1978 period (Groisman et al. 2012). A recent report examined trends in heavy precipitation events for every state in the Midwest from 1961 to 2011 (Saunders et al. 2012). The authors found that precipitation events of 3 inches or more increased by 26 percent in Illinois, and increases were even greater in Indiana (77 percent), Michigan (54 percent), and Wisconsin (92 percent) (Saunders et al. 2012). Another report shows that there has been an increase in the number of "100-year" (7.58 inches or greater) and "10-year" (4.47 inches or greater) storm events in Chicago in recent decades (Chicago Metropolitan Agency for Planning 2013).

Climate models project a global increase in the number of heavy precipitation events by the end of the century (IPCC 2012, 2014). There is greater agreement among models at high latitudes and in the tropics, but model projections for the central United States suggest a potential increase in these events, especially during winter months (IPCC 2012). Other future climate projections indicate that the Midwest may experience 2 to 4 more days of extreme precipitation by the end of the century (Diffenbaugh et al. 2005). However, downscaled projections for the Midwest indicate less projected change in heavy precipitation events (greater than 1 inch) in the southern half of the region (including the Chicago area) than in the Midwest as a whole (Kunkel et al. 2013). A study that specifically focused on the Chicago area suggests that the frequency of extremely wet days (days with greater than 1.57 inches of precipitation) will increase by 25 to 60 percent by the end of the century (Vavrus and Van Dorn 2010). These increases are greater than the increase in total precipitation, indicating there will also be a decrease in the number of days with light precipitation. Similar patterns of increased heavy precipitation were also projected by Hayhoe et al. (2010).

Thunderstorms, Tornadoes, and Wind Storms

Thunderstorms, tornadoes, and wind storms are common phenomena in the Chicago area, and can lead to tree damage from lightning strikes and strong winds. There is no evidence of a change in the severity or frequency of thunderstorms across the United States over the past 100 years (Kunkel et al. 2008). Thunderstorms are reported as days when thunder audibly occurs; therefore, there is a propensity toward human error and inconsistency in record-keeping for these measurements (Changnon 2003). At first glance, the historical record seems to indicate an increase in the total number of tornadoes in the United States over the past century (Diffenbaugh et al. 2008). However, this trend is largely the result of an increase in the detection of tornadoes through technological enhancements and improved monitoring networks (Kunkel et al. 2008). It also appears that the number of severe tornadoes in the United States has decreased over the past century (Diffenbaugh et al. 2008). However, the severity of a tornado is determined not by its wind speed but by the level of damage done to structures. Building construction has also changed over the past century, so it is difficult to discern whether we are observing weaker storms or simply less damage because of changes in construction practices. There are also many issues with collecting reliable wind data in order to detect trends. Based on available data, one study found no increasing or decreasing trend in wind speed between 1979 and 2006 (Pryor and Ledolter 2010).

Although there are no clear trends for the past, modeling research suggests severe storms may become more frequent in the future. GCMs do not operate at a scale small enough to model thunderstorms explicitly, but a few studies have found a slight increase in the frequency of conditions favorable for intense thunderstorms in the Midwest by the end of the century (Trapp et al. 2007, 2009). Tornadoes are a result of both convective available potential energy (CAPE) and wind shear. In general, current global climate models suggest that CAPE may increase, while wind shear may decrease (Diffenbaugh et al. 2008, 2013). The balance of these two forces, as well as potential seasonal and geographic shifts in that balance, has been a key question. A recent study using the most recent set of climate models for the IPCC Fifth Assessment Report sheds new light on this question (Diffenbaugh et al. 2013). That study suggests that the timing of the decrease in wind shear is offset from the days with increased CAPE, indicating that conditions for severe storms, including tornadoes, may increase. For the Chicago area, this increase appears to be especially concentrated in the spring, and secondarily in the fall. As temperatures increase, this could mean a longer season for thunderstorms and tornadoes. Some research has also examined projected changes in wind speed, but currently there is insufficient information to tell whether wind speeds are likely to increase or decrease in the Midwest (Winkler et al. 2012).

Winter Storms

Winter storms are common in the Chicago area, occurring about one to two times per year on average (Changnon 2006). From 1949 through 2003, there appeared to be neither a negative nor a positive trend in the number of winter storms in the central United States (including the Chicago area). However, there was a trend toward an increasing amount of damage from those storms due to both an increase in infrastructure and an increase in storm intensity, which was interpreted as a trend consistent with increased warming (Changnon 2007).

Ice storms can be particularly damaging to trees in the region, leading to stem and branch breakage and crown loss (Hauer et al. 2006). Ice storms are a severe form of a freezing rain event. The Chicago area has on average 3 to 4 days of freezing rain events per year, which can occur between November and April, with a peak in January (Changnon and Karl 2003). A study examining changes in freezing rain across the United States from 1949 through 1999 showed a "U-shaped" pattern in the number of freezing rain events in the Chicago area; the number decreased between 1949 and 1989 and then increased during the 1990s, without an overall upward or downward trend (Changnon and Bigley 2005).

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 also some evidence to suggest that these events could be more intense when they do happen (Vavrus and Van Dorn 2010). Wang and Zhang (2008) examined changes in risk of extreme precipitation during the winter months under the A2 emissions scenario using statistically downscaled climate projections. They found an increased risk for extreme winter events at the end of the century for the Chicago Wilderness region. Whether these events occur as rain, snow, or ice will depend on the exact timing of these events and their interaction with projected changes in temperature. In general, more research is needed before we can determine the most likely effects of future climate change on winter storms.

Drought

Droughts place great stress on trees in both urban and natural areas, and can often lead to secondary effects of insect and disease outbreaks on stressed trees (Fahey et al. 2013). No studies on droughts are available specifically for the Chicago Wilderness region, but information is available for the states of Illinois and Indiana. Over the past century (1916 to 2007), the frequency of extreme and exceptional droughts in Illinois and Indiana decreased (Mishra et al. 2010). Exceptional droughts are the most severe form of drought in the region, and extreme droughts are the second most severe. Until the recent drought of 2012, all of the exceptional droughts were prior to 1970, and the majority of them occurred during the Dust Bowl era of the 1930s. In general, more-recent drought events have been less intense in their severity, duration, and spatial extent than in the 20th century. However, the 1988 drought was the fifth-driest year on record in Illinois and led to severe water shortages throughout the state (Lamb 1992). In addition, the 2012 drought was the most extensive drought on record across the United States since 1956 (NCDC 2012). Changes in precipitation coupled with warmer temperatures are also likely to lead to changes in drought characteristics, such as intensity, duration, frequency, and spatial extent. One study suggests that extreme and exceptional droughts in Illinois and Indiana may increase in duration, frequency, and spatial extent compared to the last 30 years of the 20th century (Mishra et al. 2010). These findings are consistent with a global-scale study that found a projected increase in drought frequency, duration, and severity across the central United States (Sheffield and Wood 2008). However, there is a lot of model uncertainty in summer precipitation, and thus we cannot say with high certainty the magnitude and direction of changes in droughts in the Chicago region over the next century (Kunkel et al. 2013).

Changes in Soils and Hydrology

Information about how temperature and precipitation patterns may change in the Chicago area can further be used to examine how these changes may affect the cycling of water in urban and natural environments. 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). This can lead to changes in streamflow, soil moisture, and drought conditions.

Soil Moisture

Adequate soil moisture is important for supporting tree growth. From 1916 to 2007, annual soil moisture in the top 4 inches increased in the area around Chicago by about 0.02 inches, which is small but enough to be statistically distinguishable from chance (Mishra et al. 2010). Total soil moisture (down to 6.6 feet) apparently did not change, however (Mishra et al. 2010).

Changes in soil moisture are largely driven by the balance of precipitation and evapotranspiration (the sum of evaporation and transpiration by plants), and thus there is some uncertainty about future changes. Based on projected decreases in precipitation during summer and fall and increases in temperature throughout the year, one study found that surface soil moisture was projected to decrease in Illinois and Indiana over the next century (2009 to 2099) by a small amount, primarily during late summer, fall, and winter (1.2 to 1.6 percent, depending on scenario; Mishra et al. 2010). Total soil moisture was also projected to decrease in the late summer and fall and increase in winter and spring. Another study in the region suggests a decrease in soil moisture during winter and early spring and increases in soil moisture during the growing season (Winter and Eltahir 2012). The difference between the two studies suggests that model assumptions made and scenarios chosen can have a large impact on projections of future soil moisture in the Midwest.

Soil Frost and Freeze-Thaw

The duration and depth of soil frost and the number of freeze-thaw cycles can also affect winter and spring hydrologic cycles in the Midwest. An increase in frozen soil can lead to increases in spring peak flows due to a reduction of water infiltration into the soil. Soil frost can also increase water storage in the soil over the winter months. Soil temperatures in winter, and thus soil frost, can be influenced by changes in air temperature and the amount and duration of snowpack. In the Indiana portion of the Chicago Wilderness region, the duration of seasonal soil frost decreased from 1991 to 2006, but did not change for the rest of the region (Sinha et al. 2010). Temperatures hovering around the freezing point can increase the frequency of freeze-thaw events, which can increase susceptibility to soil erosion. Historical data indicate that the frequency of freeze-thaw events in Chicago averages around 6.5 events per year. There are no clear upward or downward trends in the number of freeze-thaw cycles in the region.

As temperatures increase, some changes in soil frost are expected. One study suggests that over the next century, the Chicago Wilderness region may have a dramatic reduction in soil frost, up to 50 fewer days by the end of the century, from both an earlier spring and a later fall (Sinha and Cherkauer 2010). With a shorter frost season, a reduction in frost depth is also projected to occur. The number of freeze-thaw cycles in the region is projected to stay near the current average.

Snowfall and Snow Cover

Snow plays an important role in the hydrology of the Chicago Wilderness region. The amount of snow influences annual runoff, recharge, and water supplies and can have local effects on temperature through its

Winter in Hazel Crest, IL. Photo by K. Persons, Village of Hazel Crest Open Lands Commission, used with permission.

reflectivity (albedo). In addition, rapid melting after a large snowfall event can lead to flooding. Snow can also be an insulator to tree roots, protecting them from temperature extremes. Between 1981 and 2010, the region received an average of about 30 to 72 inches per year, with the greatest snowfall on the eastern side of Lake Michigan (Kunkel et al. 2013). According to the Illinois state climatology office, statewide snowfall has decreased in the most recent 20 years and is below the long-term average (Angel 2012b). However, some areas around Lake Michigan have had an increase in precipitation, particularly on the eastern side (Kunkel et al. 2013). Also, as mentioned earlier, snowfall intensity is increasing, meaning that more snow is falling in heavy storms when it does occur (Changnon 2007). There is also a trend toward earlier snowmelt and decreasing snow depth in the area, consistent with a warming trend (Dyer and Mote 2006).

Future projected changes in snow are complex. The total amount of snow may not change substantially because, despite a shorter cold season, increased winter precipitation may create a greater probability of snow on any cold days that do occur (Hayhoe et al. 2008). However, another regional study suggests that the increase in temperature would be sufficient to reduce snowfall, with decreases in snow water equivalent up to 80 percent by the end of the century (Sinha and Cherkauer 2010). Projections for southeastern Wisconsin also indicate a similar reduction in snowfall (Notaro et al. 2011). Neither of these studies accounts for "lake effect" snow, which may increase on the eastern side of Lake Michigan (including northwestern Indiana and southwestern Michigan) as lake temperatures warm and ice cover decreases (see the "Lake Effect" box on the next page) (Wright et al. 2013). On both the west and east sides of Lake Michigan, any snow that does fall is more likely to fall in heavy storm events (Vavrus and Van Dorn 2010, Wang and Zhang 2008). Regardless of changes in the amount of snowfall, snow cover duration and extent may decrease, and at a faster rate than it did during the 20th century (Brown and Mote 2009, Frei and Gong 2005). By the end of the century, the number of days with snow on the ground is projected to decrease from an annual average of 40 days (between 1961 and 1990) to between 13 and 23 days per year (Hayhoe et al. 2008).

Streamflow, Runoff, and Flooding

Streamflow is an important indicator of flood risk and affects important decisions about water use and management. It can be difficult to attribute any trends in streamflow specifically to climate change, as there have been large-scale land-use changes in the area that can obscure any climate-related signal (Tomer and Schilling 2009, Zhang and Schilling 2006). A study examining trends in streamflow in the Mississippi River Basin from 1940 to 2003 showed a trend toward increasing streamflow across the Midwest, mostly due to an increase in baseflow attributed to agricultural land-use

Lake Effect

Lake Michigan exhibits a strong influence on the climate and hydrology of the Chicago Wilderness region. The presence of Lake Michigan moderates temperature, reducing the annual difference between summer highs and winter lows and the daily difference between nighttime and daytime temperatures (Notaro et al. 2013). The lake effect also increases precipitation during both winter (especially in the areas east of the lake) and summer in the Chicago Wilderness region compared to what it would be if the lake were not present (Notaro et al. 2013). Other major influences of Lake Michigan on the area include greater cloud cover, higher winter winds, and higher humidity in winter months compared to the surrounding area (Notaro et al. 2013). Lake Michigan can also cause an increase in winter storms, especially on the east side in December and January, before much of the lake freezes over (Notaro et al. 2013).

Lake Michigan will continue to influence the climate in its vicinity over the next century, and large-scale changes in climate may alter its influence. As temperatures increase, the length of time that the lake remains frozen and the total area that freezes are likely to decrease, or the lake may stop freezing altogether. In fact, ice cover on Lake Michigan decreased by 77 percent from 1973 to 2010 (Wang et al. 2012). This reduction in ice cover and an increase in lake temperatures could cause a decrease in lake levels, and thus changes in the coastline and water availability, due to an earlier start to the evaporation season (Lenters et al. 2013). Lake levels have already been declining in Lake Michigan: the lake reached its lowest recorded level in 2013 after a particularly hot, dry year (Gronewold and Stow 2014). However, there is much uncertainty in the projections of future lake levels; some models project an increase and others a decrease (Angel and Kunkel 2010, Hayhoe et al. 2010, Lofgren et al. 2011, MacKay and Seglenieks 2013). A loss of ice cover can also result in an increase in lake-effect snow: a recent modeling study found that a warmer, ice-free Lake Michigan could lead to a 50-percent increase in lake-effect snow downwind of the lake (i.e., on its east side), and the area with the greatest lake-effect precipitation could shift inland (Wright et al. 2013).

As the climate changes at global and continental scales, it will be important to keep in mind how these changes may affect the influence of Lake Michigan on local conditions. Most models fail to fully account for the influence of Lake Michigan and other Great Lakes on local climates. Future advances in modeling to incorporate these influences will help us gain a richer understanding of what exactly these changes may be.

Storm surge at Burnham Park, Chicago. Photo by J. Scott, Chicago Park District, used with permission.

changes (Zhang and Schilling 2006). One study in Iowa, Missouri, and Illinois showed that when changes in land use are accounted for, an increase in discharge consistent with local climate changes could be observed (Tomer and Schilling 2009). These changes were largely observed since the 1970s, and are due to an increase in the ratio of precipitation to potential evapotranspiration (i.e., evaporative demand). Streamflow is also projected to change in the near future, with changes varying by season. Winter and spring, which have historically had the greatest number of high-flow days, are projected to have further increases during these seasons (Cherkauer and Sinha 2010). Projected changes in high-flow days in the summer and fall are more mixed and vary based on geographic location. Changes in low-flow days also will vary by season: the number of low-flow days is projected to increase in summer and fall and decrease in the winter and spring.

Runoff can be a major management issue in cities due to the large amount of impervious cover. Runoff is typically greatest in the spring, when there is high precipitation coupled with snowmelt. Runoff increased in the Chicago area from 1950 to 2009, and this increase was attributed to human influence (e.g., increases in impervious cover) rather than increases in precipitation (Velpuri and Senay 2013). Although no climate-driven changes have yet been observed, changes in climate will influence runoff in the Chicago Wilderness region in the future. Runoff is projected to increase slightly in winter and spring and decrease in summer and fall, roughly in line with projected changes in precipitation (Cherkauer and Sinha 2010). This is independent of additional likely increases in runoff from changes in land use. An increase in runoff, coupled with heavy precipitation in the area, is likely to lead to an increased risk of soil erosion in the region (Segura et al. 2014).

Floods in the area typically peak in the spring (Villarini et al. 2011). Across the Midwest, economic losses from flooding have been increasing at a greater rate than elsewhere in the nation. Over a 45-year period (1955 through 1999), Illinois sustained more than $5 billion in flood losses, and 74 percent of these losses occurred after 1985 (Angel 2012a). Although there are signs that flooding has increased in recent years, the link to changes in climate is less clear. Flooding in the region is partially linked to climate factors such as snowmelt and heavy precipitation events, but is more strongly influenced by non-climate factors such as land-use change and the construction of dams and other water infrastructure (Changnon and Demissie 1996). One study examined trends in peak floods in the Chicago metropolitan area. The researchers found that both an increase in heavy precipitation events and changes in land use contributed to increased peak floods across the region, but land-use change contributed a larger amount (Hejazi and Markus 2009).

Change in flood risk under future climate change is difficult to determine because there are currently insufficient records to even determine flood risk at a particular location, irrespective of climate (Stedinger and Griffis 2011). Studies examining future projections for hydrology suggest that the magnitude of flooding could potentially increase in winter and spring due to increases in total runoff and peak streamflow during those time periods (Cherkauer and Sinha 2010). During summer and fall, there could be an increase in “flashiness,” with periods of very low flow followed by rapid flooding in response to heavy rain events (Cherkauer and Sinha 2010). One study specifically examined the potential effects of future climate change on heavy storms and flooding in six watersheds in the Chicago metropolitan area using a regional climate model (Markus et al. 2012). The study found that watersheds in the northern parts of the region could sustain 16- to 20-percent increases in heavy storms and corresponding floods by the 2050s compared to the last decade of the 20th century under a range of emissions scenarios. However, they found that the southeastern Chicago area may not experience any significant changes under a high emissions scenario, but it may have significant decreases in heavy storms (and flooding) under PCM B1. More research is needed to understand whether, in fact, these regional differences exist, and if so, what the underlying causes are.

Growing Season Length

A large body of research indicates that the growing season has been getting longer on a global scale, largely from an earlier onset of spring (Christidis et al. 2007, Parmesan and Yohe 2003, Root et al. 2003, Schwartz et al. 2006). Growing season length is often determined biologically, through the study of the timing of leaf out and senescence, but can also be estimated climatologically. Growing season length can be defined as the period between the date of the last spring freeze and first fall freeze, as determined by minimum temperatures of 32 °F (0 °C). Using this definition, one

Chicago-area community garden. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

study determined the climatological growing season lengthened by about 1 week on average between 1906 and 1997 across Illinois, mostly due to an earlier date for the last spring freeze (Robeson 2002). Another study examined changes in growing season length from 1911 through 2000 across the Corn Belt, including Illinois and Indiana, and found no discernible trend in the data, which were largely driven by a cool period in the 1920s and a warm period in the 1990s (Miller et al. 2005). Since these studies were conducted, a number of years have had last freezes that occurred very early in the spring, such as spring 2012, which may be indicative of things to come.

Information for future projections of growing season length is primarily limited to length of time between the last day below 32 ˚F in the spring and the first day below 32 ˚F in the fall. A study covering the entire Midwest region examined the changes in dates for the last spring frost and first fall frost under a range of climate scenarios (Wuebbles and Hayhoe 2004). This study projected that growing season would be extended by 30 to 70 days by the end of the century, from both an earlier last spring freeze and a later first fall freeze. A more recent study suggests an increase in the frost-free season at mid-century of 20 to 26 days across the Chicago Wilderness region, with the largest increase in the Indiana portion (Kunkel et al. 2013). 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.

Hardiness and Heat Zones

Hardiness zones and, more recently, heat zones are used to determine suitability for planting. As temperatures increase, it is expected that hardiness and heat zones will shift. Hardiness zones are determined by the average coldest temperature in a year. Chicago and areas around Lake Michigan in Indiana are in zone 6a (mean annual lowest temperature -10 to -5 ˚F, or -21 to -23 ˚C), and most of the surrounding area is currently in hardiness zone 5b (mean annual lowest temperature -15 to -10 ˚F, or -26 to -23 ˚C). The combination of the urban heat island effect and the moderating effects of Lake Michigan contributes to warmer temperatures in Chicago and northwestern Indiana. By the end of the century, hardiness zones are expected to shift to between 6a and 6b under a low emissions scenario up to potentially 7b under a high emissions scenario (Table 2) (see also maps in Appendix 4). However, it is important to keep in mind that hardiness zones are based on a 30-year average and some very cold winters could still be possible.

Heat zones are determined by the average number of days greater than 86 ˚F (30 ˚C). Much of the Chicago Wilderness region is in heat zone 5 (30 to 45 days exceeding 86 ˚F). Lake Michigan helps to moderate temperatures in areas along the coast, so the greatest effects of the Chicago area's urban heat island during the day are actually observed in the western suburbs in DuPage and Will Counties (which are in heat zone 6; 45 to 60 days). Lake and Porter Counties in Indiana are

Table 2.—Projected shifts in plant hardiness and heat zones for the Chicago Wilderness region for two climate model-emissions scenario combinations[1]

	PCM B1				GFDL A1FI			
	1980-2009	2010-2039	2040-2069	2070-2099	1980-2009	2010-2039	2040-2069	2070-2099
Hardiness zone	5b-6a	5b-6a	6a-6b	6a-6b	5b-6a	6a-6b	6b-7a	7a-7b
Heat zone	4 - 5	5 - 6	5 - 6	5 - 6	4 - 5	6 - 7	7 - 8	8

[1] For maps and a description of methods, see Appendix 4.

also in heat zone 6. Lake County, IL and southeastern Wisconsin have cooler summer maximum temperatures and are in heat zone 4 (14 to 30 days). If summer maximum temperatures continue to rise, heat zones will also shift in the area, and some areas will be too hot to be suitable for some species. For the PCM B1 scenario, heat zones are not expected to change much from current conditions, but for the GFDL A1FI scenario they could shift up to zone 8 (90 to 120 days exceeding 86 °F) (Table 2).

Summary

Temperature and precipitation increased in the Chicago Wilderness region during the historical record, but future projections suggest that precipitation patterns may become more erratic. Across a range of potential futures, temperatures will almost certainly increase across all seasons over the 21st century, reaching annual temperatures that are 2 to 8 °F higher than the last 30 years of the 20th century. This will lead to longer growing seasons and shifts in plant hardiness and heat zones. However, extreme cold events may still occur and potentially even become more frequent. Precipitation is projected to increase in winter and spring, leading to increased runoff, streamflow, and possibly flooding in some areas, especially when combined with continued urban development in the area. Climate models disagree about how precipitation may change in summer and fall. However, it appears likely that more rain will fall as heavy storm events with intermittent dry periods. Warmer winters will reduce the period when snowfall occurs, but snow will still be a key fixture in the area, especially in areas that are prone to "lake effect" snow.

Key Points

- Over the past century, the Chicago Wilderness region has warmed by about 1 °F on average and has had a significant increase in precipitation, especially during the summer (3-inch increase).
- Mean annual temperature is projected to increase by 2.3 to 8.2 °F by the end of the 21st century, with temperature increases across all seasons.
- Precipitation is projected to increase in winter and spring over the 21st century, but projections for summer and fall precipitation are less clear.
- Heavy precipitation events have been increasing in number and intensity and are projected to increase further, which could increase runoff and local flooding from stormwater.
- Extreme and exceptional droughts may increase in duration, frequency, and spatial extent compared to the end of the 20th century.
- Rises in temperature may lead to a shift of one to two hardiness zones and two to four heat zones.

CHAPTER 3

CLIMATE CHANGE IMPACTS AND THE ADAPTIVE CAPACITY OF THE URBAN FOREST

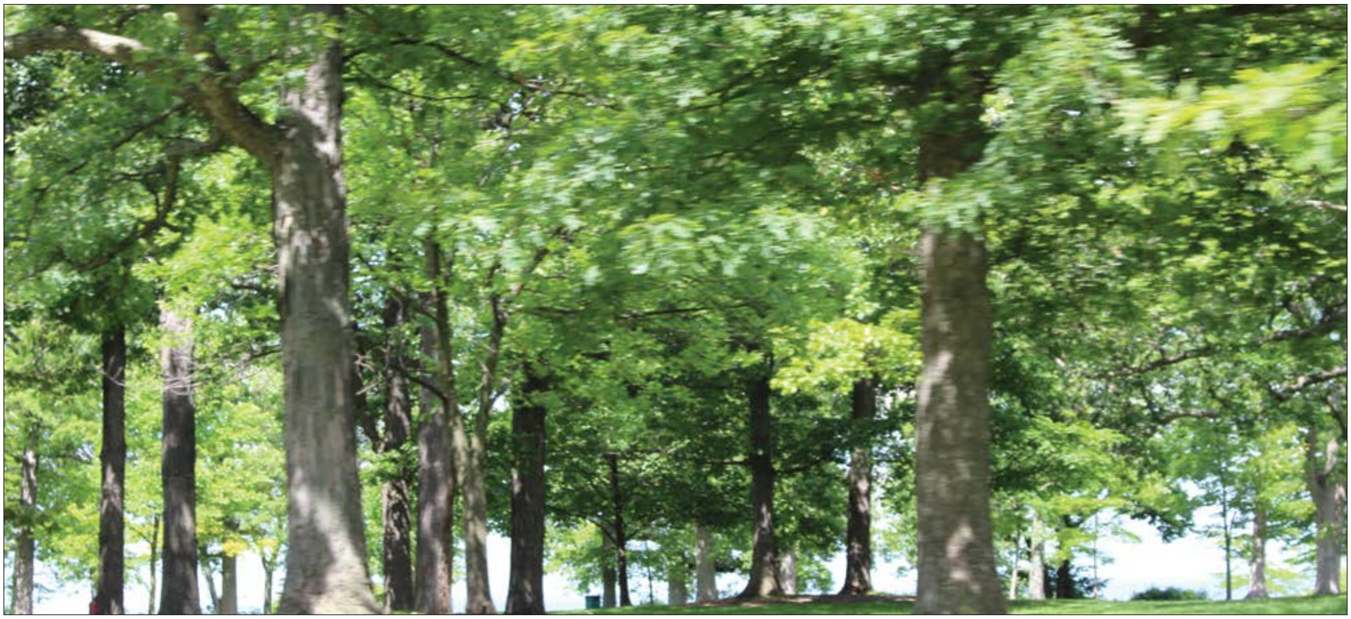
A changing climate could have potentially profound effects on forests of the Chicago Wilderness region. Many tree species that are currently present may suffer declines in habitat suitability under warmer temperatures and altered precipitation patterns. Other species may gain improved habitat suitability under these conditions. Some species not currently present could be planted in the area, as long as they are able to withstand the periods of extreme cold that could still occur during some winters. In addition, climate change can have indirect effects on the urban forests in the region by influencing insect pests, pathogens, and invasive species, and changing the probability, severity, and extent of severe storms. Planted and naturally occurring trees will differ in their capacity to adapt to stressors. This chapter synthesizes the potential impacts of climate change on urban forests in the Chicago Wilderness region, with an emphasis on changes in habitat suitability and the adaptive capacity of different species.

Modeled Projections of Habitat Suitability

Climate change has the potential to alter the habitat suitability for tree species. Scientists can project future habitat suitability using species distribution models (SDMs). These models establish a statistical relationship between the current distribution of a species or ecosystem and key attributes of its habitat. This relationship is used to make projections about how the range of the species will shift as climate change affects those attributes. SDMs are much less computationally expensive than process models, which model ecosystem and tree species dynamics based on interactive mathematical representations of physical and biological processes. Because of their relative computational ease, SDMs can typically provide projections for the suitable habitat of many species over a large area. There are some caveats to be aware of when using SDMs, however (Wiens et al. 2009). SDMs use the realized niche for a species instead of the fundamental niche. The realized niche is the actual habitat a species occupies given predation, disease, and competition with other species. The fundamental niche, in contrast, is the habitat it could potentially occupy in the absence of competitors, diseases, or predators. Given that the fundamental niche may be greater than the realized niche for a species, 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. If some constraints are removed due to future change, the opposite could also occur. Furthermore, fragmentation or other physical barriers to migration may create obstacles for species otherwise poised to occupy new habitat. With these caveats in mind, SDMs can still be a useful tool to understand general projections of changes in habitat suitability across species.

Modeling Native Trees

Suitable habitats for tree species native to the eastern United States were modeled in the Chicago Wilderness region by using the DISTRIB model, an SDM that is a component of the Tree Atlas toolset (Iverson et al. 2008; U.S. Forest Service, n.d.). DISTRIB measures relative abundance, referred to as "importance values," for 134 eastern tree species. Inputs include tree species distribution data from the U.S. Forest Service Forest Inventory and Analysis (FIA) program and environmental variables (pertaining to climate, soil properties, elevation, land use, and fragmentation), which are used to statistically model the current abundance of species with respect to current habitat distributions. DISTRIB then projects future importance values and suitable habitat for individual tree species using projections of future climate conditions on a 12-mile grid (U.S. Forest Service, n.d.). For this assessment, the DISTRIB model uses the GFDL A1FI and PCM B1 model-scenario combinations. The results provided here differ slightly from those of the online Climate Change Tree Atlas because they are specific to the



Mature trees in a municipal park in Glencoe, IL. Photo by T. McDonald, Glencoe Park District, used with permission.

assessment area and use a slightly different statistically downscaled climate dataset than shown in the online tool (see Chapter 2 for climate model descriptions). For lists of the common and scientific names of species mentioned in this report, see Appendix 1.

Of the 134 tree species modeled in DISTRIB, 70 were of interest to the Chicago Wilderness region because they are currently present or expected to gain suitable habitat in the area. Projected changes in potential suitable habitat for these 70 species are compared to present values for the years 2070 through 2099 in Table 3. Species were categorized based on whether the results from the two climate-emissions 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 under one or both scenarios. See Appendix 5 for projections of importance values under each model-scenario combination for three different time periods (2010 through 2039, 2040 through 2069, and 2070 through 2099). When examining these results, it is important to keep in mind that model reliability was generally higher for more-common species than for rare species. Appendix 5 shows the ranking of model reliability for each species.

Suitable habitat for 11 of the 70 species examined was projected to decline under both climate scenarios. One species projected to decline in habitat suitability, black cherry, is one of the most common species in the Chicago region, according to the Regional Tree Census (Nowak et al. 2013). Other common species projected to decline are quaking aspen, red pine, black ash, and northern pin oak.

Suitable habitat for only two species, American basswood (American linden) and black oak, was projected to remain relatively stable under projected climate change. The Chicago Wilderness region is near the center of the range for both species.

Climate scenarios disagreed on the direction of change for 17 of the species examined. For some of these species, such as eastern hophornbeam (ironwood), northern red oak, and sugar maple, differences between projections were small and indicated little change in either direction. Other species, such as American beech and jack pine, are not common in the region, so low model reliability for these species may explain the mixed results.

Twenty-five species were projected to have an increase in suitable habitat in the Chicago Wilderness region. Southern species, such as mockernut hickory, pignut hickory, and American sycamore, are projected to have large gains in suitable habitat. Many common bottomland species in the area, such as eastern cottonwood, silver maple, and hackberry are also projected to have increases in suitable habitat.

Habitat was projected to become newly suitable under one or both scenarios for 15 species. A few species

Table 3.—Projected changes in habitat suitability for trees native to the Chicago Wilderness region

Decrease under Both Scenarios

Common name	FIA IV[†]	PCM B1	GFDL A1FI
Bigtooth aspen	12	large decrease	large decrease
Black ash	69	large decrease	small decrease
Black cherry	752	small decrease	large decrease
Eastern white pine	18	large decrease	large decrease
Northern pin oak	66	large decrease	large decrease
Paper birch	25	large decrease	large decrease
Quaking aspen	80	large decrease	large decrease
Red pine	70	large decrease	small decrease
Scarlet oak	13	small decrease	large decrease
Shortleaf pine	4	large decrease	large decrease
White spruce	5	large decrease	large decrease

No Change under Both Scenarios

Common name	FIA IV	PCM B1	GFDL A1FI
American basswood	130	no change	no change
Black oak	206	no change	no change

Mixed Results Between Scenarios

Common name	FIA IV	PCM B1	GFDL A1FI
American beech	27	large increase	small decrease
American plum	18	small decrease	large increase
Boxelder	452	no change	small increase
Bur oak	403	small decrease	no change
Common chokecherry	9	no change	large decrease
Eastern hophornbeam	66	small increase	small decrease
Jack pine	5	large decrease	large increase
Northern red oak	274	small increase	small decrease
Red maple	148	no change	small increase
Rock elm	4	large decrease	no change
Shagbark hickory	214	small increase	no change
Shellbark hickory	1	no change	small increase
Sugar maple	213	small increase	small decrease
Sweetgum	1	small increase	no change
White ash	138	small increase	no change
White oak	431	no change	large decrease
Yellow-poplar (tuliptree)	18	large increase	no change

Increase under Both Scenarios

Common name	FIA IV	PCM B1	GFDL A1FI
American elm	372	small increase	small increase
American hornbeam (ironwood)	14	large increase	large increase
American sycamore	5	large increase	large increase
Bitternut hickory	68	large increase	large increase
Black locust	145	small increase	large increase
Black walnut	42	large increase	small increase
Black willow	90	small increase	small increase

Increase under Both Scenarios *(continued)*

Common name	FIA IV	PCM B1	GFDL A1FI
Blackgum	22	small increase	small increase
Common hackberry	57	large increase	small increase
Eastern cottonwood	101	small increase	large increase
Eastern redcedar	3	large increase	large increase
Flowering dogwood	15	large increase	large increase
Green ash	166	small increase	small increase
Honeylocust	107	large increase	large increase
Mockernut hickory	1	large increase	large increase
Osage-orange	67	large increase	small increase
Pignut hickory	42	large increase	large increase
Pin oak	63	large increase	large increase
Red mulberry	129	large increase	large increase
River birch	20	small increase	small increase
Sassafras	28	large increase	small increase
Shingle oak	1	small increase	small increase
Silver maple	70	small increase	large increase
Slippery elm	107	small increase	small increase
Swamp white oak	26	large increase	large increase

Species Gaining New Habitat

Common name	FIA IV	PCM B1	GFDL A1FI
Black hickory	0	new habitat	new habitat
Blackjack oak	0	new habitat	new habitat
Cedar elm	0	NA	new habitat
Chinkapin oak	0	new habitat	new habitat
Common persimmon	0	new habitat	new habitat
Eastern redbud	0	new habitat	new habitat
Kentucky coffeetree	0	new habitat	new habitat
Longleaf pine	0	new habitat	NA
Ohio buckeye	0	new habitat	new habitat
Pawpaw	0	new habitat	new habitat
Pecan	0	new habitat	new habitat
Post oak	0	new habitat	new habitat
Sugarberry	0	NA	new habitat
Turkey oak	0	new habitat	NA
Winged elm	0	NA	new habitat

[†]FIA IV is the importance value of each species based on Forest Inventory and Analysis data. See Appendix 5 for more information.

NA: no suitable habitat under current or projected climate conditions.

are already planted in the area, including Kentucky coffeetree, Ohio buckeye, eastern redbud, and chinkapin oak. However, none of the species is commonly found.

Note that these projections are available only for native species and are based on data collected in natural areas. Because they were developed for natural areas, projections are not directly applicable to native species planted in highly developed cultivated settings.

Modeling Species in Cultivated Settings

Additional efforts are underway to model future habitat suitability for trees in cultivated settings. Researchers at the Chicago Botanic Garden are using a species distribution model to examine future habitat suitability of cultivated trees in the Chicago region (A. Bell and S. Still, Chicago Botanic Garden, pers. comm., 2015). They are using the species distribution modeling approach Maxent (Phillips et al. 2006) to model changes in habitat suitability between now and three future time points (2020, 2050, and 2080) for 54 species and cultivars. Survey data about the relative success of trees growing in botanic gardens and arboretums across the eastern United States are entered into the model for habitat suitability. Only cultivated settings are used as inputs because (1) the growing conditions from cultivated trees will better predict success in cultivated settings, and (2) many of the trees are not present in natural settings. To examine future climate, a multi-model average is used with a high emissions scenario (A2).

Results of this study have not yet been published, but some preliminary results are available. These results suggest that habitat suitability may remain particularly favorable for pecan, American smoketree, 'Autumn Gold' ginkgo, 'Village Green' Japanese zelkova, sweetgum, yellow-poplar (tuliptree), American sycamore, sweetbay magnolia, and baldcypress. Some species and cultivars that may undergo a reduction in habitat suitability according to this model are American basswood; 'Legacy' sugar maple; Sargent cherry; eastern hophornbeam; shagbark hickory; Amur maackia; and Norway, Black Hills, and Serbian spruce.

Projected changes in habitat suitability for native species in this study do not always align with those published in the Tree Atlas (discussed earlier), which could be for a number of reasons. First, these modeling efforts rely on different downscaled climate datasets as inputs to the models. Second, they use different modeling approaches with different underlying model structure and climate parameters. Third, the tree data are from a different source for each model: Tree Atlas relies on FIA data from natural environments, whereas this study relied on survey data from cultivated settings. This discrepancy does not mean that either or both of these model projections are wrong, but rather that modeling habitat suitability in urban environments is complex and may depend on site-specific situations and the degree to which a site is developed.

Projected Changes from Hardiness and Heat Zone Shifts

Model information is not available for all species and cultivars that are found in the Chicago Wilderness region or many of the species being considered for future planting. These species are usually either too rare in the region to be modeled reliably, not native to North America, or cultivars. To understand how a changing climate may affect these species, one approach is to examine hardiness and heat zone ranges of the species to see how they compare to projected future zones in the region. Species that are currently present in the area or in consideration for city or regional planting lists were evaluated (Table 4). Species that are currently marginal for hardiness zone (lowest zone is 5 or higher) may benefit from milder winters. Species that are marginal for heat zone (highest zone is 7 or lower) may be negatively affected by hotter summers. See Chapter 2 for projections of hardiness and heat zones in the area. Note that using hardiness and heat zones to estimate which species will benefit or fare worse in a changing climate is not as informative as the species distribution modeling described previously, because the models take into account changes in precipitation, seasonal climate changes, and other habitat requirements such as soil texture. This analysis is meant to provide only a coarse estimate of potential changes in habitat suitability.

Based on this method, 28 species (23 percent of the 121 species evaluated) may show a positive effect from an increase in hardiness zone over the next century (Table 4). Twelve of these species are currently found in the region according to the Regional Tree Census (Nowak et al. 2013), although some are invasive species such as tree of heaven and privet.

Twenty-three species (19 percent) may show a negative effect from an increase in heat zone. Four of these species are relatively common in the Chicago Wilderness region: Norway maple, Amur maple, European alder, and cockspur hawthorn.

Table 4.—Potential effects of shifts in hardiness and heat zones for tree species currently found in the Chicago Wilderness region or being considered for planting lists in the area that do not have any species distribution model information

Common name	Estimated number of trees	Species hardiness zone range[1]	Species heat zone range[1]	Potential effect of zone change on habitat suitability[2]
'Accolade' elm	0	5 to 8	8 to 1	positive
'Accolade' flowering cherry	0	5 to 8	8 to 1	positive
Allegheny serviceberry	0	3 to 9	9 to 3	no effect
American smoketree	13,070	5 to 9	9 to 3	positive
American witchhazel	206,360	4 to 8	8 to 1	no effect
Amur cherry	0	2 to 6	n/a	insufficient information
Amur corktree[3]	66,490	3 to 7	8 to 1	no effect
Amur honeysuckle[3]	3,370,400	3 to 8	9 to 1	no effect
Amur maackia	0	3 to 7	7 to 4	negative
Amur maple[3]	744,480	3 to 8	7 to 1	negative
Apple/crabapple species	1,724,980	4 to 8 (varies)	9 to 1 (varies)	no effect
Apple serviceberry	0	3 to 7	7 to 1	negative
Austrian pine	983,160	5 to 8a	8 to 1	positive
Autumn-olive[3]	228,040	3 to 8	8 to 1	no effect
Baldcypress	26,030	5 to 11	12 to 5	positive
Balsam fir	205,390	3 to 6	6 to 1	negative
Blackhaw	68,650	3 to 9	9 to 1	no effect
Black Hills spruce	0	2 to 8	7 to 1	negative
Black maple	69,910	4 to 8	8 to 3	no effect
Blue spruce	1,107,240	4 to 7	8 to 1	no effect
Callery pear[3]	257,690	5 to 9a	8 to 3	positive
Cherry plum	157,440	4b/5a to 8a	9 to 1	positive
Chestnut oak	0	4 to 8	8 to 1	no effect
Chinese catalpa	0	n/a	n/a	insufficient information
Chinese chestnut	11,090	4 to 8	8 to 1	no effect
Chinese fringetree	0	5 to 9	9 to 3	positive
Chinese juniper	0	3 to 9	9 to 1	no effect
Cockspur hawthorn	320,200	3 to 7	7 to 1	negative
Common elderberry	197,340	4 to 10	9 to 1	no effect
Common lilac	109,050	4 to 8	8 to 1	no effect
Common pear	266,140	4 to 8	9 to 5	no effect
Common persimmon	0	4 to 9	9 to 1	no effect
Cornelian cherry dogwood	11,090	4 to 8	8 to 5	no effect
Crimean linden	0	3 to 7	7 to 1	negative
Cucumbertree	0	4 to 8	8 to 2	no effect
Dawn redwood	0	5 to 9	10 to 5	positive
'Discovery' elm	0	n/a	n/a	insufficient information
Douglas-fir	108,410	4 to 7	7 to 1	negative
Downy serviceberry	57,460	4 to 9	9 to 1	no effect
Eastern hemlock	268,660	4 to 8	8 to 1	no effect
Eastern wahoo	46,320	n/a	n/a	insufficient information
European alder[3]	382,610	3 to 7	7 to 1	negative
European beech	20,240	5 to 8	8 to 1	positive
European buckthorn[3]	44,281,470	3 to 8	n/a	no effect

(Continued)

Table 4.—*(Continued)* Potential effects of shifts in hardiness and heat zones for tree species currently found in the Chicago Wilderness region or being considered for planting lists in the area that do not have any species distribution model information

Common name	Estimated number of trees	Species hardiness zone range[1]	Species heat zone range[1]	Potential effect of zone change on habitat suitability[2]
European filbert	17,440	4 to 8	8 to 1	no effect
European hornbeam	99,760	4 to 7	8 to 1	no effect
European larch	0	2 to 6	6 to 1	negative
European mountain-ash	0	3 to 7	7 to 1	negative
Freeman maple	280,470	4 to 7	8 to 1	no effect
‘Frontier’ elm	0	n/a	n/a	insufficient information
Glossy buckthorn[3]	500,900	4 to 6	n/a	no effect
Gray alder	0	2 to 6	6 to 1	negative
Gray birch	145,590	3 to 6	6 to 1	negative
Gray dogwood	68,010	4 to 8	8 to 3	no effect
‘Harvest Gold’ linden	0	3 to 7	7 to 1	negative
Hedge maple	0	5 to 8	8 to 4	positive
Heritage® oak	0	n/a	n/a	insufficient information
Higan cherry	0	5 to 8	8 to 6	positive
Horse chestnut	40,250	3 to 8	8 to 1	no effect
Japanese maple	36,060	6 to 8	8 to 2	positive
Japanese red pine	11,090	4 to 7	7 to 1	negative
Japanese tree lilac	19,020	4 to 7a	7 to 1	negative
Japanese zelkova	11,090	5 to 8	9 to 5	positive
Katsura tree	11,090	4 to 8	8 to 1	no effect
Korean mountain-ash	0	5 to 8	10 to 1	positive
Korean Sun™ pear	0	n/a	n/a	insufficient information
Kousa dogwood	0	5 to 8	8 to 5	positive
Leatherleaf viburnum	17,440	5 to 8	8 to 6	positive
Littleleaf linden	243,320	3 to 7	8 to 1	no effect
London planetree	0	4 to 8	n/a	insufficient information
Maidenhair tree	199,650	4 to 9	9 to 3	no effect
Miyabe maple	0	4 to 8	8 to 1	no effect
Morden hawthorn	0	4 to 7	n/a	no effect
Nannyberry	69,310	2 to 8	8 to 1	no effect
Northern catalpa	59,440	4 to 8	8 to 1	no effect
Northern white-cedar	2,457,220	3 to 7	7 to 1	negative
Norway maple[3]	1,858,800	4 to 7a	7 to 1	negative
Norway spruce	377,510	3 to 8	8 to 1	no effect
Oriental spruce	0	4 to 9	9 to 1	no effect
Pacific Sunset® maple	0	4 to 8	8 to 1	no effect
Pagoda dogwood	34,590	4 to 8	8 to 1	no effect
Peach	107,320	5 to 9	9 to 1	positive
Peachleaf willow	77,720	1 to 10	11 to 1	no effect
Peking lilac	0	3 to 7	6 to 1	negative
Pin cherry	40,550	2 to 8	n/a	insufficient information
‘Prairie Gem’ Ussurian pear	0	n/a	n/a	insufficient information
Prickly ash	207,940	3 to 9	8 to 1	no effect
Privet[3]	28,830	7 to 10	10 to 7	positive

(Continued)

Table 4.—*(Continued)* Potential effects of shifts in hardiness and heat zones for tree species currently found in the Chicago Wilderness region or being considered for planting lists in the area that do not have any species distribution model information

Common name	Estimated number of trees	Species hardiness zone range[1]	Species heat zone range[1]	Potential effect of zone change on habitat suitability[2]
'Prospector' Wilson Elm	0	n/a	n/a	insufficient information
Pussy willow	55,420	4 to 8	8 to 2	no effect
Robusta poplar	0	n/a	n/a	insufficient information
Rose-of-Sharon	77,240	5 to 9	9 to 1	positive
Russian-olive[3]	54,970	2 to 8	8 to 1	no effect
Sargent cherry	80,070	5 to 8a	9 to 4	no effect
Saucer magnolia	26,030	5 to 9	9 to 5	positive
Scholar tree	0	5 to 8a	9 to 5	positive
Scotch pine	23,500	3 to 7	7 to 1	negative
Serbian spruce	78,160	4 to 7	8 to 1	no effect
Shantung maple	0	4 to 8	8 to 1	no effect
Shumard oak	0	5 to 10	9 to 1	positive
Siberian elm[3]	2,240,590	2 to 9	9 to 1	no effect
Silver linden	0	6 to 9	n/a	insufficient information
Smoothleaf elm	0	5 to 8	n/a	positive
'Snow Goose' cherry	0	5 to 8	8 to 5	positive
Staghorn sumac	0	3 to 8	8 to 1	no effect
Star magnolia	4	4 to 9	9 to 5	no effect
Sycamore maple	0	5 to 8	8 to 1	positive
Tree of heaven	1,830,940	5 to 8a	n/a	positive
Triumph™ elm	0	4 to 9	9 to 1	no effect
Turkish hazelnut	0	5 to 7	7 to 4	negative
Washington hawthorn	23,100	4 to 8a	8 to 1	no effect
Weeping willow	11,090	4 to 9	9 to 1	no effect
White fir	0	3 to 7	7 to 1	negative
White fringetree	0	4 to 9	9 to 1	no effect
White mulberry[3]	1,584,250	3b to 9	8 to 1	no effect
White poplar	95,600	4 to 9	9 to 1	no effect
Willow oak	0	6 to 9	9 to 3	positive
Winged burningbush[3]	148,650	4 to 9	9 to 1	no effect
'Winter King' green hawthorn	0	4 to 7	7 to 5	negative
Yellow buckeye	0	3 to 8	8 to 1	no effect
Yellowwood	0	4 to 8	9 to 1	no effect

[1] Species hardiness/heat zone range is the range of zones for which the species is considered suitable for planting. See Chapter 2 for projected shifts in hardiness and heat zones.

[2] Climate change was considered to have a positive effect on habitat suitability if the lowest zone for which the species was hardy was 5 or higher. Climate change was considered to have a negative effect on habitat suitability if the highest heat zone that the species can tolerate was 7 or lower.

[3] Invasive species.

The abbreviation "n/a" indicates information not available.

A value of "0" means no individuals were detected in the most recent tree census (Nowak et al. 2013). These species are either currently rarely planted, have been planted since the last census, or are being considered for planting in the area.

For about half of the species evaluated (57 species), shifts in hardiness or heat zone may not have an effect on habitat suitability. However, these species could be affected by other climate-related changes, such as shifts in precipitation or insect or disease outbreaks. These include many of the most common species in the area, but several of them, such as European buckthorn, Siberian elm, and white mulberry, are invasive species.

There was insufficient information on current hardiness and heat zones for 13 species, so a determination could not be made.

Adaptive Capacity of Urban Trees

The results just presented provide information on potential changes in tree species habitat suitability across a range of projected future temperature and precipitation regimes, but do not account for all factors that may influence tree species under a changing climate. For the most part, models such as the ones described earlier consider only the direct effects of temperature and precipitation, and do not account for other changes, such as changes in flood regime, extreme weather events, insects and disease, and invasive species.

To understand the capacity of tree species and cultivars in the area to adapt to these other effects of climate change, we relied on a scoring system developed by Matthews et al. (2011) called modifying factors. Other scoring systems have been developed (e.g., Roloff et al. 2009), but we found the system developed by Matthews and colleagues to be the most comprehensive for all potential climate change-related stressors. Modifying factors can include life history traits or environmental factors that make a species more or less likely to persist on the landscape (Matthews et al. 2011). Examples of modifying factors are fire or drought tolerance, dispersal ability, shade tolerance, site specificity, and susceptibility to insect pests and diseases. These factors can then be weighted by their intensity, level of uncertainty about their impacts, and relative importance to future changes to arrive at a numerical score (Matthews et al. 2011) (see Appendix 6). Modifying factors are highly related to the adaptive capacity of a species: the ability to adjust to a changing climate (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Intergovernmental Panel on Climate Change [IPCC] 2014). A species with a large number of positive modifying factors would have a high adaptive capacity, and a species with a large number of negative modifying factors would have a low adaptive capacity.

We revised the modifying factors developed previously to better capture the unique environment of urban areas. Planted trees on developed sites (such as street trees, residences, city parks, and campuses) and naturally occurring trees (native or naturalized species that regenerate on their own) have very different growing environments. Thus, we developed two separate adaptive capacity scores. For naturally occurring trees, we kept factors developed by Matthews and colleagues, but added a few factors (salt tolerance, soil and water pollution) that we thought were particularly important in urban environments (Table 5). The weighting of some scores was also adjusted to account for regional climate changes and the additional stresses of urban areas. For planted trees, we eliminated factors related to seed dispersal, establishment, and reproduction because they would not apply. We also eliminated fire-related factors because we assume wildfire and prescribed fire will not be a common occurrence for planted trees on developed sites. We added factors that were important to nursery cultivation and maintenance of cultivated trees. We also added an "invasive potential" factor to take into account the expectation that species which are likely to be invasive will probably not be selected for future planting.

We developed modifying factor scores for all 120 species listed as occurring in the Chicago area according to the recent Regional Tree Census (Nowak et al. 2013). In addition, we included other species that are being considered on planting lists for the City of Chicago and the Chicago Region Trees Initiative, bringing the total number of species evaluated to 179. For species present only in a cultivated setting, we generated only one score. Native species, even if not currently used in cultivated settings, were given scores for both planted and naturally occurring settings. Scores were then converted to categories of high, medium, and low adaptive capacity (Tables 6–11). See Appendix 6 for specific modifying factor scores and subscores for each species and a description of the two numerical scoring systems.

For planted conditions, 66 species received a high adaptability score, 24 received a low adaptability score, and the remaining 89 received a medium adaptability score. Common native species with high adaptability scores in planted environments include northern red oak, eastern hophornbeam, and hackberry. Many invasive species such as European buckthorn,

Table 5.—Codes and descriptions for modifying factors[1]

Factor	Code	Type	Description (if positive)	Description (if negative)
Air pollution	AIP	N, P	Tolerant of air pollution	Intolerant of air pollution
Browse	BRO	N,P	N/A	Susceptible to browsing
Competition-light	COL	N, P	Tolerant of shade or limited light conditions	Intolerant of shade or limited light conditions
Disease	DISE	N, P	N/A	Has a high number and/or severity of known pathogens that attack the species
Dispersal	DISP	N	High ability to effectively produce and distribute seeds	N/A
Drought	DRO	N,P	Drought-tolerant	Susceptible to drought
Edaphic specificity	ESP	N, P	Wide range of soil tolerance	Narrow range of soil requirements
Environmental habitat specificity	EHS	N	Wide range of slopes/aspects/topographic positions	Small range of slopes/aspects/topographic positions
Fire regeneration	FRG	N	Regenerates well after fire	N/A
Fire topkill	FTK	N	Resistant to fire topkill	Susceptible to fire topkill
Flood	FLO	N, P	Flood-tolerant	Flood-intolerant
Ice	ICE	N,P	N/A	Susceptible to breakage from ice storms
Insect pests	INS	N, P	N/A	Has a high number and/or severity of insects that may attack the species
Invasive plants	INPL	N,P	N/A	Strong negative effects of invasive plants on the species, either through competition for nutrients or as a pathogen
Invasive potential	INPO	P	N/A	Has the potential to become invasive
Land-use/Planting site specificity	LPS	P	Can be planted on a wide variety of sites	Can be planted only in a narrow range of sites or as a specimen
Maintenance required	MAR	P	Requires little pruning, watering, or cleanup	Requires considerable pruning, watering, or cleanup of debris
Nursery propagation	NUP	P	Easily propagated in nursery and widely available	Not easily propagated or not usually available
Planting establishment	PLE	P	Easily transplanted and requires little care to establish	Difficult to transplant or requires considerable care to establish
Restricted rooting conditions	RRC	P	Can tolerate restricted rooting conditions	Intolerant of restricted rooting conditions
Salt tolerance	SAL	N,P	Tolerant of road salt/salt spray	Intolerant of road salt/salt spray
Seedling establishment	SES	N	High ability to regenerate with seeds to maintain future populations	Low ability to regenerate with seeds to maintain future populations
Soil and water pollution	SWP	N,P	Tolerant of soil or water pollution	Intolerant of soil or water pollution
Temperature gradients	TEM	N,P	Tolerant of a wide range of temperatures	Narrow range of temperature requirements
Vegetative reproduction	VRE	N	Capable of vegetative reproduction through stump sprouts or cloning	N/A
Wind	WIN	N,P	N/A	Susceptible to breakage from wind storms

[1] Traits are listed if they were among the main contributors to the overall adaptability score. See Appendix 6 for more information.

N: Applies to naturally occurring trees

P: Applies to planted trees.

N/A: not applicable.

Table 6.—Tree species with high adaptability in planted environments, based on modifying factor scores

Common name	Positive traits[1]	Negative traits[1]
Accolade® elm	TEM LPS NUP	--
Allegheny serviceberry	LPS	DRO AIP
American hornbeam	FLO TEM NUP	DRO AIP
Amur cherry	LPS RRC	TEM AIP
Amur honeysuckle[2]	TEM AIP ESP LPS PLE MAR	INPO
Amur maackia	DRO TEM LPS RRC NUP	FLO
Apple serviceberry	LPS RRC NUP	DRO FLO AIP
Baldcypress	FLO RRC NUP	AIP
Blackgum	RRC	AIP
Blackhaw	NUP TEM	INS
Bur oak	DRO TEM AIP LPS NUP	DISE INSE FLO
Chestnut oak	LPS	INS AIP
Chinese fringetree	LPS RRC	--
Chinese juniper	DRO LPS NUP	FLO
Common hackberry	DRO TEM LPS NUP	--
Cockspur hawthorn	DRO TEM LPS RRC NUP	INS AIP
Common persimmon	DRO FLO TEM ESP RRC NUP	--
Crimean linden	DRO TEM LPS RRC NUP	--
'Discovery' elm	TEM LPS NUP	INS
Downy serviceberry	TEM NUP	AIP
Eastern hophornbeam (ironwood)	DRO TEM LPS RRC NUP	FLO AIP
Eastern redcedar	DRO TEM LPS RRC	AIP
European buckthorn[2]	DRO TEM ESP NUP	INPO
European hornbeam	TEM	--
European mountain-ash	LPS RRC NUP	--
European smoketree	DRO LPS RRC NUP	FLO
Freeman maple	TEM ESP LPS NUP	--
'Frontier' elm	DRO TEM LPS RRC	--
Glossy buckthorn[2]	FLO TEM ESP NUP	INPO
Hedge maple	TEM LPS NUP	INS
Heritage® oak	DRO TEM LPS NUP	DISE INS
Japanese tree lilac	RRC LPS NUP	AIP
Japanese zelkova	TEM LPS RRC NUP	--
Kentucky coffeetree	DRO LPS NUP	AIP
Korean Sun™ pear	TEM LPS RRC NUP	--
Kousa dogwood	NUP	DRO AIP
Leatherleaf viburnum	NUP	AIP
Littleleaf linden	LPS NUP	INS SAL
Maidenhair tree	DRO TEM LPS RRC NUP	FLO
Miyabe maple		AIP
Mockernut hickory	TEM	AIP
Nannyberry	TEM RRC NUP	--
Northern red oak	TEM LPS NUP	DISE INS INPL
Norway maple[2]	DRO FLO ESP RRC NUP	INS INPO
Osage-orange	DRO TEM ESP RRC NUP	AIP
Pacific Sunset® maple	DRO TEM LPS RRC	INS
Peking lilac	LPS NUP	FLO TEM
'Prairie Gem' Ussurian pear	TEM LPS NUP	AIP
Rose-of-Sharon	NUP	AIP
Russian-olive[2]	DRO TEM NUP	INPO
Saucer magnolia	TEM NUP	DRO FLO
Scarlet oak	ESP LPS	AIP
Scholar tree	DRO TEM LPS RRC NUP	FLO
Shantung maple	DRO TEM LPS RRC NUP	INS
Shingle oak	DRO NUP	DISE INS AIP
Shumard oak	DRO FLO TEM LPS RRC NUP	--
'Snow Goose' cherry	NUP	--
Swamp white oak	TEM RRC NUP	AIP
Tree of heaven[2]	DRO TEM AIP ESP	LPS NUP INPO
'Triumph' elm	DRO TEM LPS RRC NUP	--
Turkish hazelnut	DRO TEM LPS RRC	--
White fringetree	LPS RRC	--
Willow oak	FLO LPS RRC NUP	--
Winged burningbush[2]	TEM NUP	INPO
'Winter King' green hawthorn	LPS RRC NUP	--
Yellowwood	TEM RRC	AIP

[1] See Table 5 for trait codes.
[2] Invasive species.

Table 7.—Tree species with moderate adaptability in planted environments, based on modifying factor scores

Common name	Positive traits[1]	Negative traits[1]
'Accolade' flowering cherry	TEM NUP	FLO
American basswood (American linden)	FLO TEM NUP	AIR RRC
American beech	--	FLO AIP LPS RRC
American elm	NUP	DISE DRO
American plum	NUP	AIP
American sycamore	TEM NUP	--
American witchhazel	TEM	INS AIP
Amur corktree[2]	TEM NUP	RRC INPO
Amur maple[2]	TEM LPS	INPO
Austrian pine	TEM RRC	DISE INS
Autumn-olive[2]	LPS	AIP NUP INPO
Balsam fir	NUP	DRO TEM AIP
Bitternut hickory	DRO	AIP
Black Hills spruce	--	TEM AIP
Black locust	DRO TEM	FLO AIP LPS RRC INPO
Black maple	TEM	AIP
Black oak	DRO TEM	DISE INS
Black walnut	--	DRO AIP LPS RRC
Blue spruce	NUP	INS FLO AIP
Boxelder	DRO FLO TEM	AIP INPO
Callery pear[2]	DRO TEM RRC NUP	INS INPO
Cherry plum	NUP	INS AIP
Chinese catalpa	FLO TEM	AIP
Chinese chestnut	TEM	--
Chinkapin oak	DRO TEM LPS	DISE INS AIP
Common chokecherry	NUP	DISE FLO AIP
Common elderberry	FLO TEM	AIP INPO
Common lilac	RRC NUP	FLO AIP
Cornelian cherry dogwood	TEM	AIP
Crabapple species	TEM LPS RRC NUP	DISE INS AIP
Cucumbertree	NUP	DRO AIP
Dawn redwood	TEM	AIP
Eastern redbud	FLO TEM NUP	AIP
Eastern wahoo	--	AIP
European alder[2]	FLO	DISE AIP INPO
European beech	NUP	DRO LPS RRC
European filbert	NUP	AIP RRC
European larch	--	DRO TEM AIP
Flowering dogwood	TEM LPS	DRO FLO AIP RRC
Gray alder	FLO	DRO AIP
Gray dogwood	TEM	--
Green ash	FLO NUP	INS MAR
'Harvest Gold' linden	RRC	AIP
Higan cherry	--	FLO AIP RRC
Honeylocust	DRO TEM RRC NUP	--
Horse chestnut	TEM	AIP
Japanese maple	NUP	DRO AIP
Korean mountain-ash	NUP	AIP
London planetree	DRO FLO TEM NUP	DISE AIP
Morden hawthorn	NUP	AIP
Northern pin oak (Hill's oak)	DRO LPS	TEM AIP
Northern white-cedar (arborvitae)	NUP	DRO AIP
Norway spruce	NUP	INS FLO AIP
Ohio buckeye	--	AIP
Oriental spruce	--	AIP
Pagoda dogwood	NUP	AIP
Paper birch	NUP	DRO TEM AIP
Peach	NUP	DRO FLO
Pignut hickory	TEM	--
Pin oak	FLO TEM RRC NUP	DISE INS AIP
Privet[2]	TEM NUP	AIP INPO
'Prospector' Wilson elm	DRO LPS	--
Red maple	FLO TEM ESP LPS NUP	INS DRO AIP
Red mulberry	TEM NUP	AIP
River birch	TEM LPS NUP	DISE INS DRO
Robusta poplar	DRO NUP	--
Sargent cherry	TEM LPS RRC	WIN AIP
Sassafras	DRO NUP	--
Scots pine	NUP	INS
Serbian spruce	NUP	INS
Shagbark hickory	TEM	AIP
Siberian elm	DRO	WIN INPO
Silver linden	TEM NUP	INS AIP
Silver maple	FLO TEM NUP	RRC
Slippery elm	TEM LPS	DISE
Staghorn sumac	DRO TEM	AIP RRC
Star magnolia	NUP	DRO AIP
Sugar maple	NUP	INS FLO AIP
Sugarberry	DRO FLO TEM	WIN AIP NUP
Sweetgum	--	INS DRO RRC
Sycamore maple	NUP	INS AIP
Washington hawthorn	DRO TEM RRC NUP	DISE INS
Weeping willow	FLO TEM NUP	INS AIP LPS RRC
White fir	--	DLO AIP
White mulberry[2]	NUP	LPS INPO
White oak	TEM ESP LPS	FLO AIP
White poplar	DRO TEM ESP NUP	INS WIN LPS RRC
White spruce	INS	--
Yellow buckeye	DRO AIP	--

[1] See Table 5 for trait codes.
[2] Invasive species.

Table 8.—Tree species with low adaptability in planted environments, based on modifying factor scores

Common name	Positive traits[1]	Negative traits[1]
Bigtooth aspen	--	--
Black cherry	DRO TEM	AIP LPS RRC
Black willow	FLO	INS DRO AIP RRC
Common pear	TEM NUP	DRO AIP
Douglas-fir	NUP	DRO FLO TEM LPS
Eastern cottonwood	TEM NUP	DISE INS AIP LPS RRC
Eastern hemlock	NUP	DRO AIP LPS
Eastern white pine	NUP	DISE INS DRO TEM AIP LPS RRC
Gray birch	--	DISE INS AIP LPS
Jack pine	DRO	AIP LPS RRC
Japanese red pine	--	AIP
Katsura tree	DISE INS NUP	DRO WIN AIP RRC
Northern catalpa	--	AIP
Peachleaf willow	FLO	AIP
Pecan	NUP	AIP LPS RRC
Pin cherry	--	DRO AIP LPS
Prickly ash	--	AIP LPS INPO
Pussy willow	FLO TEM NUP	DRO AIP LPS RRC
Quaking aspen	TEM NUP	INS DRO AIP RRC INPO
Red pine	--	INS DRO AIP RRC
Shellbark hickory	--	DRO AIP
Smoothleaf elm	--	DISE AIP
White ash	TEM NUP	INS AIP RRC
Yellow-poplar (tuliptree)	NUP	DRO AIP RRC

[1] See Table 5 for trait codes.

Table 9.—Tree species with high adaptability in natural areas and other locations where they are allowed to regenerate on their own, based on modifying factor scores

Common name	Positive traits[1]	Negative traits[1]
Allegheny serviceberry	COL	INPL DRO AIP
American elm	EHS	DISE DRO AIP
American hornbeam	FLO COL SES	INPL DRO FTK
American witchhazel	COL EHS	INS INPL AIP
Amur corktree[2]	SES	COL
Amur honeysuckle[2]	TEM AIP COL ESP EHS DISP SES VRE	--
Autumn-olive[2]	EHS DISP	AIP
Bigtooth aspen	VRE FRG	INPL DRO FTK AIP COL
Blackgum	COL	INPL
Blackhaw	EHS	INS INPL
Black locust	DRO	INPL DRO AIP
Black maple	COL EHS	INPL AIP INS
Black oak	DRO	DISE INS INPL
Boxelder	DRO FLO TEM COL DISP SES	AIP
Bur oak	DRO TEM AIP	DISE INS FLO
Chestnut oak	EHS SES VRE	INS INPL
Common elderberry	FLO EHS DISP SES VRE	AIP COL
Common hackberry	DRO	INPL FTK
Downy serviceberry	COL EHS SES FRG	INPL FTK
Eastern hophornbeam (ironwood)	DRO TEM COL EHS	INPL FLO AIP
Eastern redbud	FLO	INPL AIP
European buckthorn[2]	DRO TEM AIP COL ESP DISP SES VRE	--
Flowering dogwood	COL	INPL DRO FLO AIP
Glossy buckthorn[2]	FLO TEM AIP COL DIP SES	--
Gray dogwood	SES	INPL FTK
Honeylocust	DRO	INPL
Nannyberry	COL	INPL
Northern red oak	--	DISE INS INPL
Norway maple[2]	DRO FLO COL ESP EHS SES	INS
Osage-orange	DRO ESP EHS	INPL
Pignut hickory	EHS	--
Prickly ash	EHS VRE	INPL AIP
Privet[2]	COL EHS DISP SES VRE	AIP
Red maple	FLO COL ESP EHS SES VRE	INS INPL DRO
Russian-olive[2]	DRO TEM DISP EHS SES	COL
Scarlet oak	ESP EHS VRE	INPL AIP
Shagbark hickory	INPL AIP	--
Siberian elm	DRO EHS SES	WIN COL
Silver maple	FLO COL DISP SES	INS INPL
Staghorn sumac	DRO TEM SES VRE FRG	INPL FLO FTK COL
Sugar maple	COL	INS INPL FLO AIP
Tree of heaven[2]	DRO AIP ESP EHS DISP SES VRE FRG	--
White mulberry[2]	EHS SES	--
White oak	TEM ESP EHS	INPL AIP
Winged burningbush[2]	COL EHS	FTK
Yellow-poplar (tuliptree)	EHS SES FRG	INPL DRO AIP

[1] See Table 5 for trait codes.

[2] Invasive species.

Table 10.—Tree species with moderate adaptability in natural areas and other locations where they are allowed to regenerate on their own, based on modifying factor scores

Common name	Positive traits[1]	Negative traits[1]
American basswood (American linden)	FLO COL	INPL AIP SES
American beech	TEM	FLO FTK AIP COL
American plum	--	INPL AIP
American sycamore	--	INPL
Bitternut hickory	DRO	INPL COL
Black cherry	DRO EHS SES	INPL FLO FTK AIP COL
Black walnut	SES	INPL DRO COL
Chinkapin oak	DRO TEM	DISE INS INPL
Common chokecherry	--	DISE INPL FLO AIP COL
Eastern cottonwood	TEM	DIS INS INPL AIP COL
Eastern redcedar	DRO	INPL FTK COL
Eastern wahoo	COL	INPL AIP
Eastern white pine	--	DISE INS INPL DRO FTK AIP
Gray alder	FLO	INPL DRO FTK AIP
Gray birch	--	DISE INS AIP LPS
Green ash	FLO	INS INPL COL
Kentucky coffeetree	DRO LPS NUP	AIP
Mockernut hickory	--	INPL FTK COL
Northern pin oak (Hill's oak)	DRO	INPL
Northern white-cedar	COL	INPL DRO SIP
Pagoda dogwood	COL	INPL FTK
Paper birch	NUP	DRO TEM AIP
Pin cherry	SES FRG	INLP DRO AIP COL
Pin oak	FLO	DISE INS INPL FTK COL
Pussy willow	FLO DISP SES FRG	INPL DRO AIP COL EHS
Quaking aspen	TEM EHS VRE	INS INPL DRO FTK AIP COL
Red mulberry	COL	INPL AIP FTK
River birch	--	DISE INS INPL DRO FTK COL
Shellbark hickory	COL	INPL DRO AIP EHS
Shingle oak	DRO NUP	DISE INS AIP
Shumard oak	DRO FLO TEM LPS RRC NUP	--
Slippery elm	--	DISE INPL FTK AIP COL
Swamp white oak	--	INPL AIP
White ash	--	INS INPL AIP COL

[1] See Table 5 for trait codes.

Table 11.—Tree species with low adaptability in natural areas and other locations where they are allowed to regenerate on their own, based on modifying factor scores

Common name	Positive traits[1]	Negative traits[1]
Black willow	FLO	INS INPL DRO COL FTK AIP
Northern catalpa	--	INPL AIP COL EHS
Ohio buckeye	COL	NPL SES
Peachleaf willow	FLO	INPL AIP COL SES

[1] See Table 5 for trait codes.

Amur honeysuckle, and tree of heaven also had high adaptability scores. Some very common native species had low adaptability scores for planted environments, including black cherry, eastern cottonwood, and white ash. Common pear was the most common nonnative species to receive a low adaptability score.

For naturally occurring species (both native and naturalized), 46 received a high adaptability score, 4 received a low adaptability score, and 34 received a medium adaptability score. Native species that received a high adaptability score for natural areas but not in planted environments include boxelder, American elm, sugar maple, silver maple, and white oak. All invasive species received a high adaptability score.

Overall Vulnerability of the Chicago Region's Trees

Vulnerability is the susceptibility of a system to the adverse effects of climate change (IPCC 2007). It is a function of potential climate change impacts and the adaptive capacity of the system. Overall vulnerability of trees in the Chicago region can be estimated by considering the impacts on individual trees using model projections or changes in hardiness or heat zone, together with the adaptive capacity of trees as described in the previous section. This approach is meant to give a coarse picture of vulnerability, and readers should weigh the relative confidence in vulnerability estimates based on the level of information available (see Appendix 7).

Of the 179 species and cultivars evaluated, 15 (8 percent) are considered to have high vulnerability (Table 12). These species account for 9 percent of the individual trees in the Chicago region counted in the Regional Tree Census. Thirteen of these species are native to North America, and two are nonnative (Japanese red pine and katsura tree). The highly vulnerable species tended to be native to mountainous or northern areas. Examples are black cherry, red and white pine, white spruce, gray and paper birch, quaking and bigtooth aspen, balsam fir, and Douglas-fir.

Sixteen species of those evaluated (9 percent) are considered to have moderate-high vulnerability. These account for 6 percent of trees in the Chicago region. Two of these species are considered to be invasive: Amur maple and European alder. Common native species considered to have moderate-high vulnerability are white ash and northern white-cedar (arborvitae).

Fifty-four species of those evaluated (30 percent) are considered to have moderate vulnerability, and account for 17 percent of the trees in the region. These include many native species such as green ash (which is vulnerable for other reasons besides climate change), sugar maple, black walnut, eastern cottonwood, and white oak. Commonly planted species in this category include Norway maple, apple/crabapple species, blue spruce, and Morden and cockspur hawthorn.

Forty-two of the species evaluated (23 percent) are considered to have low-moderate vulnerability. They make up 18 percent of the total trees in the region. They include many common native species such as American elm, silver maple, shagbark and bitternut hickory, honeylocust, American basswood, eastern hophornbeam, and river birch. The invasive species Siberian elm, white mulberry, and Callery pear fall into this category.

Fifty-two species (29 percent) of those evaluated are considered to have low vulnerability. Of these, 19 are native and 6 are invasive, with the remainder being nonnative planted species or cultivars. Based on the total number of trees surveyed in the Regional Tree Census, half would be considered to have low vulnerability. However, European buckthorn accounts for 70 percent of those individual trees, and collectively 77 percent of individuals with low vulnerability ratings are invasive. Other common invasive species considered to have low vulnerability are Amur honeysuckle, tree of heaven, and glossy buckthorn. However, several common native trees, such as boxelder, black locust, bur oak, and hackberry, are also considered to have low vulnerability. Species that are often used in cultivated settings which had low vulnerability were littleleaf linden, Freeman maple, maidenhair tree, and European hornbeam.

Vulnerability of species and cultivars recommended for planting in The Morton Arboretum's Northern Illinois Tree Species List (The Morton Arboretum 2015) was also evaluated. This list includes many species and cultivars that are not widely planted and were not included in our assessment. Thus, many species and cultivars on the list have no vulnerability rating.

Of the species recommended for planting in parks and residential areas, 10 percent were considered to have moderate-high or high vulnerability. These include many northern species such as black cherry, white and jack pine, paper birch, eastern hemlock, and aspen species. Sixteen percent were considered to have low vulnerability. These included native and nonnative species along with some cultivars. Thirty-seven percent had either low-moderate or moderate vulnerability. Thirty-six percent had no rating as this list included many uncommon species and cultivars.

Table 12.—Tree species in each vulnerability class

High	Moderate-High	Moderate	Low-Moderate	Low
Balsam fir	Amur maple[1]	American beech	'Accolade' flowering cherry	Accolade® elm
Bigtooth aspen	Black Hills spruce	American plum	American basswood	Allegheny serviceberry
Black cherry	Common chokecherry	Amur maackia	American elm	American hornbeam
Douglas-fir	Common pear	Apple serviceberry	American sycamore	Amur cherry
Eastern hemlock	European alder[1]	Apple/crabapple species	American witchhazel	Amur honeysuckle[1]
Eastern white pine	European larch	Black maple	Amur corktree	Baldcypress
Gray birch	Gray alder	Black walnut	Austrian pine	Black gum
Jack pine	'Harvest Gold' linden	Black willow	Autumn-olive[1]	Blackhaw
Japanese red pine	Northern catalpa	Blue spruce	bitternut hickory	Black locust
Katsura tree	Northern white-cedar	Chinese catalpa	Callery pear[1]	Black oak
Northern pin oak (Hill's oak)	Peachleaf willow	Chinese chestnut	Cherry plum	Boxelder
Paper birch	Pin cherry	Chinkapin oak	Common elderberry	Bur oak
Quaking aspen	Scotch pine	Cockspur hawthorn	Eastern hophornbeam (ironwood)	Chestnut oak
Red pine	White ash	Common lilac	Eastern redbud	Chinese fringetree
White spruce	White fir	Cornelian cherry dogwood	Eastern redcedar	Chinese juniper
	White oak	Crimean linden	European beech	Common hackberry
		Cucumbertree	Flowering dogwood	Common persimmon
		Dawn redwood	Higan cherry	'Discovery' elm
		Eastern cottonwood	Honeylocust	Downy serviceberry
		Eastern wahoo	Korean mountain-ash	European buckthorn
		European filbert	Mockernut hickory	European hornbeam
		European mountain-ash	Northern red oak	European smoketree
		Gray dogwood	Peach	Freeman maple
		Green ash	Pignut hickory	'Frontier' elm
		Horse chestnut	Pin oak	Glossy buckthorn[1]
		Japanese maple	Privet[1]	Hedge maple
		Japanese tree lilac	Red maple	Heritage® oak
		London planetree	Red mulberry	Japanese zelkova
		Morden hawthorn	River birch	Kentucky coffeetree
		Norway maple[1]	Sassafras	Korean Sun™ pear
		Norway spruce	Shagbark hickory	Kousa dogwood
		Ohio buckeye	Shingle oak	Leatherleaf viburnum
		Oriental spruce	Shumard oak	Littleleaf linden
		Pagoda dogwood	Siberian elm[1]	Maidenhair tree
		Pecan	Silver maple	Miyabe maple
		Peking lilac	Slippery elm	Nannyberry
		'Prospector' Wilson elm	Staghorn sumac	Osage-orange
		Pussy willow	Sugarberry	'Prairie Gem' Ussurian pear
		Robusta poplar	Swamp white oak	Prickly ash
		Sargent cherry	Sweetgum	Rose-of-Sharon
		Scarlet oak	Sycamore maple	Russian-olive[1]
		Serbian spruce	White mulberry[1]	Saucer magnolia
		Shellbark hickory		Scholar tree
		Silver linden		Shantung maple
		Smoothleaf elm		'Snow Goose' cherry
		Star magnolia		Pacific Sunset® maple
		Sugar maple		Tree of heaven[1]
		Turkish hazelnut		Triumph™ elm
		Washington hawthorn		White fringetree
		Weeping willow		Willow oak
		White poplar		Winged burningbush[1]
		'Winter King' green hawthorn		Yellowwood
		Yellow buckeye		
		Yellow-poplar (tuliptree)		

[1] Invasive species.

Only 8 percent of trees recommended for planting on city parkways (boulevards) were considered to have high or moderate-high vulnerability. Twenty-three percent had low vulnerability, and 43 percent had low-moderate or moderate vulnerability. The low number of vulnerable tree species is likely due to the need for street trees to withstand a wide variety of stressors; thus, recommended species tend to have high adaptive capacity. Twenty-seven percent were not rated.

Impacts of Climate Change on the Urban Forest

The impacts of climate change on individual trees will have important implications for the urban forest of the Chicago Wilderness region as a whole. There is increasing empirical evidence of the impacts of climate change on urban forests at both the global and local level (Gunderson et al. 2012, Hayhoe et al. 2008, Hellman et al. 2010, IPCC 2007, Staudinger et al. 2012). Urban sites are often more extreme (e.g., in terms of extreme heat, temperature fluctuations, flooding) than non-urban sites (Wilby 2008). Global climate change is projected to increase the frequency and duration of these extreme climatic events (Breshears et al. 2005). Therefore, urban trees and forests that are already under stress due to the intense urban environment are likely to have interactive and additional stress from the effects of global climate change (Gill et al. 2007, Kirshen et al. 2008). Many urban trees may be adaptable to these changes either because they were selected for planting based on their tolerance of stress or because they have propagated and thrived naturally as a result of their wide adaptability. Following is a summary of some of the key impacts for the urban forest in the Chicago Wilderness region, recognizing that the urban forest is only a component of a broader urban ecosystem (see the sidebar).

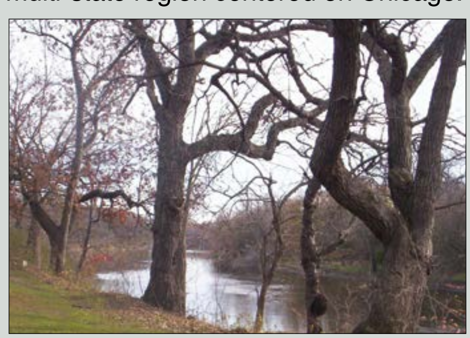
Heat Stress

Increases in temperature from climate change can be exacerbated in urban areas (Wilby 2008). Urban areas with 1 million or more people can be 1.8 to 5.4 °F (1 to 3 °C) warmer than their surrounding rural areas due to the urban heat island effect from heat-absorbing infrastructure such as pavement and buildings (Akbari 2005). The heat island effect can make urban areas one hardiness zone warmer than the surrounding area, allowing some more-southern species to be planted (U.S. Department of Agriculture 2012). In addition

Other Resources on Climate Change Impacts on the Chicago Wilderness Region

In this chapter, we focus specifically on climate change impacts on trees and the urban forest. We recognize that trees are only one component of a broader urban ecosystem that includes nonforested terrestrial and aquatic systems, grasses and herbaceous plants, insects, vertebrate species, fungi, micro-organisms, and of course people. If you would like to learn more about how other ecosystems and species may be affected by climate change in the area, helpful resources are available:

- **Changing Landscapes in the Chicago Wilderness Region: a Climate Change Update to the Biodiversity Recovery Plan** (Chicago Wilderness 2012). This online resource summarizes the key effects of climate change on species and ecosystems across the Chicago Wilderness region.
- **Climate Change and Chicago: Projections and Potential Impacts. Chapter 5—Ecosystems** (Hellmann et al. 2008). This chapter describes the likely impacts of warming temperatures and changing precipitation on plant species, wildlife, invasive species, pests, and agricultural ecosystems across the Chicago region.
- **Climate Change Impacts on Terrestrial Ecosystems in Metropolitan Chicago and its Surrounding, Multi-state Region** (Hellmann et al. 2010). This article summarizes the impacts of climate change on plants, wildlife, invasive species, pests, and agricultural ecosystems across the multi-state region centered on Chicago.



Riparian area, Riverside, IL. Photo by M.G. Collins, Village of Riverside, used with permission.

Daffodils coming up in early spring, Hazel Crest, IL. Photo by K. Persons, Village of Hazel Crest Open Lands Commission, used with permission.

to milder winters, however, the heat island effect can make summer temperatures higher, especially near dark pavements and buildings. Thus, some plants that are marginal for the area based on heat zones could exhibit negative effects. Excessive heat can cause scorching of leaves and twigs and sunburn on branches and stems. In addition, photosynthetic rates are often reduced at high temperatures, leading to reduced growth rates and early leaf senescence.

Drought Stress

Severe and long-term droughts can have dramatic impacts on the Chicago Wilderness region's urban forest. During drought years, growth can be reduced, with variation among species and land use (Fahey et al. 2013). Despite uncertainty about future changes in drought over the next century, some evidence suggests that trees may become more water-stressed from increased evapotranspiration under higher temperatures or less frequent rain events (Chapter 2). Species known for their drought tolerance, such as Kentucky coffeetree, may show less of a negative effect than species that are adapted to more mesic environments, such as yellow-poplar and sugar maple. Trees in developed areas, such as near residences and along streets, may be less susceptible to drought due to reduced competition and increased maintenance. However, some street trees planted in confined spaces could also undergo drought stress if there is insufficient soil. Droughts in the Chicago Wilderness region tend to not be as severe as those in the desert Southwest, and growth tends to bounce back in the years after a drought (Fahey et al. 2013). However, if droughts do become more severe in the future, large-scale mortality could occur (Breshears et al. 2005).

Wind Damage

On average, urban areas tend to have lower wind speeds than surrounding rural areas (Mishra et al. 2015), but buildings and other urban infrastructure can create "street canyons" with localized areas of altered wind speed and turbulence (Rotach 1995). Wind damage to trees can be particularly problematic in urban areas because of the increased risk to human life and property. As noted in Chapter 2, conditions could become favorable for more thunderstorms and straight-line wind events in the future, and tornadoes could occur earlier in the season and in more clustered outbreak sequences. When the urban forest is subjected to severe wind disturbance, falling limbs and trees can result in loss of electric service, displace families and businesses, and impede emergency vehicles from reaching damaged areas.

Several factors influence the resilience of trees to wind damage. Trees that have defects (e.g., codominant stems, decay, severed roots) are more likely to be damaged or uprooted by strong winds. Large trees sustain more damage because they have larger crowns exposed to wind. Furthermore, wind speeds increase with increased distance from the ground, thereby exerting greater force on taller trees. Wind-related damage and mortality can also be species-specific and depend on factors such as tree architecture and wood material properties. For example, silver maple, Siberian elm, and yellow-poplar are among the species reported to be frequently damaged in wind storms, whereas white oak, baldcypress, and hickory species are among the most resilient to wind damage (Duryea et al. 2007). Certain cultivars (e.g., Bradford pear) have growth forms that make them highly susceptible to wind damage. Pruning can reduce wind loading and increase wind resistance if done properly (Ciftci et al. 2014, Gilman et al. 2015, Smiley and Kane 2006).

Winter Storm Damage

Winter storm damage to trees can be of particular concern in urban areas because of the risk to infrastructure. Winter storms occur frequently across the region, and could become less frequent, but when they do occur under future climate conditions they could be more severe with wetter snow (Chapter 2). Less salt may have to be applied to roads and sidewalks with wetter snow, which might reduce stress on parkway landscaping and street trees, reducing the need to maintain and replace trees in the region (Jaffe and Woloszyn 2013). However, dense, wet snow may behave much like heavy ice deposited by ice storms and freezing rain, with the weight of the snow damaging trees and surrounding structures (Jaffe and Woloszyn 2013). In general, tree species and cultivars that are more likely to have included bark, decurrent branching patterns, and a large branch surface area will be more susceptible to winter snow and ice damage (Hauer et al. 1994). Susceptible species include American basswood, hackberry, silver maple, and eastern cottonwood. Resistant trees generally lack included bark and have coarse branching patterns and excurrent branching. Resistant trees include baldcypress, eastern hophornbeam, Kentucky coffeetree, and swamp white oak (Hauer et al. 1994).

Flooding and Stormwater Runoff

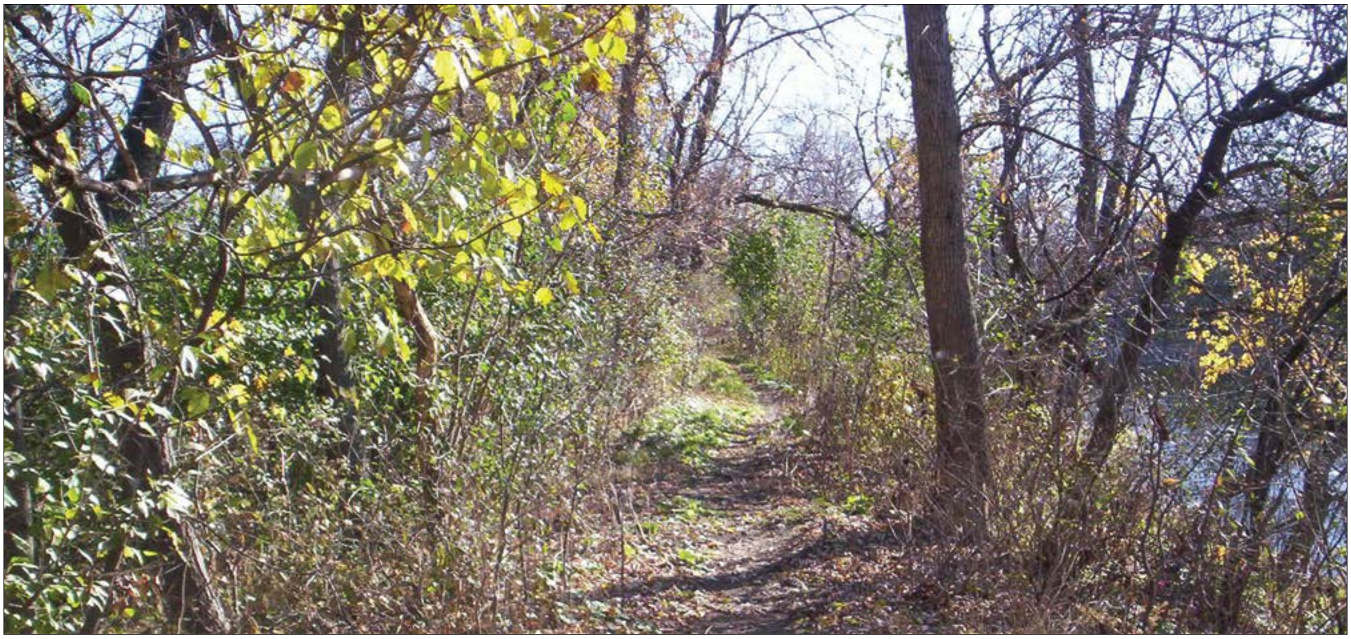
Urban environments are more susceptible to stormwater runoff due to the high concentration of impervious surfaces. Increases in impervious cover can dramatically increase the size and frequency of so-called 100-year flood events (Hollis 1975). This effect is likely to be exacerbated by the increase in heavy rain events that is already occurring and projected to accelerate in the area under a changing climate (Chapter 2). Typically, urban floods are short-lived, but extended flooding can stress trees, leading to leaf yellowing, defoliation, and crown dieback. If damage is severe, mortality can occur. In addition, flooding can lead to secondary attacks by insect pests and diseases (Bratkovich et al. 1993). Some species are more tolerant of flooding than others. Flood-intolerant species include upland species such as bitternut and shagbark hickory, Kentucky coffeetree, and white oak (Bratkovich et al. 1993). Species that tend to be tolerant of flooding include species that are generally native to wetlands and riparian areas such as baldcypress, American sycamore, and red maple (Bratkovich et al. 1993). In addition to differences among species, age class and vigor can affect flood-related damage and mortality.

Air and Soil Pollution

Air and soil pollution from ozone, nitrogen deposition, and sulfur dioxide can all affect tree health. In 2015, the Chicago region was ranked 19th in the nation for highest ozone pollution (American Lung Association® 2015). Elevated temperatures can increase the rate of ground-level ozone formation (Jacob and Winner 2009), leading to leaf damage and secondary damage from insects and disease. Regional increases in summer temperatures could worsen effects already experienced due to the heat island effect (Wilby 2008). However, new air quality standards could help mitigate this effect (U.S. Environmental Protection Agency 2015b). Although nitrogen deposition and sulfur dioxide levels have decreased in the area in recent years, they are still far above ambient levels (Illinois Environmental Protection Agency 2013). Stress from sulfur dioxide and nitrogen deposition can interact with climate change-induced stressors to lead to tree decline and mortality (McNulty and Boggs 2010).

Carbon Dioxide Increases

The urban forest in the Chicago region is estimated to absorb about 2.5 million tons of carbon dioxide (CO_2) per year (Nowak et al. 2013). Elevated CO_2 may enhance growth and water use efficiency of some species (Ainsworth and Rogers 2007, Norby et al. 2005), potentially offsetting the negative effects of drier conditions later in the growing season. There is already some evidence for increased forest growth under elevated CO_2 in the eastern United States (Cole



Riparian area invaded with European buckthorn, Riverside, IL. Photo by M.G. Collins, Village of Riverside, used with permission.

et al. 2010, McMahon et al. 2010), 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).

Shifts in Phenology

Climate change may lead to shifts in the timing of leaf out, flowering, fruit production, and senescence in urban trees. Trees and shrubs may break dormancy earlier in the year in response to earlier, warmer springs (Chicago Wilderness 2012, Fahey 2016). This could have negative effects if the spring warming is followed by a frost period. For example, in 2012, the apple crop in the northern Midwest was severely reduced by an unusually warm March followed by a killing frost. Other negative effects are possible if leaf out and insect emergence occur before the arrival of insectivorous migratory birds; insect herbivory could increase as a result (Chicago Wilderness 2012). Early bud burst may also lead to early flowering, which could be problematic in insect-pollinated trees if pollinators have not yet arrived. At the end of the growing season, senescence may occur later due to warmer temperatures in autumn. Although a longer growing season could be beneficial in absorbing carbon dioxide, it could also place additional stress on trees if there are also declines in water availability later in the growing season.

Invasive Plant Species

Invasive species can be problematic in natural areas in the Chicago Wilderness region as mentioned in Chapter 1. Many invasive species that currently threaten natural areas in the Chicago Wilderness region are likely to benefit from projected climate change. As noted earlier in this chapter, invasive species tend to have high adaptive capacity and low vulnerability, meaning they will be among those most successful in a changing climate. Changes in climate may allow some invasive plant species to survive farther north than they had previously (Dukes et al. 2009). Kudzu is an invasive vine that has blanketed forests in the southeastern United States, blocking access to sunlight for native trees and plants. The current northern distribution of kudzu is limited by winter temperature. A modeling study suggests that warmer temperatures could aid the spread of kudzu across Illinois by the end of the century (Bradley et al. 2010). Although the risk to the Chicago area was projected to be low, the urban heat island effect was not accounted for in this study. Another study examined the potential future distribution of kudzu for the year 2035 using trends in observed climate data; results also suggest that kudzu will move northward but will still be south of Chicago (Jarnevich and Stohlgren 2009). Chinese and European privet are invasive flowering shrubs that crowd out native species and form dense thickets. Model projections suggest that the risk of privet invasion into the Chicago Wilderness region may be similar to that of kudzu by the end of the century (Bradley et al. 2010).

Insect Pests and Pathogens

Warmer temperatures and stressed trees may increase the abundance of pests and pathogens that are currently present in the Chicago Wilderness region. Milder winters could be beneficial for the emerald ash borer, which is already causing extensive damage to ash trees across the area (Venette and Abrahamson 2010). Drought stress, which could occur later in the growing season, may make trees susceptible to attacks by boring insects such as bronze birch borer and two-lined chestnut borer and to diseases such as Botryosphaeria canker. Oak wilt, a high-mortality disease of oaks in the region, benefits from cool, moist conditions for transmission and hot, dry conditions for disease progression. Thus, wetter springs followed by hot dry summers could make oak wilt a larger problem in the Chicago Wilderness region in the coming decades (see the box below). Gypsy moth, which attacks oaks and other shade trees, could benefit from warming temperatures (Logan et al. 2007). However, wetter springs could curtail its spread to some extent: a fungal pathogen of the larvae has been shown to reduce populations in years with wet springs (Andreadis and Weseloh 1990).

A changing climate is also likely to increase the susceptibility of tree species to pests and diseases that are not currently a problem in the Chicago Wilderness region. High spring precipitation has been associated with severe outbreaks of bur oak blight in Iowa, which could put Chicago-area bur oaks at risk if springs become wetter (Harrington et al. 2012). Milder winter temperatures could allow southern pine beetle to migrate northward (Ungerer et al. 1999). Beech bark disease and thousand cankers disease may benefit from warmer winter temperatures (Kasson and Livingston 2012, Luna et al. 2013). However, the risk for some diseases may be reduced under a changing climate. Climate conditions are currently only marginal for sudden oak death in the Chicago Wilderness region (Kluza et al. 2007, Venette and Cohen 2006), and models suggest that conditions may become less suitable in the future (Venette 2009). Additional pests and diseases may invade for reasons other than climate change. The northern distribution of Asian longhorned beetle does not appear to be driven by winter temperatures, and this pest has already been found in Chicago (Antipin and Dilley 2004, Roden et al. 2009).

Focus on Oaks

Project to preserve historic oak genetic stock through propagation, Oak Park, IL. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

Oak species once dominated the landscape of the Chicago Wilderness region (Fahey et al. 2012). Efforts are currently underway to restore oak ecosystems in natural areas in the region and to increase the component of native oak trees in the urban landscape (Chicago Wilderness 2015). Given projected changes in climate, one might wonder if oaks will continue to thrive in the region. Model projections mentioned earlier in this chapter are mixed for many oak species, including northern red, bur, and white oak. Despite a projected loss in suitable habitat under some scenarios, many of these species have adaptive capacity factors that could allow them to persist, such as drought tolerance and low susceptibility to breakage during storms. These factors may allow them to perform better than the models suggest. However, there are several pests and diseases of oaks that could become more problematic under a changing climate, such as oak wilt, two-lined chestnut borer, and bur oak blight.

Taken together, these factors paint a complex picture for oaks in the area under a changing climate. Ultimately, management decisions regarding if and where to plant particular oak species will depend on a variety of factors. The benefits of restoring native biodiversity and the ecosystem service benefits that oaks provide, such as habitat for a wide diversity of insect species (Tallamy 2009), may be weighed with the direct and indirect risks and benefits of climate change.

Tree- and Forest-dependent Wildlife

Wildlife that depends on the urban forest in the Chicago Wilderness region may also be subject to effects of climate change (Hellmann et al. 2010). Suitable habitat for wildlife may shift due to both direct effects of temperature and precipitation and indirect effects through changes in the vegetation and food sources upon which they depend. Based on species distribution modeling that accounts for both vegetation shifts and direct climate effects, habitat for 52 to 54 bird species may increase at least 10 percent in the greater Chicago region over the next century (Hellmann et al. 2010). Another 64 to 76 species could lose habitat within this area (Hellmann et al. 2010). There are currently 115 butterfly species in the greater Chicago region, of which 20 could lose suitable habitat and 19 could gain habitat based on range boundaries (Hellmann et al. 2010). Many species common in urban environments, such as raccoons, skunks, and gray squirrels, may remain unaffected by climate change, as they are tolerant of a wide range of climatic conditions (Hellmann et al. 2010).

Some wildlife species, such as white-tailed deer, can have negative effects on the urban forest by feeding on seedlings or saplings (Urbanek and Nielsen 2012). Currently, there is little evidence to indicate how deer will respond to climate change in the Chicago Wilderness region. An analysis of climate change impacts on white-tailed deer in Wisconsin suggests that deer in that area are likely to experience 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 Chicago remains unknown.

Summary

Results from species distribution modeling suggest that habitat suitability for many tree species may shift across the Chicago Wilderness region, leading to declines in some species and increases in others. Species at the southern extent of their range are generally projected to decline in suitable habitat. Species at the northern extent of their range or south of the area could have an increase in suitable habitat, especially in areas where there is an urban heat island effect. Model projections are mixed for many oak species that were once dominant on the landscape before European settlement. Other factors that are not included in models, such as changes in extreme events, insects, and diseases, may also affect the survival of particular tree species and make them more or less adaptable to climate change-induced pressures than the models would suggest. Overall, the vulnerability of trees and the surrounding urban forest will need to be gauged based on the complex interaction of multiple stressors and benefits.

Key Points

- Species distribution modeling for native species suggests that suitable habitat under a changing climate may decrease for 11 primarily northern species, and increase or become newly suitable for 40 species.
- For species for which no model information is available (rare, nonnative, or cultivars), shifts in hardiness and heat zones could have a positive effect on about 23 percent of species that are either present in the area or considered for planting, and a negative effect on about 19 percent.
- Adaptive capacity of 179 species was evaluated by using scoring systems for planted and natural environments, with invasive species among those with the highest capacity to adapt to a range of stressors.
- An analysis of vulnerability that combines model projections, shifts in hardiness and heat zones, and adaptive capacity showed that 17 percent of the tree species currently present in the region have either moderate-high or high vulnerability to climate change, and 77 percent of individual trees with low vulnerability are invasive species.
- Key impacts to trees in the Chicago Wilderness region projected over the next century include increased drought and heat stress, increased stormwater runoff and flooding, increases in wind damage, and increases in tree pests and pathogens.

CHAPTER 4

URBAN FOREST VULNERABILITY CASE STUDIES

This chapter focuses on the vulnerability of urban forests in the Chicago Wilderness region to climate change. Vulnerability is the susceptibility of a system to the adverse effects of climate change (Intergovernmental Panel on Climate Change [IPCC] 2007). It is a function of potential climate change impacts and the adaptive capacity of the system. We consider urban forests to be vulnerable if they are anticipated to suffer substantial declines in health or productivity, similar to assessments of natural ecosystems (Brandt et al. 2014; Butler et al. 2015; Handler et al. 2014a, 2014b; Janowiak et al. 2014). However, unlike in previous assessments of forested areas largely away from urban areas, considerations of social, economic, and organizational factors are critical in determining the overall vulnerability of an urban forest (Ordóñez and Duinker 2014). Urban forests can be considered social-ecological systems, where resilience of human communities and the ecological systems they depend upon are intertwined (Hale et al. 2015, Mincey et al. 2013, Tidball 2014, Vogt et al. 2015). In urban forests with a more natural composition of native species, such as those found in forest preserves, systems are also vulnerable if climate change would fundamentally alter their composition or character.

Urban Vulnerability Assessment Process

We developed a vulnerability assessment process to help urban forestry professionals assess the vulnerability of municipalities, park districts, and forest preserves to climate change (for more details on methods, see Appendix 8). This process built upon concepts for assessing the vulnerability of urban forests (Ordóñez and Duinker 2014) as well as vulnerability assessments focused on natural forests and completed for the Climate Change Response Framework (Brandt et al. 2014; Butler et al. 2015; Handler et al. 2014a, 2014b; Janowiak et al. 2014). Our process was designed to draw upon urban forestry professionals' knowledge about the urban forests that they manage and to consider how these systems may change given projected climate changes.

Our process evaluated vulnerability for two key components: impacts and adaptive capacity (Glick et al. 2011, Swanston and Janowiak 2016). Climate change impacts are the direct and indirect effects of climate change on the system in question. Impacts were subdivided into physical, biological, or human factors that could influence the exposure or sensitivity of the urban forest (Fig. 15). Considerations under the physical factor category were related to soil type, topography, and proximity to large bodies of water. Considerations under the biological factor category included projected shifts in habitat suitability for urban trees and anticipated effects of climate change on organisms that influence tree health, such as insect pests, pathogens, and herbivores. Human factor considerations included the relative magnitude of the urban heat island effect, amount of impervious surface, and capacity of the storm sewer system to absorb heavier storms.

Adaptive capacity is the ability of a species or ecosystem to accommodate or cope with potential climate change impacts with minimal disruption. Adaptive capacity was subdivided into biological, organizational/technical, economic, or social factors that could enhance or inhibit the capacity of the urban forest to adapt to changes in climate. Biological factor considerations included the

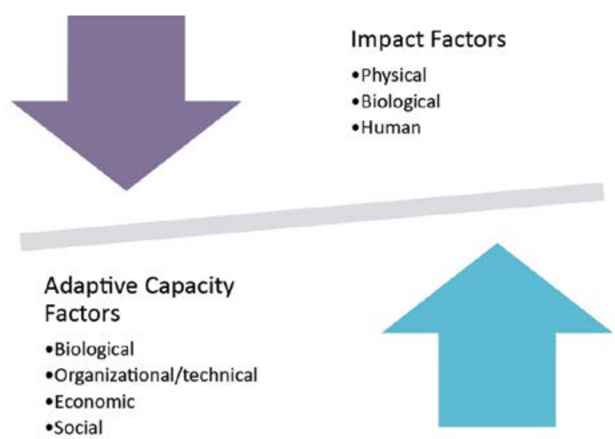


Figure 15.—Impact and adaptive capacity factors that were evaluated during the vulnerability assessment process. In general, impacts have a negative influence on vulnerability and adaptive capacity factors have a positive influence. For examples of each factor, see Appendix 6.

Measuring tree diameter for the 2010 tree census. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

overall condition of the current forest and the diversity of species, genotypes, and age classes. Organizational/technical factor considerations included whether the area had trained forestry professionals, tree care ordinances, and plans, as well as the availability of nursery stock. Economic factor considerations focused on whether there was sufficient funding to plant or maintain trees. Social considerations included the value that the public places on trees and the extent to which volunteers or local organizations provide support.

Potential impacts and adaptive capacity factors specific to the Chicago Wilderness region were used to pre-populate a worksheet for urban forestry professionals (see Appendix 8). Regional impacts were summarized from the information presented in Chapters 2 and 3, and adaptive capacity factors were identified from the literature (Ordóñez and Duinker 2014). Each consideration within a factor included a question to prompt the professionals to evaluate specific ways in which it could affect their work. Professionals were asked to answer the question, give an assessment of its overall effect on the urban forest (positive, negative, or neutral), and rate their level of confidence in that effect (high, medium, low). To allow for flexibility, the professionals using the worksheet could remove considerations that did not apply and add other considerations that may apply. Professionals were asked to rate each factor, and then use these factor ratings to determine overall impacts and adaptive capacity. They were then asked to place a mark on a vulnerability figure based on their determinations of impact and adaptive capacity (Fig. 16).

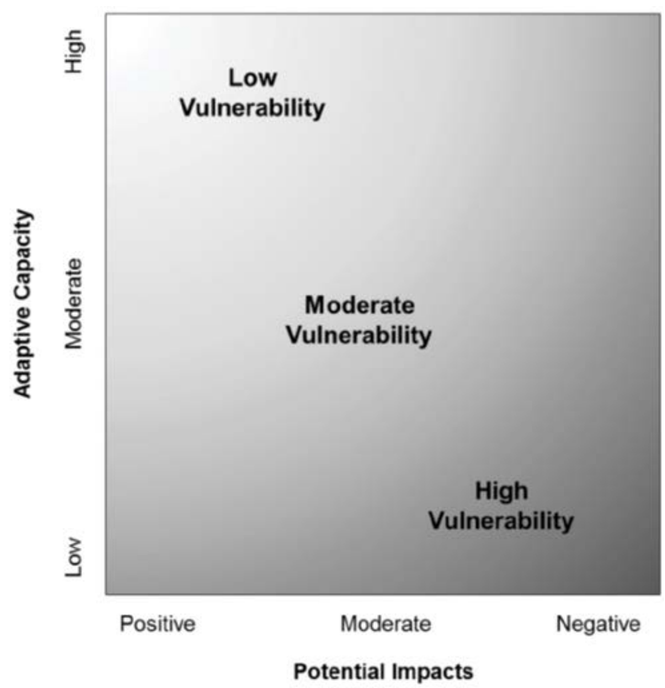


Figure 16.—Vulnerability diagram used to determine overall vulnerability from impacts and adaptive capacity (based on Swanston and Janowiak 2012).

Vulnerability Case Studies

Urban forestry professionals from four municipalities, three park districts, and three forest preserve districts in the Chicago Wilderness region (Fig. 17) completed the vulnerability assessment process to test the approach. Representatives from each organization participated in a focused workshop where they completed the worksheets and assessed the vulnerability of their management area to climate change. Professionals were asked to consider the impacts of climate change over the next century, and the adaptive capacity of the urban forest that they manage. After the workshops, information from the worksheets was summarized in narrative form for each location. In the following case study summaries, we highlight the key considerations for the impact and adaptive capacity factors that urban forestry professionals identified as having the greatest influence on climate change vulnerability for the areas they manage. When inventories were available, we also evaluated the number of species and total trees in the inventory considered vulnerable based on changes in habitat suitability and adaptive capacity (see Chapter 3). Overall ratings of vulnerability ranged from low-medium to medium-high, and were primarily driven by differences in adaptive capacity (Table 13).

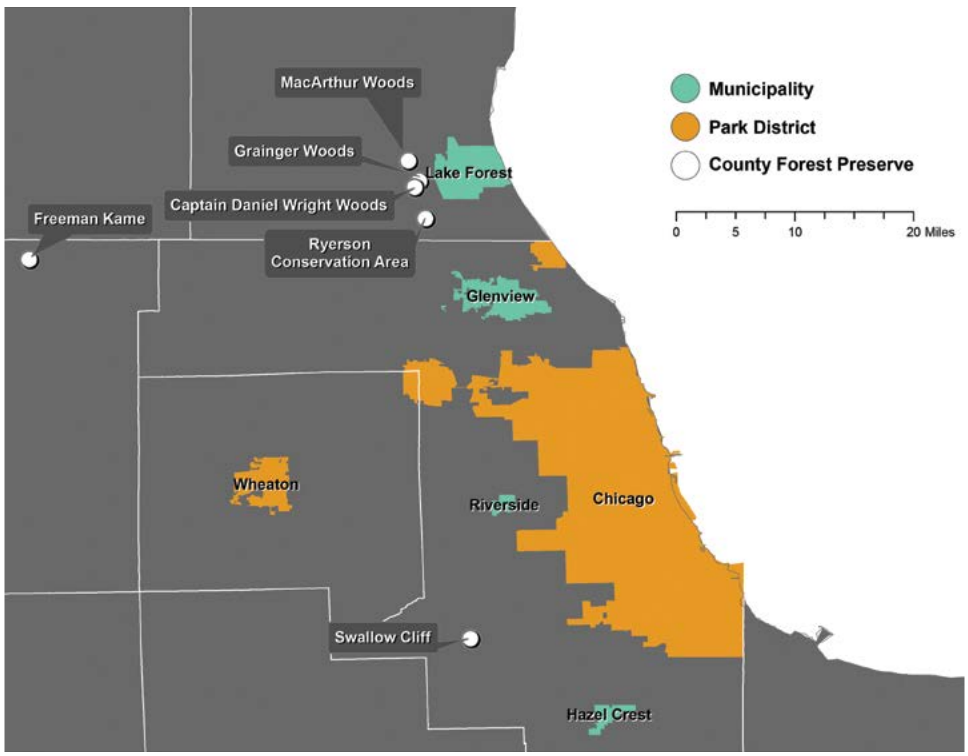


Figure 17.—Case study areas in the Chicago Wilderness region. Note that the municipal boundaries are shown for the park districts.

Table 13.—Summary of vulnerability assessment results for four municipalities, three park districts, and three forest preserves in the Chicago Wilderness region

		Impacts				Adaptive capacity					Vulnerability
Location	Type	Physical	Biological	Human	Overall	Biological	Organizational/ Technical	Economic	Social	Overall	
Riverside	M	moderate-negative	moderate	moderate	moderate	high	high	high	high	high	low-moderate
Lake Forest	M	moderate	negative	moderate	moderate-negative	high	moderate	high	high	moderate-high	moderate
Hazel Crest	M	moderate	moderate-negative	moderate-negative	moderate-negative	low	moderate-high	low	moderate	low-moderate	moderate-high
Glenview	M	moderate-negative	moderate-negative	moderate-negative	moderate-negative	moderate	high	high	high	high	moderate
Glencoe Parks	P	moderate	moderate-negative	negative	moderate-negative	moderate	low-moderate	low-moderate	low	low-moderate	moderate-high
Wheaton Parks	P	moderate	negative	negative	moderate-negative	high	high	high	moderate-high	high	moderate
Chicago Parks	P	moderate-negative	moderate-negative	moderate-positive	moderate-negative	moderate	moderate-high	moderate-high	moderate-high	moderate-high	low-moderate
Southern Des Plaines River Preserves	F	negative	moderate-negative	negative	moderate-negative	low-moderate	moderate	moderate-high	high	moderate	moderate
Freeman Kame Preserve	F	moderate-negative	moderate-negative	negative	moderate-negative	moderate	moderate	moderate	moderate-high	moderate-high	moderate
Swallow Cliff Preserve	F	moderate	moderate-negative	moderate	moderate-negative	low	moderate	low	low-moderate	low-moderate	moderate-high

M indicates municipality **P** indicates park district **F** indicates forest preserve

Residential neighborhood, Chicago. Photo by L. Darling, The Morton Arboretum, used with permission.

MUNICIPALITIES

Village of Riverside

Low-Moderate Vulnerability

This residential community has a diverse mix of tree species that are well-maintained by professionals and the community, thus a very high adaptive capacity. The primary concern in the area is an increase in pests and diseases due to milder winters.

The Village of **Riverside** is a suburban village in Cook County, IL. A significant portion of the village is in the Riverside Landscape Architecture District, designated a National Historic Landmark in 1970, and designed by Frederick Law Olmstead. The population of the village was 8,875 at the 2010 census with a median income of $85,703 (note that population and income data for each municipality, park district, and forest preserve district are from the 2010 U.S. Census [U.S. Census Bureau 2011]). Riverside is located about 9 miles west of downtown Chicago and 2 miles outside city limits.

Impacts—moderate

Physical factors—moderate-negative

The areas south and north of the railroad have different physical properties. On the south side, the area near the Des Plaines River can become flooded and may be more vulnerable if heavy storms increase. The soils in the area are relatively well-drained, however. On the north side of the railroad, the area is more developed and soils tend to be more compacted with heavy clay content. This can lead to temporary flooding during heavy rain events. Storm damage is a bigger concern on the south side of the village, where trees are more exposed because there are fewer structures to block the wind.

Biological factors—moderate

The area tends to have high species diversity and does not have many trees that are expected to be particularly vulnerable to shifts in temperature or precipitation. Fewer than 6 percent of the trees in the village are considered to have moderate-high or high vulnerability, and more than half have low or low-moderate vulnerability ratings (Table 14). However, there are many species of oak that could be susceptible to increased pest and disease pressure such as oak wilt, gypsy moth, and bur oak blight. Herbivory from deer is an issue throughout the area, and could become more problematic if winters become milder. Invasive species competition from European buckthorn is primarily a problem along the river and could become a larger issue as native species become more stressed under a changing climate. (For lists of the common and scientific names of species mentioned in this report, see Appendix 1.)

Table 14.—Number of tree species and the proportion of total trees inventoried in each vulnerability class for the Village of Riverside, based on a 2014 inventory of all park and street trees

Vulnerability class	Number of species	Percentage of trees
Low	18	23.1
Low-Moderate	27	38.7
Moderate	26	25.2
Moderate-High	5	3.9
High	6	1.9
Not rated[1]	22	6.5

[1] This category includes trees that were only identified to genus in the inventory and extremely uncommon species or cultivars.

Human factors—moderate

The area is primarily residential, with a mix of greenspace and impervious cover. The more developed north side has more impervious cover, and thus could experience increases in runoff and decreases in water infiltration into the soil if heavy rain events increase. The area is relatively densely populated and thus susceptible to air pollution.

Bitternut hickory planted in a Riverside neighborhood. Photo by M.G. Collins, Village of Riverside, used with permission.

Adaptive Capacity—high

Biological factors—high

Riverside is a National Historic Landscape District that was designed by Olmsted to provide connected greenspace. In keeping with original plans, a wide mix of native species with a high genetic diversity has been planted throughout the village. Trees are a good mix of age classes with few trees approaching the end of their lifespan.

Organizational/technical factors—high

The Village of Riverside has a forester on staff, comprehensive inventory, planting list, and long-term plan. The village is part of a mutual aid network and has conducted a risk assessment of its urban forest to natural disasters. Trees are regularly pruned and maintained to reduce vulnerability to storm damage. There is a lack of diverse nursery stock to keep up with demand, however.

Economic factors—high

There is currently sufficient funding for the village to plant and maintain trees in the area, but it can fluctuate from year to year. Private homeowners typically have sufficient economic means to care for their trees, but this capability varies.

Social factors—high

The area has extensive community support and involvement in planting and maintaining trees and a wide network of organizations for sharing ideas and resources.

City of Lake Forest

Moderate Vulnerability

The area has many trees that are vulnerable to the direct and indirect effects of a changing climate. Municipal trees are not maintained as often as would be optimal. However, the city has a well-funded forestry program and a community with the means and desire to care for its trees.

Lake Forest is a suburb in the North Shore area along Lake Michigan in Lake County with a population of 19,375. The median household income is $147,162. When Lake Forest was first developed in the 1850s, the original design limited road access in order to maintain a tranquil setting. More development has occurred on the west side of the city in recent decades, but the east side remains relatively secluded. It is an affluent area and home to Lake Forest College.

Impacts—moderate-negative

Physical factors—moderate

The City of Lake Forest has soils with a high clay content and poor drainage, making the area susceptible to flooding and runoff during heavy rain events. However, the clay soils could help retain some moisture later in the growing season.

Biological factors—negative

The city has many common trees that are vulnerable to projected changes in climate, especially white ash, black cherry, and several northern conifer species. Overall, about 10 percent of the trees in the area are considered to have moderate-high or high vulnerability based on the most recent inventory (Table 15). The city is also experiencing outbreaks of pests and diseases, especially emerald ash borer, and has a relatively large concentration of herbivores such as deer. All of these stressors could become worse with milder winters. Canopy cover, and thus cooling from trees, is being lost due to ash mortality. Many of the trees are susceptible to wind and ice damage.

Table 15.—Number of tree species and the proportion of total trees inventoried in each vulnerability class for the City of Lake Forest, based on a 2013 inventory of all park and street trees

Vulnerability class	Number of species	Percentage of trees
Low	23	14.7
Low-Moderate	26	27.4
Moderate	33	36.1
Moderate-High	8	7.3
High	12	2.4
Not rated[1]	73	12.0

[1] This category includes trees that were only identified to genus in the inventory and extremely uncommon species or cultivars.

Human factors—moderate

This primarily residential area does not experience an urban heat island effect. Although it does not have a high amount of impervious cover, irrigation in the area combined with insufficient ravines to channel water can lead to runoff issues during heavy storm events.

Adaptive Capacity—moderate-high

Biological factors—high

The mix of tree species and genetic diversity are high. Most of the trees are at mid-age so they are not particularly at risk for mortality from potential dry periods or storms. In the past, a single tree species was planted on a block, which increased vulnerability to canopy loss from climate change or pest outbreaks. However, newer planting programs are working to increase the diversity.

Field and woodlot, Lake Forest. Photo by P. Gordon, City of Lake Forest, used with permission.

Organizational/technical factors—moderate

The City of Lake Forest has professional forestry staff overseeing the selection and care of its street trees. It also has a planting list and tree care ordinance, a long-term plan, and a tree inventory. Private residents typically care for and maintain their trees. Maintenance of city trees is not as often as would be optimal, with pruning occurring every 13 to 17 years. The city does not have a risk assessment or disaster response plan.

Economic factors—high

There is currently sufficient funding for the city to plant and maintain trees in the area. The area has a high median income, and private homeowners have sufficient economic means to care for their trees.

Social factors—high

Residents tend to value their trees. Likewise, the city offers several programs as an incentive to residents. The Forestry Section offers a cost-sharing program to residents, which allows those residents who do not already have a parkway tree to split the cost 50/50 with the city. It also has a wholesale tax-exempt native tree sale for residents to encourage the planting of native trees.

Flooded area in open land, Hazel Crest. Photo by K. Persons, Village of Hazel Crest Open Lands Commission, used with permission.

Village of Hazel Crest

Moderate-High Vulnerability

The vulnerability of the Village of Hazel Crest is primarily driven by its lack of biodiversity from an overdominance of silver maple. Its adaptive capacity is also hindered by an insufficient budget and a lack of public involvement and support.

Hazel Crest is a village in Cook County, IL. The population of approximately 14,100 is racially diverse with a median income of $49,489. The village is located in an area known as the Chicago Southland and is about 25 miles south of the Chicago Loop.

Impacts—moderate-negative

Physical factors—moderate
Soils in the area tend to be very well-drained, which makes them susceptible to drying. Flooding is not a major issue in the area, with only temporary flooding occurring after large storm events. One exception is the open lands, which are left undeveloped due to their susceptibility to flooding.

Biological factors—moderate-negative
Silver maple is the dominant tree planted on the village's streets. It is extremely vulnerable to wind and ice damage, which could be more problematic as severe storms increase. Emerald ash borer is also killing ash trees in the area, leading to a reduction in canopy cover.

Human factors—moderate-negative
Hazel Crest is situated at the intersection of Interstate 80 and 294, which contributes vehicle pollution and an urban heat island effect. Like most suburban areas, it has impervious cover, but not any more than others in the Chicago Wilderness region.

Adaptive Capacity—low-moderate

Biological factors—low
Biodiversity of street trees in the village is very low; most street trees are silver maple. Many of these trees are reaching the end of their lifespan. As they are replaced, a more diverse mix of species is being planted, but it will be a long time before the area has a diverse, mature canopy.

Organizational/technical factors—moderate-high
The village has a certified arborist, tree board, and open lands commission. Its planting ordinance is being revised to increase flexibility. It has a risk assessment and participates in a mutual aid network. It does not have a comprehensive inventory or a long-term plan. In general, street trees are maintained, but routine maintenance has fallen behind due to the need to remove ash damaged by emerald ash borer.

Economic factors—low
Funding for the planting and maintenance of trees is generally less than what is needed. Residents tend to be in the low-to-middle income range and do not have extra resources to care for trees in private residences.

Social factors—moderate
Support for the planting and care of trees in the area is mixed. On average, older residents tend to place more value on trees than newer residents. There is a large volunteer base that helps with the planting and care of trees in open lands, but there is not a similar volunteer base to aid in the care of street trees. The village does offer incentives for the planting of street trees in front of private residences.

Village of Glenview

Moderate Vulnerability

This developed suburban area has many trees that could be susceptible to projected changes in climate, but has a large adaptive capacity due to trained staff, a sufficient budget, and a supportive community that values urban trees.

Glenview is a suburban village located about 14 miles north of downtown Chicago in Cook County, IL. It is a mid-sized municipality of 50,692 people that is relatively affluent, with a median household income of $92,350.

Impacts—moderate-negative

Physical factors—moderate-negative

Some areas directly north of the Chicago River can become flooded occasionally, but it is not a severe issue. Soils in the area tend to be poorly drained, which could be helpful in retaining moisture as long as moisture is not excessive enough to cause uprooting. Wind storms are a major issue in the area, but not particularly severe compared to other areas in the region.

Biological factors—moderate-negative

It is estimated that roughly two-thirds of the trees in Glenview may have reduced habitat suitability, with the remaining having improved habitat suitability (Table 16). Pests and pathogens can be an issue in the area, and are expected to become more problematic in the future. Herbivory by deer can be an issue on the east and west sides of town, and could increase if winters are milder.

Table 16.—Number of tree species and the proportion of total trees inventoried in each vulnerability class for the City of Glenview, based on a 2012–2014 street tree inventory

Vulnerability class	Number of species	Percentage of trees
Low	27	18.1
Low-Moderate	31	37.9
Moderate	32	25.6
Moderate-High	10	8.2
High	14	2.2
Not rated[1]	54	8.1

[1] This category includes trees that were only identified to genus in the inventory and extremely uncommon species or cultivars.

Human factors—moderate-negative

The area is a developed, primarily residential area with a large amount of impervious cover and soil pollution from road salt and fertilizers. If runoff increases from increased heavy rain events, it could lead to more frequent street flooding and reduced rainfall infiltration. Runoff could concentrate pollutants in low-lying areas and streams.

Adaptive Capacity—high

Biological factors—moderate

The area has a relatively diverse mix of tree species, but there is an overemphasis on honeylocust and maples, which could be problematic if those species are affected by climate change. Many of the same species can be concentrated on a single block, which could also make some neighborhoods vulnerable to complete loss of canopy cover if those species are lost. This is an older suburb, and thus many of the trees are aging and susceptible to storm damage.

Residential area, Glenview. Photo by R. Flackne, Village of Glenview, used with permission.

Organizational/technical factors—high

The Village of Glenview has professional forestry staff overseeing the selection and care of its street trees. It also has a planting list, a long-term plan, a tree inventory, and a disaster response plan. Trees are routinely pruned, but do not receive additional maintenance between pruning cycles. The village does not have a risk assessment, however, and the long-term plan could be expanded to account for the impacts of climate change.

Economic factors—high

There is currently sufficient funding for the village to plant and maintain trees in the area. Private homeowners typically have sufficient economic means to care for their trees.

Social factors—high

The area has public support for planting and maintaining trees and a wide network of organizations for sharing ideas and resources. The village has not made use of volunteers for any planting or maintenance to date.

Fall foliage, Glencoe. Photo by T. McDonald, Glencoe Park District, used with permission.

PARK DISTRICTS

Glencoe Park District

Moderate-High Vulnerability

The area's large number of mature oak trees and proximity to Lake Michigan make it vulnerable to wind-related damage. Despite abundant funding and flexibility to plant a wide range of species, a lack of funding for maintenance of older trees reduces the adaptive capacity in the area.

Glencoe is an affluent residential village in Cook County, IL, located on the North Shore of Lake Michigan. It has a population of 8,723 and a median income of $161,976. It is bordered by natural areas to the north and west. The Glencoe Park District manages 24 parks and other facilities in the village, including a beach and sanctuaries for birds and wildflowers.

Impacts—moderate-negative

Physical factors—moderate
Soils in the Glencoe Park District tend to be well-drained, reducing flood susceptibility but also increasing susceptibility to late-season drying. Low-lying areas still are susceptible to flooding. The area's proximity to Lake Michigan increases exposure to heavy winds. Areas directly adjacent to the lake, though cooler than the surrounding area, also have experienced greater warming over the past century.

Biological factors—moderate-negative
Some conifers and sugar maple may be vulnerable to increases in temperature, but many other species common in the area are not expected to suffer direct negative effects from climate change (Table 17). Other organisms, such as insect pests, herbivores, and invasive plants, may benefit from milder winters and cause negative impacts to trees in the area's parks. Many of the trees are older and susceptible to storm damage.

Table 17.—Number of tree species and the proportion of total trees inventoried in each vulnerability class for the Glencoe Park District, based on a 2012 inventory of all park trees

Vulnerability class	Number of species	Percentage of trees
Low	15	10.5
Low-Moderate	19	38.3
Moderate	22	37.5
Moderate-High	8	4.8
High	7	2.2
Not rated[1]	20	6.6

[1] This category includes trees that were only identified to genus in the inventory and extremely uncommon species or cultivars.

Human factors—negative

The area is primarily residential and thus has a combination of pervious and impervious cover. There is not much of an urban heat island effect due in part to its proximity to Lake Michigan. A new threat is redevelopment, where older, smaller homes are replaced with larger new homes. This leads to direct disturbance to existing trees and loss of greenspace, decreasing infiltration into the soil and increasing runoff, which could become more problematic if heavy precipitation events increase.

Adaptive Capacity—low-moderate

Biological factors—moderate

The Glencoe Park District has made a concerted effort to enhance species diversity and genetic diversity by growing trees from seeds instead of buying clonal cultivars. However, about one-third of the trees in the park district are older oaks, which could increase vulnerability to some extent. In addition, many of the mature trees have not been pruned recently, increasing susceptibility to storm damage.

Organizational/technical factors—low-moderate

The park district has two certified arborists on staff who ensure a diversity of trees are planted and maintained. At this time, however, only the youngest trees are pruned. Glencoe has an inventory, but it has not been updated recently and has not been used to assess risks of natural disasters.

Economic factors—low-moderate

Glencoe has a sufficient budget for planting new trees, but not for maintenance.

Social factors—low

Residents in the area value trees, but there is not a strong network of organizations engaged in supporting the area's trees. No incentive programs are currently in place to encourage the planting and care of trees in the area.

Wheaton Park District

Moderate Vulnerability

Despite negative impacts of the interaction of climate change and stressors such as invasive species and development, the area has sufficient biological, organizational, economic, and social capacity to adapt.

The City of **Wheaton** is the county seat of DuPage County, IL. It is about 25 miles west of Chicago. It has a population of 52,894 and a median income of $86,124.

Lincoln Marsh, Wheaton Park District. Photo by R. Sperl, Wheaton Park District, used with permission.

The Wheaton Park District received the National Gold Medal Award for Excellence from the National Recreation and Park Association four times, most recently in 2005. It has 52 parks covering more than 800 acres, including the 135-acre Lincoln Marsh Natural Area, with over 300 species of prairie and wetland plants and animals.

Impacts—moderate-negative

Physical factors—moderate

Soils in the Wheaton Park District tend to be heavily compacted with high clay content. This creates poorly drained soils that can be susceptible to flooding. The likely increase in local flooding as a result of more heavy rain events is expected to have negative effects on the area. However, the high clay content could aid in moisture retention later in the growing season when conditions may become drier.

Biological factors—negative

The park district tends to have many tree species that are planted from southern latitudes and few trees from northern climates, which should benefit adaptation to warmer temperatures (Table 18). However, stressors such as insect pests, diseases, and invasive species are likely to continue to be a problem in the area. The area's ash trees are currently being affected by the emerald ash borer.

Table 18.—Number of tree species and the proportion of total trees inventoried in each vulnerability class for the Wheaton Park District, based on a 2014 inventory of all park trees

Vulnerability class	Number of species	Percentage of trees
Low	15	18.3
Low-Moderate	19	24.2
Moderate	11	29.6
Moderate-High	7	8.1
High	5	7.4
Not rated[1]	17	12.3

[1] This category includes trees that were only identified to genus in the inventory and extremely uncommon species or cultivars.

Human factors—negative

The Wheaton area has a large amount of green space and is far enough away from the urban core that the urban heat island effect and air pollution are not major issues. However, the area is heavily developed; redevelopment and existing roads have led to a large amount of impervious cover and soil and water pollution. Impervious cover can make the area more susceptible to flooding, which is projected to increase in the region from heavy precipitation events. Extreme precipitation could also transport pollutants to low-lying areas.

Adaptive Capacity—high

Biological factors—high

Wheaton parks have a wide diversity of species, with the exception of a high abundance of Norway maple. The parks have many native species from local seed sources, and the forests contain a diverse array of age classes. All these factors are anticipated to allow forests in the park district to withstand a wide range of climate-induced stressors.

Organizational/technical factors—high

The Wheaton Park District has trained foresters and horticulturists on staff and works to maintain and prune the trees in the area to reduce the risk of damage from storms. It has a list of preferred species and a long-term plan for planting that builds in flexibility to allow for adjustments. Wheaton parks do not currently have a comprehensive inventory, which limits the ability to assess risks, but one is underway.

Economic factors—moderate-high

The area is relatively affluent, so both the city and homeowners have adequate funding to plant and maintain trees in the area.

Lincoln Marsh, Wheaton Park District. Photo by R. Sperl, Wheaton Park District, used with permission.

Social factors—high

Wheaton has an actively engaged citizenry that cares a great deal about its parks and trees. The park district has an annual plant sale that is an extremely popular fundraiser, and local organizations such as scout troops have helped plant trees.

Chicago Park District

Low-Moderate Vulnerability

The Chicago Park District benefits from a large, trained staff and engaged public to facilitate the planting of a variety of trees. However, trees are not always maintained regularly enough, are exposed to the pollution associated with a heavily populated urban environment, and are sometimes vandalized.

Chicago is a densely populated city with 2,695,598 residents and a median income of $47,270. The Chicago Park District is the oldest park district in the United States. It has the largest budget of any U.S. park district, and among large U.S. municipalities, it spends the most per capita on its parks. The Chicago Park District oversees more than 580 parks with over 8,100 acres of municipal parkland as well as 24 beaches, 77 pools, 11 museums, 2 world-class conservatories, 16 historic lagoons, and 10 bird and wildlife gardens.

Impacts—moderate-negative

Physical factors—moderate-negative
Many parks in the area are susceptible to flooding due to flat terrain and lack of sewer access. Soils in the area have been heavily disturbed from development, so not much is known about their characteristics. Although adjacent Lake Michigan may provide some cooling, the extent of urban development in the city results in an overall heat island effect.

Biological factors—moderate-negative
Because of the harsh environment in the city, most of the trees in the area have been selected for their adaptation to a range of conditions, reducing their vulnerability to climate change. However, some trees at the north end of their range may be susceptible to severe winters, if extremely cold winters like those experienced in 2013–2014 become more common. Many of the trees in the area are more mature and susceptible to wind and winter storm damage.

Human factors—moderate-positive
Chicago parks offer a refuge from the urban heat island effect and tend to be slightly cooler than the surrounding areas. However, their location in the middle of the city increases their susceptibility to air pollutants, some of which can become more problematic during extremely hot periods.

Adaptive Capacity—moderate-high

Biological factors—moderate
Species and genetic diversity is somewhat lower because species selection is limited by the harsh urban environment. However, Chicago parks have a large number of trees and a mix of both young and mature individuals.

Organizational/technical factors—moderate-high
The Chicago Park District has an arborist on staff and a large crew of trained personnel. The district strives to plant a mix of species, following a city planting list. However, pruning and maintenance may not always be sufficient once trees are planted. The district could benefit from more in-depth long-term planning and risk assessments. It also lacks a comprehensive inventory.

Economic factors—moderate-high
Chicago has sufficient funding for planting and replacing trees, but does not always have resources for the maintenance of existing trees.

Social factors—moderate-high
The large and diverse population holds a wide range of attitudes toward trees. Many organizations are engaged in helping to plant and care for trees in the area. However, some trees are vandalized by the public as well.

Two municipal parks in Chicago: Indian Boundary Park (l) and Harrison Park. Photos by J. Scott, Chicago Park District, used with permission.

Spring ephemerals growing in the first season after canopy clearing in a Lake County forest preserve. Photo by M. Ueltzen, Lake County Forest Preserves, used with permission.

FOREST PRESERVE DISTRICTS

Southern Des Plaines River Preserves

within the Lake County Forest Preserve District

Moderate Vulnerability

The location of the preserves along the Des Plaines River floodplain coupled with altered hydrology from drainage tile may make them vulnerable to heavy rain events. Nonetheless, the preserves have sufficient technical, economic, and social capacity to restore the area and conserve native vegetation.

The **Lake County Forest Preserve District** manages and protects more than 30,100 acres and is the second largest forest preserve district in Illinois. Oak woodlands define the unique natural and historic landscape of Lake County, and efforts are underway to actively restore oak ecosystems in preserves. Several preserves located along the southern Des Plaines River, including MacArthur Woods, Grainger Woods, Captain Daniel Wright Woods, and Ryerson Conservation Area, are currently being targeted for restoration efforts.

Impacts—moderate-negative

Physical factors—negative

Portions of the preserves are located in the Des Plaines River floodplain, and additional low-lying areas could be susceptible to flooding if heavy rains increase. This is further exacerbated by the fact that many soils in the area are poorly drained. Wetter winters and springs could also reduce the window for prescribed burning, which is used in oak restoration projects in the area.

Biological factors—moderate-negative

The preserves have a large number of oaks that are in the center of their range, so they are not expected to be very positively or negatively affected by direct changes in temperature or precipitation. However, climate conditions could be more favorable for diseases that attack oaks, such as oak wilt and bur oak blight, and could also be more favorable for species such as European buckthorn that shade out oak seedlings in the understory. In more mesic areas, maples are more common, some of which could be vulnerable to potential dry periods later in the growing season or higher temperatures.

Human factors—negative
The area is largely forested with little impervious cover and low-density housing surrounding the preserve. But parts of the area have drain tiles remaining from former agricultural use, which exacerbates precipitation-induced changes in hydrology. Stormwater runoff from local residential areas could also concentrate in the preserves.

Adaptive Capacity—moderate

Biological factors—low-moderate
The preserves tend to have low species and age-class diversity; they are dominated by older oak trees. However, these trees are native, naturally regenerating populations that are adapted to local conditions and are likely to have high genetic diversity.

Organizational and technical factors—moderate
The preserves have a management plan and a trained natural resources operations staff to carry it out. If new trees are planted, a diverse mix of native seed is used.

Economic factors—moderate-high
Adequate funding is currently available to carry out management of natural areas and plant trees as needed.

Social factors—high
Several conservation groups are heavily engaged and willing to assist the preserves in achieving management goals. There is a strong volunteer base and residents in the area value the preserves.

Freeman Kame Forest Preserve

within the Kane County Forest Preserve District

Moderate Vulnerability

The preserves have a diverse mix of native species at the center of their range. However, they may be vulnerable to increased insect attack and invasive species competition in a changing climate due to lack of resources to manage these stressors.

The **Freeman Kame Forest Preserve** is located on the northern edge of a kettle-moraine complex north of Gilberts, IL in north-central Kane County. It is named after the wooded glacial hills that can be found there. It is considered a high-risk natural area.

Impacts—moderate-negative

Physical factors—moderate-negative
The forest preserve has extremely well-drained soil with a high gravel content, which decreases its susceptibility to flooding. This soil condition makes it more susceptible to drying due to projected reductions in precipitation later in the growing season. The area's topography also makes it susceptible to windthrow. More frequent fires could be beneficial to oaks in the area.

Biological factors—moderate-negative
Most of the dominant trees in the area are at the center of their distribution range, and are not expected to be directly affected by changes in temperature or precipitation. However, milder winters could increase damage from insect pests and herbivores and competition from invasive species such as European buckthorn. Another concern is that earlier springs could lead to asynchrony between pollinator arrival and flowering, reducing seed production and thus reducing natural regeneration.

Human factors—negative
The area is primarily rural and thus not susceptible to the urban heat island effect and urban pollution. However, the preserve already receives a large quantity of agricultural runoff, and more heavy precipitation events could exacerbate this further. If the late growing season becomes drier or droughts increase as some models project, groundwater demands could increase, decreasing baseflow in area streams.

Freeman Kame-Meagher Forest Preserve. Photo by K.A. Miller, Kane County Development Department, used with permission.

Adaptive Capacity—moderate-high

Biological factors—moderate
Although the preserve is dominated by oak and hickory species, other species are also common. A large diversity of age classes is represented, and reforestation centers on local seed sources.

Organizational and technical factors—moderate
The preserve has a long-term vision and a trained staff of trained forestry professionals to carry it out. If new trees are planted, a diverse mix of native seed is used. The preserve does not have a comprehensive inventory, however.

Economic factors—moderate
There is currently sufficient funding for reforestation efforts from the district, but insufficient funding to carry out management of existing forests, such as buckthorn removal.

Social factors—moderate-high
The Kane County forest preserves are engaged with other collar counties in the Chicago area to share resources and expertise. Not enough volunteers are currently available in the area to help with management, such as invasive species removal.

Swallow Cliff Preserve
within the Forest Preserves of Cook County

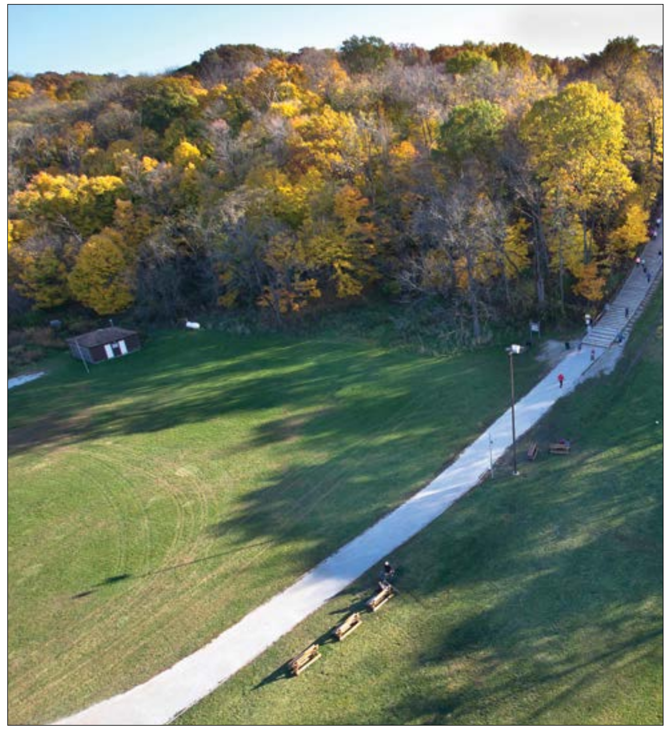
Moderate-High Vulnerability

The preserve is dominated by older oak trees that are susceptible to wind damage because of elevated topography. Lack of funding for management and replanting has reduced regeneration in the understory, increasing vulnerability.

The **Forest Preserves of Cook County** encompass about 68,000 acres of open space around Chicago and its surrounding suburbs. Swallow Cliff Preserve is located in Palos Park, IL and features a 100-foot-high bluff that formed 12,000 years ago when glacial meltwater carved out the Sag Valley Steep walls and a varied landscape of morainal hills and pothole lakes were left behind. The area includes woodlands, prairies, wet marshes, and sedge meadows.

Impacts—moderate-negative

Physical factors—moderate
The area is not in a floodplain and has well-drained soils; thus, it is not susceptible to flooding. The hilly topography of the preserve increases its susceptibility to windthrow and soil erosion during heavy storm events, however.



Near the falls at Swallow Cliff Preserve. Photo by J. Occhiuzzo, Joe Occhiuzzo Photography, used with permission.

Biological factors—moderate-negative
Most of the dominant trees in the area are at the center of their distribution range, and are not expected to be directly affected by changes in temperature or precipitation. But milder winters could increase damage from insect pests and deer herbivory and competition from invasive species such as European buckthorn. Another concern is that earlier springs could lead to asynchrony between pollinator arrival and flowering, reducing seed production and thus reducing natural regeneration.

Human factors—moderate
Although the Preserve is located in Cook County, a highly urban area, it has a large acreage around it that buffers it from the urban heat island effect and pollution. The preserve is largely upslope from the surrounding area, so it does not receive runoff.

Adaptive Capacity—low-moderate

Biological factors—low
The preserve is dominated by oak and hickory species. The trees are primarily older, and little regeneration has happened in the understory. These mature trees are more susceptible to breakage and tip-ups during heavy storms, and have already been damaged by recent storms. The location in a fragmented urban area means that there is little opportunity for migration or genetic exchange.

Organizational and technical factors—moderate
The preserve has ecologists and arborists on staff. They have a set of best management practices and a species list to help guide them, as well as a long-term plan. However, the preserve does not have a comprehensive inventory or a disaster response plan in place.

Economic factors—low
There is currently insufficient funding for planting new trees or for management of the existing forest.

Social factors—low-moderate
The people in the area do not appear to place a high value on public trees and there is an insufficient volunteer base to assist with management. But some restoration volunteers do provide assistance.

Case Study Outcomes

Participants indicated in written evaluations that the workshop presentations and worksheet exercise improved knowledge on climate change impacts and vulnerability in the places they worked. They reported the greatest knowledge gains in their understanding of the adaptive capacity of their systems. They also reported that they had increased their ability to identify those climate change impacts that are most relevant to the places they manage. They self-reported that they already had considerable knowledge about climate change going into the workshop; thus, gains in knowledge for these participants may not be as great as for groups with less prior knowledge.

We asked these professionals to identify the factors that they perceived would contribute most strongly to their ratings of impacts and adaptive capacity for their respective municipality, park district, or forest preserve. Key physical considerations were generally related to potential impacts from intense precipitation and extreme storm events; areas susceptible to these impacts were perceived as being at greater risk. These included areas with very poorly drained soils, floodplains, and areas susceptible to flooding due to infrastructure. Areas with high susceptibility to wind events were also considered to have negative impacts due to dominance of a wind-susceptible species, older trees, or topography. Key biological considerations pertained to shifts in habitat suitability for trees and the organisms that influence them, such as insects, pathogens, and invasive species. Key human-related considerations centered on how impervious cover could exacerbate issues associated with increased heavy precipitation events and how higher temperatures could potentially make ozone pollution more severe.

Riparian area in Riverside after removal of European buckthorn. Photo by M.G. Collins, Village of Riverside, used with permission.

The factors identified as most important for the adaptive capacity of ecosystems differed notably between natural areas and more developed areas. Urban forestry professionals from all areas emphasized funding and trained staff, and many identified the lack of funding for maintenance or management of their forests as a negative contributor to adaptive capacity. In contrast, representatives from forest preserve districts identified biological considerations, such as genetic and biological diversity, as more important contributors to overall adaptive capacity. Participants from park districts and municipalities placed a greater emphasis on social and organizational factors, such as planting lists and ordinances, the value residents place on trees, and the participation of volunteers.

We also asked the professionals to add factors to the worksheet if they thought they were important. Additional physical impact factors identified were more frequent and severe fires in natural areas, susceptibility to erosion, and susceptibility to extreme cold events. Participants from forest preserve districts identified an asynchrony between plants and pollinators as another key biological impact factor. Additional human impact factors identified were population growth and development, more groundwater withdrawal during hot/

Baldcypress planted as part of reforestation efforts in Riverside. Photo by M.G. Collins, Village of Riverside, used with permission.

dry periods, and the potential for stress from road salt to exacerbate climate stress.

A few additional adaptive capacity factors were identified. Several participants added education as a key adaptive capacity factor, stating that educational programs on the planting and maintenance of trees would enhance residents' capacity to adapt to a changing climate. Capacity to allow for wider planting spaces on parkways was another factor identified.

Participants differed between natural areas and developed areas in which factors they thought were less important in contributing to vulnerability. In developed areas, participants did not think that the following factors listed in the worksheet would contribute strongly to overall impacts: changes in herbivore damage, shifts in winter freeze-thaw cycles, and changes in invasive plant species. Representatives of forest preserve districts listed the urban heat island effect, impervious cover, and pollution as being less important contributors.

Overall, levels of confidence tended toward a "medium" ranking for most factors. Impact factors that tended to have a high confidence level were susceptibility to severe storms and flooding, and increased temperatures. There was also high confidence that high species diversity would enhance adaptive capacity. Municipalities had high confidence in their organizational and technical capacity as a whole. There was high confidence that funding contributed significantly to adaptive capacity, but uncertainty was also expressed about future funding.

There were several areas of uncertainty where participants would have liked more information. Although participants acknowledged the importance of shifts in habitat suitability of trees in the area, the overall confidence was low in this factor because of two issues. First, many places lacked a comprehensive inventory or the inventory was outdated. Without knowing what trees are present in the first place, it is hard to discern the proportion that may be vulnerable to climate change. Second, participants lacked confidence in some of the model results, especially when the results did not line up with expectations. For example, several oak species were in the center of their range in the Chicago area, yet were projected to decline in habitat suitability.

Another area of low confidence was projected changes in pests and diseases. There is currently very little information on how insect pests and diseases may change in a changing climate. Many participants made the assumption that the overall effect of climate change would be to increase these stressors, but currently only a limited amount of research is available to support these assumptions. In particular, participants were interested in how climate change may affect the many diseases and pests that afflict oaks, such as bur oak blight, oak wilt, and gypsy moth.

Although we selected a range of communities from across the Chicago Wilderness region, implications for the region as a whole should be considered with caution. The fact that these groups chose to participate in the workshop indicates an interest and engagement on climate change that may not be representative of other communities. Some communities that did not participate may be more vulnerable to climate change due to lower organizational adaptive capacity. Other communities may have chosen not to participate because they felt they already had a considerable understanding of local climate change impacts, and because of this greater organizational adaptive capacity could be less vulnerable.

Chicago Region Trees Initiative urban forestry basic training. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

Summary

Urban forestry professionals in the Chicago Wilderness region representing several municipalities, park districts, and forest preserve districts used a common tool to assess the vulnerability of their forests to climate change. The professionals generally rated the impacts of climate change on the places they managed as moderately negative, mostly driven by the effects that extreme storms and heavy precipitation events could have on trees in the area. The capacity of forests to adapt to climate change ranged widely based on several economic, social, and organizational factors, as well as the species and genetic diversity of trees in the area. The assessment process and resultant case studies may be used by other communities in the Chicago Wilderness region or elsewhere to understand how specific urban forests may be vulnerable to climate change.

Key Points

- We developed a process for municipalities, park districts, and forest preserve districts to assess their vulnerability to climate change based on impacts and adaptive capacity.
- Ten case studies were developed in the Chicago Wilderness region using this approach.
- Most of the variation in vulnerability among case studies was in adaptive capacity, driven by differences in biological, organizational, economic, and social factors among communities.

CHAPTER 5

MANAGEMENT CONSIDERATIONS

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 selection of species for planting, management of existing trees, and public engagement. This chapter provides an overview of climate change impacts on decisionmaking, management practices, and other issues related to urban and community forestry in the Chicago Wilderness region. This chapter does not make recommendations as to how management should be adjusted to account for these changes. A separate document, Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd edition (Swanston et al. 2016), has been developed to assist forest managers in a decisionmaking process to adapt their land management to projected impacts.

Management implications are summarized by theme, which were selected to encompass a range of issues that urban foresters face. These themes, and their descriptions, are by no means comprehensive, but provide a springboard for thinking about management implications of climate change. The More Information sections provide links to key resources for urban forestry professionals about the impacts of climate change on that theme.

Wildlife

Wildlife habitat is among the many benefits urban trees and natural communities provide that could be altered by a changing climate. Urban forests in the Chicago Wilderness region support a wide variety of wildlife species, including invertebrates, birds, and mammals (Chicago Wilderness 1999). The Chicago Wilderness region is a critical stopover area for more than 140 migratory species of songbirds that have just crossed the extensive agricultural areas of Indiana and Illinois (D. Stotz, the Field Museum, pers. comm., 2015). Most of these species rely on tree-dwelling insects for food to refuel before heading farther north to their breeding grounds. Climate change is expected to affect the phenological patterns of trees, including the timing of spring leaf out, flowering, fruiting, and leaf drop in the fall (Groffman et al. 2014). Shifts in the availability of resources will certainly affect wildlife, but the degree to which different species are affected will vary depending on their life history traits and level of specialization.

Phenological changes throughout the Midwest are already underway (Groffman et al. 2014). For example, extreme early and sustained warm-ups have occurred several times in the last two decades in the upper Midwest. A record warm March across most of North America in spring 2012 resulted in oak trees leafing out and oak-dependent insects emerging almost a month early near Chicago (Ellwood et al. 2013). In contrast, Neotropical migratory warblers that rely heavily on the insect flush that accompanies leaf out arrived only a week early because they time migration primarily in response to changes in day length instead of changing temperature. This mismatch of phenology between the trees, insects, and birds resulted in a decoupling of food availability and arrival time for the warblers (D. Stotz, pers. comm., 2015). Similar results were found in the warm springs of 2003 near Champaign, IL (Strode 2009, 2015) and 2010 in southwestern Wisconsin (Wood and Pidgeon 2015a, 2015b). These studies documented increased leaf damage to canopy trees and decreased foraging rate in migratory birds in these years with a strong asynchrony between leaf out and the peak of migration.

Climate change is already rearranging the geography of biological communities (Groffman et al. 2014). Some wildlife species will be able to track these changes and keep up with the movement of their "climate envelope." Others will be limited in their dispersal ability and unable to do so. Even for species able to keep pace with a changing environment, it may be challenging for them to find appropriate habitats due to development. It is possible the ranges of long-lived trees will shift more slowly in response to changes in temperature, precipitation patterns, and other habitat features, compared to the ranges of wildlife dependent upon them. This mismatch in movement capability could result in a lag time between the range shifts of trees and wildlife, limiting the ability of wildlife, especially host-specific species, to adapt to a changing climate (Pelini et al. 2009).

More Information

- The Climate Change Atlas documents the current and possible future distribution of 147 bird species in the eastern United States and gives detailed information on environmental characteristics defining these distributions: *www.fs.fed.us/nrs/atlas/*
- Changing Landscapes in the Chicago Wilderness Region: a Climate Change Update to the Biodiversity Recovery Plan summarizes the implications of climate change to natural areas in the Chicago Wilderness region along with some considerations for management: *http://climatechicagowilderness.org/index.php?title=Main_Page*
- Audubon's Birds and Climate Change Report presents the climate conditions birds need to survive, then maps where those conditions will be found in the future as the Earth's climate responds to increased greenhouse gases: *climate.audubon.org/*
- The Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services: Technical Input to the 2013 National Climate Assessment details current and expected climate impacts to species and systems: *nca2014.globalchange.gov/report/sectors/ecosystems*

Natural Areas

Climate change will have important implications for management of natural areas in the Chicago Wilderness region. Warmer temperatures and longer growing seasons are likely to benefit many nonnative invasive species, making the management of invasive species and the need to be on the lookout for new nonnative invasive species an increasing challenge. Prescribed fire is often used as a management tool to control invasive species and create growing conditions more suitable to oaks and other shade-intolerant native species in grasslands, savannas, and woodlands. The number of days in which prescribed burning is possible could potentially be reduced or shifted to other seasons in the future. Drier conditions in the summer and fall could increase the difficulty of controlling a prescribed burn. Warmer, wetter springs could make it more difficult to carry a fire due to saturated vegetation. Thus, the timing of burn windows may need to be adjusted to later in the fall, earlier in the spring, or during winter months (Chicago Wilderness 2012).

Restoring oak ecosystems is a key area of focus for many forested natural areas in the Chicago Wilderness region (Fahey et al. 2015). These systems tend to have greater species diversity than the maple- and European-buckthorn-dominated systems that have replaced them. Changes in habitat suitability for many oak species along with climate change-induced changes in pests and diseases could make it more challenging to restore oak-dominated ecosystems (see Chapter 3). Managers of natural areas may choose to focus on specific species already present, consider introducing new species, or undertake additional strategies to reduce the risk of pests and diseases.

More Information

- The Chicago Wilderness Biodiversity Recovery Plan: Climate Change Update summarizes the implications of climate change to natural areas in the Chicago Wilderness region along with some considerations for management: *climate.chicagowilderness.org/*
- Climate change considerations for management of natural areas and green spaces in the City of Chicago focus on adaptation, with the aim of helping resource managers in the Chicago Wilderness region jump-start the process of updating approaches to management to better incorporate these considerations—and reduce the rate of climate change: *glslcities.org/library/climate-considerations-for-management-of-natural-areas-and-green-spaces-in-the-city-of-chicago/*

Street Trees

Selection, planting, and maintenance of street trees may be affected by changes in climate. Municipal foresters currently rate tolerance of site conditions and maintaining species diversity as the two most important considerations for species selection (see Chapter 1). These considerations are often taken into account in developing planting lists, which guide species selection. However, planting lists are typically based on current climate and available nursery stock (see Nursery Industry section) and do not take future conditions into account. If these lists are not adjusted to account for future conditions, municipal foresters could observe more tree failure and a reduction in street tree diversity. In addition, municipalities that lack diversity of species or age classes may be more vulnerable to climate-related stressors such as pest and disease outbreaks.

Arbor Day activities, Joliet, IL. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

Climate change may also pose new challenges for planting and maintenance. Extremely wet springs followed by dry falls could make it difficult for newly planted street trees to get established. The timing of planting may need to be adjusted to ensure trees have the best chance of survival. An increase in extreme weather events could increase the amount of time and resources spent removing damaged trees and limbs and replacing those that are lost. Additional pruning may be required to help reduce the risk of loss and damage from these events. Increases in insect and disease outbreaks could also increase the amount of resources required to treat and remove diseased trees. Obtaining new species that are adapted to future conditions from nurseries may be difficult if nurseries are not engaged in the effort.

More Information

- The Trees for 2050 Urban Forest Adaptive Planting List includes considerations for future climate change based on habitat suitability modeling: *www.chicagobotanic.org/plantinfo/tree_alternatives*
- Growing Greener: Eco-Structure for Climate Resilience offers a guide to help local governments, organizations, and others to develop tools for their own communities, while also learning about the ways in which green infrastructure can provide natural protection from the impacts of climate change: *www.nwf.org/What-We-Do/Energy-and-Climate/Climate-Smart-Conservation/Climate-Smart-Communities/NWF-Programs/King-County/Forestry-CPR-Guidebook.aspx*

Municipal Parks

Municipal parks can range from highly developed to relatively natural areas. These parks provide active and passive recreational opportunities for residents while also serving an important role in mitigating the urban heat island effect. Many of the climate change considerations for management of natural areas and street trees also apply to municipal parks. However, the role of parks as areas for community recreation means that some additional considerations may need to be made. Warmer springs and falls are likely to improve conditions for outdoor recreation activities during those seasons (Nicholls 2012). But shifts in precipitation could also have negative impacts on spring and fall recreation activities. Increased spring precipitation could increase risks for flash flooding or simply lead to unpleasant conditions for recreation. During hot summer months, residents may take advantage of municipal parks if they offer respite from the sweltering heat via shade and water features. As park use shifts in response to a changing climate, so too may decisions about the planting of trees and other vegetation in parks.

Some municipal parks may play an important role in stormwater management through retention and detention basins. If storm frequency and severity increases, these basins may no longer be sufficient to absorb all the increased runoff. Park managers may need to reevaluate their capacity and additional investments may need to be made to handle the increase in storms.

More Information

- U.S. National Climate Assessment Midwest Technical Input Report: Outdoor Recreation and Tourism (Nicholls 2012) discusses implications of climate change for recreation and tourism: *glisa.umich.edu/media/files/NCA/MTIT_RecTourism.pdf*
- How Cities Use Parks for Climate Change Management is a briefing paper that discusses the benefits city parks provide in reducing the heat island effect and storing carbon: *www.planning.org/cityparks/briefingpapers/climatechange.htm*

Private Properties

Medium-to-large private properties such as commercial and industrial tracts and corporate or college campuses as well as golf courses and cemeteries will also experience stress from a changing climate. In addition to changes in habitat suitability for trees and other plants, some of these places may have incorporated green roofs or rain gardens that may also be affected. A few of the larger properties may have trained forestry professionals or horticulturists on staff with the skills to adapt to anticipated changes, but many may need outside assistance.

Private homeowners face many of these same challenges, but often lack the specialized knowledge and skills to manage trees on their property in light of a changing climate. If temperatures increase, private homeowners may place greater value on their trees to provide cooling and shade and reduce energy costs. They may need additional assistance in species selection to ensure they plant a species that will tolerate future climate conditions given their specific site requirements. Additional training may be needed to ensure homeowners provide sufficient water to their trees during dry periods and that trees are planted properly.

More Information

- The Climate-Friendly Gardener: a Guide to Combating Global Warming from the Ground Up explains the science linking soil, plants, and climate change; it provides practical tips for a more climate-friendly garden, and links to resources that will help gardeners adapt these tips to their own needs: *www.ucsusa.org/sites/default/files/legacy/assets/documents/food_and_agriculture/climate-friendly-gardener.pdf*
- The Morton Arboretum Plant Advice Web site offers gardeners, landscapers, and green industry professionals a wide array of help, information, and inspiration: *www.mortonarb.org/trees-plants/tree-and-plant-advice*

Green Infrastructure

Green infrastructure is an interconnected network of greenspace that conserves natural ecosystem values and functions and provides associated benefits to human populations. Green infrastructure can range in scale from site design approaches such as rain gardens and green roofs to regional planning approaches such as conservation of large tracts of open land (U.S. Environmental Protection Agency 2015a). If the trend of rising temperatures and more-frequent storms continues, the importance of green infrastructure at the site scale may be heightened as a tool to reduce the urban heat island effect and control stormwater (Gaffin et al. 2012, Gill et al. 2007). A larger regionally connected network of green infrastructure could also be important for facilitating natural migrations of wildlife to newly suitable habitat.

More Information

- Green infrastructure at the regional scale is described by the Chicago Wilderness Green Infrastructure Vision (GIV). Developed through a collaborative and consensus-based process, the GIV consists of spatial data and policies describing the most important areas to protect in the region. The GIV was originally adopted by Chicago Wilderness in 2004 and has been refined over many years with the help of The Conservation Fund: *www.cmap.illinois.gov/livability/sustainability/open-space/green-infrastructure-vision*
- The Value of Green Infrastructure for Urban Climate Adaptation provides information on the costs and benefits of green infrastructure solutions for bolstering local adaptation to climate change: *ccap.org/resource/the-value-of-green-infrastructure-for-urban-climate-adaptation/*

Glencoe Park District nursery. Photo by T. McDonald, Glencoe Park District, used with permission.

- Retrofitting Large Landscapes for Sustainability was developed to assist homeowner associations and corporate, commercial, and other large private property owners in establishing and maintaining green infrastructure: *www.mortonarb.org/trees-plants/community-trees-program/community-tree-resources/sustainable-large-landscapes*

Nursery Industry

As habitat suitability changes for tree species, managers of natural areas, street trees, and parks as well as private property owners may wish to select species that will be more likely to do well under future conditions. However, species selection will ultimately be limited by the nursery stock available. Many small local nurseries rely on large wholesalers for their supply. These wholesalers can be located in different parts of the United States and may not be familiar with local needs. If the proper economic incentives are not in place to encourage the production of new species or cultivars, nursery growers may not be able to provide them. In addition, the lack of certainty among models and the financial risks associated with expanding species diversity for a changing climate make it difficult for the nursery industry to know the climate conditions for which to develop new cultivars and what markets to target for existing stock based on future climate conditions. In light of those considerations, many nursery growers are working to develop cultivars that are adapted to a wide range of climate conditions.

More Information

- Changing Climates … Changing Tree Species contains a list of trees developed by J. Frank Schmidt & Son Co. that are tailored to meet today's sustainability goals: *www.jfschmidt.com/pdfs/JFS-MN-Short-Course-2015.pdf*

Planning and Partnerships

Climate change will remain an important consideration in planning activities for urban forestry. Many municipal foresters and other urban forest managers are recognizing the benefits of developing management plans to guide the future direction of the urban forests they manage. Currently, many municipalities lack these plans, and the ones that do often lack any specific considerations for climate change. In addition, many municipalities and metropolitan regions are beginning to develop climate action plans, of which the urban forest is a component. Many recognize the importance of the urban forest for its myriad benefits and services and believe it to be critical as a strategy, but fewer consider how the management and species selection of the urban forest may also need to be adjusted.

Municipalities often have limited staff and budget resources. Thus, many cities rely on partnerships with other organizations to manage their urban forests. In some areas, citizens participate on tree boards or other related advisory committees to help guide decisions about the urban forest. In others, partnerships promote innovative greening strategies that complement or augment existing programs (Connolly et al. 2013, Mincey and Fischer 2013). As climate change places more strain on already limited resources, these partnerships may become even more important.

Some communities rely on volunteers to assist with the planting and care of trees in cities and parks or in restoration efforts in natural areas. As extreme weather events and other stressors increase the need for planting new trees and maintenance of existing trees, the importance of using volunteers may increase. Volunteer-based urban forest initiatives may complement efforts by local governments to adapt to a changing climate (Westphal 1994, 2003).

More Information

- Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd edition, is a tool that can assist in incorporating climate change considerations into planning: *www.nrs.fs.fed.us/pubs/52760*
- The Chicago Climate Action Plan details steps for organizations of all kinds and suggests actions for every individual for greenhouse gas mitigation and adaptation: *www.chicagoclimateaction.org/*
- Climate Adaptation Guidebook for Municipalities in the Chicago Region is a resource for communities interested in adapting their planning and investment decisions to a changing climate: *www.cmap.illinois.gov/livability/sustainability/climate-adaptation-toolkit*
- Cities, Climate Change and Multilevel Governance presents a framework for multilevel governance. This framework entails integration across all levels of government and relevant stakeholders from local action plans to national policy frameworks (vertical integration), and cross-scale learning between relevant departments or institutions in local and regional governments (horizontal dimension): *www.oecd.org/governance/regional-policy/44232263.pdf*
- The Chicago Community Climate Action toolkit helps residents to learn about how climate change is affecting the Chicago region and to explore a place-based approach to climate change and models for community-led climate action. It suggests what residents can do to help design and carry out community-led climate action projects that at the same time improve local quality of life: *www.climatechicago.fieldmuseum.org/*

Summary

Changes in climate and impacts on the urban forest in the Chicago Wilderness area can have important implications for management. The management of natural areas, street trees, and landscaped parks may become more challenging due to more-severe storms and changes in habitat suitability for dominant trees. Greater financial investments may be required in the short term to maintain the urban forest so it can continue to provide benefits to the community, such as clean air, reduced heat island effects, and stormwater management, in the long term. At the same time, confronting the challenge of climate change also presents opportunities for managers and other decisionmakers to protect their investments by planning ahead, building resilient landscapes, expanding their volunteer base, and engaging with their communities to adapt to future change.

Algonquin (IL) Public Works nursery. Photo by E. Johnson, Erika Hildegard Photography, used with permission.

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GLOSSARY

adaptive capacity
the general ability of institutions, systems, and individuals to moderate the risks of climate change, or to realize benefits, through changes in their characteristics or behavior. Adaptive capacity can be an inherent property or it could have been developed as a result of previous policy, planning, or design decisions.

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.

barrens
plant communities characterized by widely spaced trees (no greater than 50 percent woody cover) and a codominant understory of grasses and other prairie plants.

basal area
the cross-sectional area of all stems of a species or all stems in a stand measured at 4.5 feet above the ground and expressed per unit of land area.

carbon dioxide (CO_2) fertilization
increased plant uptake of CO_2 through photosynthesis in response to higher concentrations of atmospheric CO_2 (Norby et al. 2005).

Chicago Wilderness
a regional alliance of more than 200 different organizations that work together to improve the quality of life of the humans and the many other species living in the Chicago area.

climate change
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. Climate change may be due to natural internal processes or external factors, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

climate model
see **general circulation model**.

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

collar county
one of the five Illinois counties that border Cook County, where Chicago is located: DuPage, Kane, Lake, McHenry, and Will.

derecho
widespread and long-lived convective wind storm 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.

detention basin
a basin whose outlet has been designed to detain stormwater runoff for some minimum time (e.g., 24 hours) to allow particles and associated pollutants to settle.

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 climate models; involves examining the statistical relationship between past climate data and on-the-ground measurements.

drought
a long period of abnormally low rainfall, especially one that adversely affects growing or living conditions.

dune
a mound or ridge of sand or other loose sediment formed by the wind.

ecological province
climatic subzones, controlled primarily by continental weather patterns such as length of dry season and duration of cold temperatures. Provinces are also characterized by similar soil orders and are evident as extensive areas of similar potential natural vegetation.

ecosystem
a system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

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.

ensemble average
the average value of a large number of output values from a climate model; a way to address some of the uncertainties in the system.

esker
a long, winding ridge of stratified sand and gravel created by glaciers.

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

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.

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)
numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions, and their feedback processes, and accounting for all or some of its known properties (also called **climate model**).

green infrastructure
an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations.

growing season
the period in each year when the temperature is favorable for plant growth.

hardiness zone
a geographically defined area in which a specific category of plant life is capable of growing, defined by the average annual winter minimum temperature.

heat zone
a geographically defined area in which a specific category of plant life is capable of growing, defined by the number of days above 86 degrees Fahrenheit.

impact
the direct and indirect consequences of climate change on systems, particularly those that would occur without adaptation.

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).

intensity
amount of precipitation falling per unit of time.

invasive species
any species that is nonnative (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause damage, injury, or disruption to ecosystem processes or other species within that ecosystem.

kame
an irregularly shaped hill or mound composed of sand, gravel, and till that accumulate in a depression on a retreating glacier, and are then deposited on the land surface with further melting of the glacier.

lake effect
the effect of any lake, especially the Great Lakes, in modifying the weather and climate in nearby areas.

mesic
referring to sites or habitats characterized by intermediate (moist, but neither wet nor dry) soil moisture conditions.

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 (Iverson et al. 2008).

modifying factor
environmental variables (i.e., site conditions, interspecies competition, disturbance, dispersal ability) that influence the way a tree may respond to climate change.

moraine
any glacially formed accumulation of unconsolidated glacial debris (soil and rock) that occurs in currently glaciated and formerly glaciated regions on Earth (i.e., a past glacial maximum), through geomorphological processes.

natural community
an assemblage of native plants and animals that tend to recur over space and time and that interact with each other and their physical environment in ways minimally modified by exotic species and negative human disturbances.

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 study of 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.

prairies
natural communities dominated by perennial grasses and forbs with scattered shrubs and very few trees (less than 10 percent canopy cover).

process model
a model that relies on computer simulations based on mathematical representations of physical and biological processes that interact over space and time.

productivity
the rate at which biomass is produced per unit area by any class of organisms, or the rate of energy utilization by organisms.

projection
a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, and are therefore subject to substantial uncertainty.

radiative forcing
the change in net irradiance between different layers of the atmosphere. A positive forcing (more incoming energy) tends to warm the system, whereas a negative forcing (more outgoing energy) tends to cool it. Causes include changes in solar radiation or concentrations of radiatively active gases and aerosols.

realized niche
the portion of potential habitat a species occupies; usually it is less than what is available because of predation, disease, and competition with other species.

refugia
locations and habitats that support populations of organisms that are limited to small fragments of their previous geographic range.

retention basin
an impoundment created by a dam or an excavation for the purpose of storing water and settling sediment and other pollutants from surface runoff. A retention basin is designed to hold a specific amount of water until the water can evaporate or infiltrate.

runoff
that part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions or storage.

savanna
fire-maintained grasslands with open-grown, scattered, orchard-like trees or groupings of trees and shrubs.

scenario
a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline (see also emissions scenario).

significant trends
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.

snow water equivalent
the amount of water contained in snowpack. It is a way of measuring the amount of snow while accounting for differences in density.

snowpack
layers of accumulated snow that usually melts during warmer months.

species distribution model
a model that uses statistical relationships to project future change.

spring
a continual or intermittent natural flow of water from the ground following a rather well-defined channel.

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.

streamflow
discharge that occurs in a natural surface stream course whether or not it is diverted or regulated.

stressor
an agent, condition, change in condition, or other stimulus that causes stress to an organism.

suitable habitat
in the context of the Climate Change Tree Atlas (a species distribution model), the area-weighted importance value, or the product of tree species abundance and the number of cells with projected occupancy.

uncertainty
an expression of the degree to which a value (such as the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can be described by using quantitative measures or by qualitative statements.

urban forest
all publicly and privately owned trees within an urban area—including individual trees along streets and in backyards, as well as stands of remnant forest.

urban heat island effect
phenomenon where a city or metropolitan area is significantly warmer than its surrounding rural areas due to human activities.

vulnerability
The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the impacts and adaptive capacity of a system.

weather
the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity, and barometric pressure.

wind shear
the rate at which wind velocity changes from point to point in a given direction.

woodland
highly variable natural communities with a canopy of trees ranging from 30- to 100-percent openness, a sparse understory, and a dense ground flora rich in grasses, sedges, and forbs.

xeric
pertaining to sites or habitats characterized by decidedly dry conditions.

APPENDIX I
SPECIES LISTS

FLORA

Common name	Scientific name
Accolade® elm	*Ulmus japonica x wilsonia 'Morton'*
'Accolade' flowering cherry	*Prunus 'Accolade'*
Allegheny serviceberry	*Amelanchier laevis*
American basswood (American linden)	*Tilia americana*
American beech	*Fagus grandifolia*
American elm	*Ulmus americana*
American hornbeam	*Carpinus caroliniana*
American plum	*Prunus americana*
American smoketree	*Cotinus obovatus*
American sycamore	*Platanus occidentalis*
American witchhazel	*Hamamelis virginiana*
Amur cherry	*Prunus maackii*
Amur corktree	*Phellodendron amurense*
Amur honeysuckle	*Lonicera maackii*
Amur maackia	*Maackia amurensis*
Amur maple	*Acer ginnala*
apple serviceberry	*Amelanchier x grandifolia*
apple/crabapple species	*Malus* spp.
aspen species	*Populus* spp.
Austrian pine	*Pinus nigra*
'Autumn Gold' gingko	*Ginkgo biloba 'Autumn Gold'*
autumn-olive	*Elaeagnus umbellata*
baldcypress	*Taxodium distichum*
balsam fir	*Abies balsamea*
bigtooth aspen	*Populus grandidentata*
bitternut hickory	*Carya cordiformis*
black ash	*Fraxinus nigra*
black cherry	*Prunus serotina*
blackhaw	*Viburnum prunifolium*
Black Hills spruce	*Picea glauca* var. *densata*
black hickory	*Carya texana*
black locust	*Robinia pseudoacacia*
black maple	*Acer nigrum*
black oak	*Quercus velutina*
black walnut	*Juglans nigra*
black willow	*Salix nigra*
blackgum	*Nyssa sylvatica*
blackjack oak	*Quercus marilandica*
blue spruce	*Picea pungens*
boxelder	*Acer negundo*
Bradford pear	*Pyrus calleryana 'Bradford'*
bur oak	*Quercus macrocarpa*
Callery pear	*Pyrus calleryana*
cedar elm	*Ulmus crassifolia*

FLORA

Common name	Scientific name
cherry plum	*Prunus cerasifera*
chestnut oak	*Quercus prinus*
Chinese catalpa	*Catalpa ovata*
Chinese chestnut	*Castanea mollissima*
Chinese fringetree	*Chionanthus retusus*
Chinese juniper	*Juniperus chinensis*
Chinese privet	*Ligustrum sinense*
chinkapin oak	*Quercus muehlenbergii*
cockspur hawthorn	*Crataegus acutifolia (crus-galli)*
common chokecherry	*Prunus virginiana*
common elderberry	*Sambucus canadensis*
common hackberry	*Celtis occidentalis*
common lilac	*Syringa vulgaris*
common pear	*Pyrus communis*
common reed	*Phragmites australis*
common persimmon	*Diospyros virginiana*
Cornelian cherry dogwood	*Cornus mas*
Crimean linden	*Tilia x euchlora*
cucumbertree	*Magnolia acuminata*
dawn redwood	*Metasequoia glyptostroboides*
'Discovery' elm	*Ulmus davidiana 'Discovery'*
Douglas-fir	*Pseudotsuga mucronata (menziesii)*
downy serviceberry	*Amelanchier arborea*
eastern cottonwood	*Populus deltoides*
eastern hemlock	*Tsuga canadensis*
eastern hophornbeam (ironwood)	*Ostrya virginiana*
eastern redbud	*Cercis canadensis*
eastern redcedar	*Juniperus virginiana*
eastern wahoo	*Euonymus atropurpurea (atropurpureus)*
eastern white pine	*Pinus strobus*
elm species	*Ulmus* spp.
European alder	*Alnus alnus (glutinosa)*
European beech	*Fagus sylvatica*
European buckthorn	*Rhamnus cathardica*
European filbert	*Corylus avellana*
European hornbeam	*Carpinus betulus*
European larch	*Larix decidua*
European mountain-ash	*Sorbus aucuparia*
European planetree	*Platanus x acerifolia*
European privet	*Ligustrum vulgare*
European smoketree	*Cotinus coggygria*
flowering dogwood	*Cornus florida*

FLORA

Common name	Scientific name
Freeman maple	*Acer x freemanii*
'Frontier' elm	*Ulmus carpinafolia x parvifolia 'Frontier'*
garlic mustard	*Alliaria petiolata*
glossy buckthorn	*Rhamnus frangula*
gray alder	*Alnus incana*
gray birch	*Betula populifolia*
gray dogwood	*Cornus racemosa*
green ash	*Fraxinus pennsylvanica*
'Harvest Gold' linden	*Tilia cordata x mongolica 'Harvest Gold'*
hedge maple	*Acer campestre*
Heritage® oak	*Quercus x macdanielii*
hickory species	*Carya* spp.
Higan cherry	*Prunus subhirtella 'Autumnalis'*
honeylocust	*Gleditsia triacanthos*
horse chestnut	*Aesculus hippocastanatum*
jack pine	*Pinus banksiana*
Japanese maple	*Acer palmatum*
Japanese red pine	*Pinus densiflora*
Japanese stiltgrass	*Microstegium vimineum*
Japanese tree lilac	*Syringa reticulata*
Japanese zelkova	*Zelkova serrata*
katsura tree	*Cercidiphyllum japonicum*
Kentucky coffeetree	*Gymnocladus dioicus*
Korean mountain-ash	*Sorbus omnifolia*
Korean Sun™ pear	*Pyrus fauriei 'Westwood'*
Kousa dogwood	*Cornus kousa*
kudzu	*Pueraria lobata*
lakeside daisy	*Hymenoxys acaulis* var. *glabra*
leatherleaf viburnum	*Viburnum rhytidophyllum*
Legacy® sugar maple	*Acer saccharum 'Legacy'*
littleleaf linden	*Tilia cordata*
London planetree	*Platanus x acerifolia*
longleaf pine	*Pinus palustris*
maidenhair tree	*Gingko biloba*
maple species	*Acer* spp.
Miyabe maple	*Acer miyabei*
mockernut hickory	*Carya alba*
Morden hawthorn	*Crataegus x mordenensis*
multiflora rose	*Rosa multiflora*
nannyberry	*Viburnum lentago*
northern catalpa	*Catalpa speciosa*
northern pin oak (Hill's oak)	*Quercus ellipsoidalis*
northern red oak	*Quercus rubra*
northern white-cedar (arborvitae)	*Thuja occidentalis*
Norway maple	*Acer platanoides*
Norway spruce	*Picea abies*
oak species	*Quercus* spp.
Ohio buckeye	*Aesculus glabra*
Oriental bittersweet	*Celastrus orbiculatus*
Oriental spruce	*Picea orientalis*
Osage-orange	*Maclura pomifera*

FLORA

Common name	Scientific name
Pacific Sunset® maple	*Acer truncatum x platanoides 'Warrenred'*
pagoda dogwood	*Cornus alternifolia*
paper birch	*Betula papyrifera*
pawpaw	*Asimina triloba*
peach	*Prunus persica*
peachleaf willow	*Salix amygdaloides*
pecan	*Carya illinoinensis*
Peking lilac	*Syringa pekinensis*
pignut hickory	*Carya glabra*
pin cherry	*Prunus pensylvanica*
pin oak	*Quercus palustris*
post oak	*Quercus stellata*
'Prairie Gem' Ussurian pear	*Pyrus ussuriensis 'MorDak'*
prickly ash	*Zanthoxylum americanum*
privet	*Ligustrum* spp.
'Prospector' Wilson Elm	*Ulmus wilsoniana 'Prospector'*
pussy willow	*Salix discolor*
quaking aspen	*Populus tremuloides*
red maple	*Acer rubrum*
red mulberry	*Morus rubra*
red pine	*Pinus resinosa*
river birch	*Betula nigra*
Robusta poplar	*Populus x euramerica*
rock elm	*Ulmus thomasii*
rose-of-Sharon	*Hibiscus syriacus*
Russian-olive	*Elaeagnus angustifolia*
Sargent cherry	*Prunus sargentii*
sassafras	*Sassafras albidum*
saucer magnolia	*Magnolia x soulangeana*
scarlet oak	*Quercus coccinea*
scholar tree	*Sophora japonica*
Scotch pine	*Pinus sylvestris*
Serbian spruce	*Picea omorika*
shagbark hickory	*Carya ovata*
Shantung maple	*Acer truncatum*
shellbark hickory	*Carya laciniosa*
shingle oak	*Quercus imbricaria*
shortleaf pine	*Pinus echinata*
Shumard oak	*Quercus shumardii*
Siberian elm	*Ulmus pumila*
silver linden	*Tilia tomentosa*
silver maple	*Acer saccharinum*
slippery elm	*Ulmus rubra*
smoothleaf elm	*Ulmus carpinifolia*
'Snow Goose' cherry	*Prunus 'Snow Goose'*
southern red oak	*Quercus falcata*
staghorn sumac	*Rhus typhina*
star magnolia	*Magnolia stellata*
sugar maple	*Acer saccharum*
sugarberry	*Celtis laevigata*
swamp white oak	*Magnolia virginiana*
sweetbay magnolia	*Quercus bicolor*
sweetgum	*Liquidambar styraciflua*

FLORA

Common name	Scientific name
sycamore maple	*Acer pseudoplatanus*
tree of heaven	*Ailanthus altissima*
Triumph™ elm	*Ulmus ‘Morton Glossy’*
turkey oak	*Quercus laevis*
Turkish hazelnut	*Corylus colurna*
‘Village Green’ Japanese zelkova	*Zelkova serrata ‘Village Green’*
walnut species	*Juglans* spp.
Washington hawthorn	*Crataegus cordata (phaenopyrum)*
weeping willow	*Salix babylonica*
white ash	*Fraxinus americana*
white fir	*Abies concolor*
white fringetree	*Chionanthus virginicus*
white mulberry	*Morus alba*
white oak	*Quercus alba*
white poplar	*Populus alba*
white spruce	*Picea glauca*
willow oak	*Quercus phellos*
winged burningbush	*Euonymus alatus*
winged elm	*Ulmus alata*
‘Winter King’ green hawthorn	*Crataegus viridis ‘Winter King’*
yellow birch	*Betula alleghaniensis*
yellow buckeye	*Aesculus flava (octandra)*
yellow-poplar (tuliptree)	*Liriodendron tulipifera*
yellowwood	*Cladrastis kentukea*

FAUNA

Common name	Scientific name
Asian longhorned beetle	*Anoplophora glabripennis*
beech bark disease (beech scale)	*Cryptococcus fagisuga*
bronze birch borer	*Agrilus anxius*
butterfly	*Lepidoptera family*
emerald ash borer	*Agrilus planipennis*
gypsy moth	*Lymantria dispar*
gray squirrel	*Sciurus carolinensis*
raccoon	*Procyon lotor*
skunk	*Mephitis mephitis*
southern pine beetle	*Dendroctonus frontalis*
two-lined chestnut borer	*Agrilus bilineatus*
walnut twig beetle (thousand cankers disease)	*Pityophthorus juglandis*
white-tailed deer	*Odocoileus virginianus*

BACTERIAL AND FUNGAL PATHOGEN SPECIES

Common name	Scientific name
beech bark disease	*Neonectria faginata* and *N. ditissima*
Botryosphaeria canker	*Botryosphaeria obtusa*
bur oak blight	*Tubakia iowensis*
Dutch elm disease	*Ophiostoma novo-ulmi*
oak wilt	*Ceratocystis fagacearum*
sudden oak death	*Phytophthora ramorum*
thousand cankers disease	*Geosmithia morbida*

APPENDIX 2

TREND ANALYSIS AND HISTORICAL CLIMATE DATA

To examine historical trends in precipitation and temperature for the analysis area, we used the ClimateWizard Custom Analysis tool (ClimateWizard 2011, 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 using a digital elevation model (digital gridded version of a topographic map). Temperature and precipitation are then derived for each pixel on a 2.5-mile grid across the conterminous United States. The closer a station is in distance and elevation to a grid cell of interest, 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: http://www.prism.oregonstate.edu/. Please note that Web addresses are current as of the publication date of this assessment but are subject to change.

Linear trend analysis for 1901 through 2011 was performed 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 Intergovernmental Panel on Climate Change Working Group I 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, for each month, and 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 (see Appendix 7 and Table 23).

The developers of the ClimateWizard tool advise users to interpret the linear trend maps in relation to the respective map of statistical confidence (Figs. 18 and 19). 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 alone. 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.

In addition, because maps are developed from weather station observations that have been spatially interpolated, developers of the ClimateWizard tool and PRISM dataset recommend that inferences about trends should not be made for single 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 (GHCN) from the National Centers for Environmental Information (NCEI) (National Oceanic and Atmospheric Administration [NOAA], National Climatic Data Center 2013, NOAA NCEI 2016).

We selected the time period 1901 through 2011 as it was sufficiently long to capture interdecadal and intra-decadal variation in climate for the region. We acknowledge that different trends can be inferred by selecting different beginning and end points in the analysis. To test the sensitivity of our trends to the selection of beginning and end dates, we also analyzed

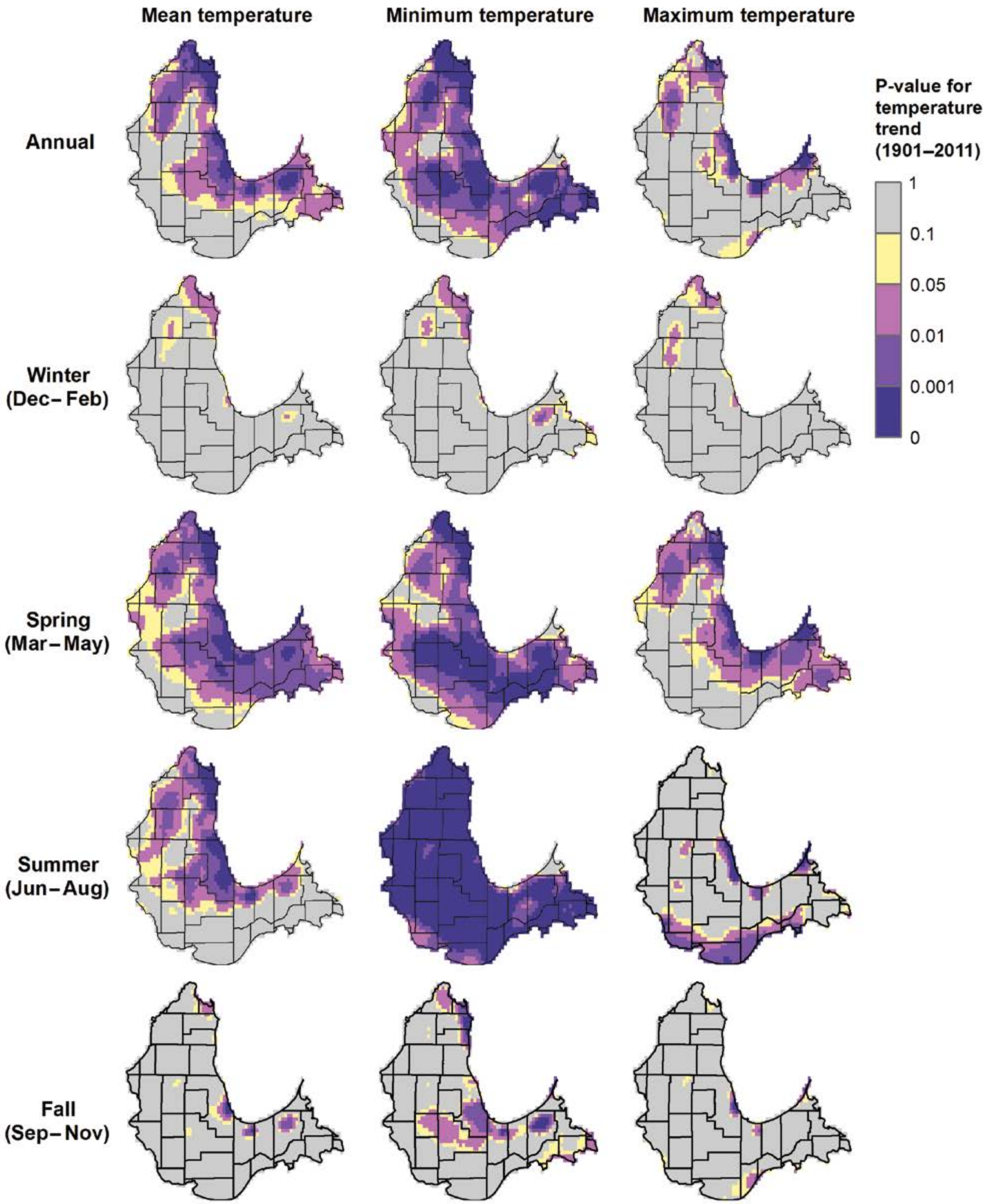

Figure 18.—Maps of statistical confidence (p-values for the linear regression) for trends in the 111-year time series for temperature in the Chicago Wilderness region. Gray values represent areas of low statistical confidence. Source: ClimateWizard (2011).

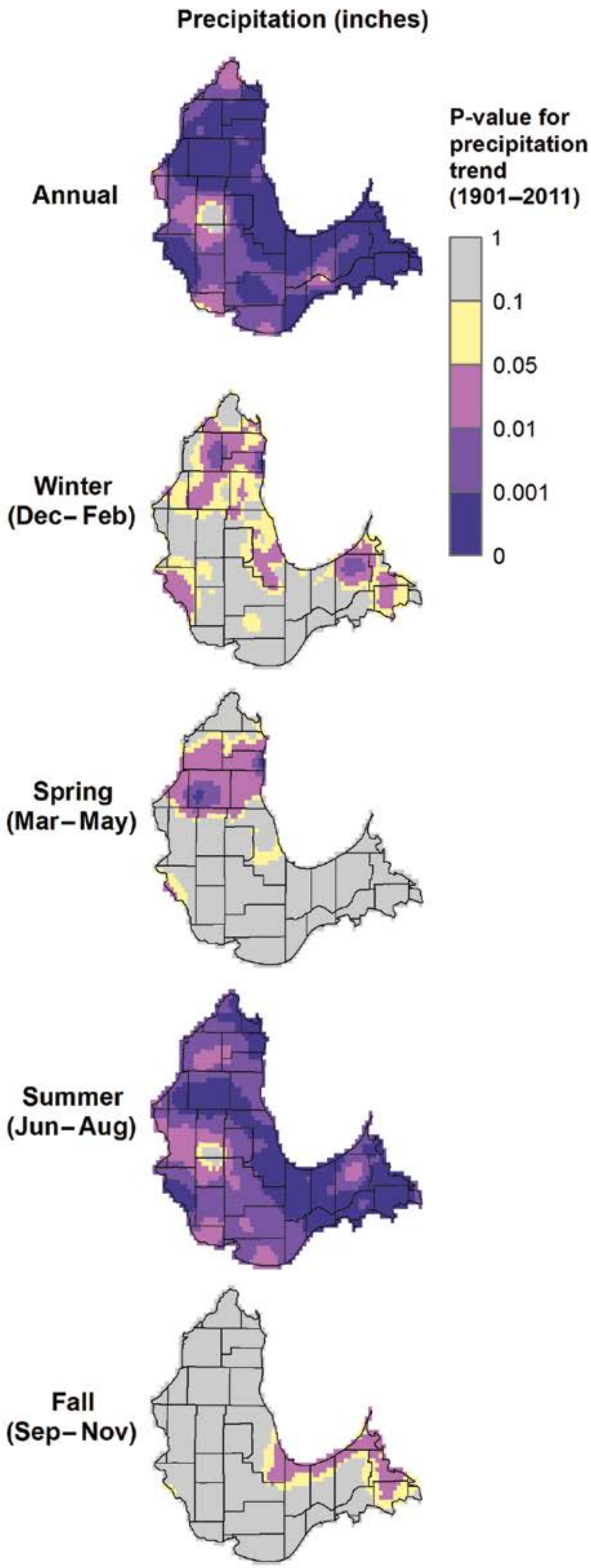

Figure 19.—Map of statistical confidence (p-values for the linear regression) for trends in the 111-year time series for precipitation in the Chicago Wilderness region. Gray values represent areas of low statistical confidence. Source: ClimateWizard (2011).

the data for the years since 1951 and since 1971 (data not shown). In general, selecting this period resulted in trends that were similar in direction and spatial pattern to the 1901 through 2011 trends, but different in slope and sometimes different in their statistical significance. Therefore, trends should be interpreted based on their relative magnitude and direction, and the slope of the particular trend should be interpreted with caution.

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APPENDIX 3

DOWNSCALED CLIMATE MODELS USED IN THIS REPORT

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 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007). The IPCC assessment includes several other models, but for simplicity, we selected two that had relatively good skill at simulating climate in the eastern United States and that bracketed a range of temperature and precipitation futures. The Geophysical Fluid Dynamics Laboratory's Climate Model (GFDL CM2; Delworth et al. 2006) is considered moderately sensitive to changes in radiative forcing. In other words, any change in greenhouse gas concentration included in the model would lead to a change in temperature that is higher than some models and lower than others. The National Center for Atmospheric Research's Parallel Climate Model (PCM; Washington et al. 2000), in contrast, is considered to have low sensitivity to radiative forcing. As mentioned in Chapter 2, the A1FI scenario is at the higher end of greenhouse gas emissions. The B1 scenario is the lowest greenhouse gas emission scenario used in the 2007 IPCC assessment, and is much lower than the trajectory for greenhouse gas emissions over the past decade. Therefore, the two model-scenario combinations span a large range of possible futures, with the GFDL A1FI model-scenario combination leading to a high-end projection of possible future temperature increases, and the PCM B1 projecting at the low end of the range. Although each projection is possible, the GFDL A1FI scenario represents a more likely projection of future greenhouse gas emissions and temperature increases (Raupach et al. 2007). It is important to note that it is possible that actual emissions and temperature increases could be lower or higher than these projections.

This assessment uses a statistically downscaled dataset for the continental United States (Stoner et al. 2012). 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 dataset uses a sophisticated statistical approach (asynchronous quantile regression) to downscale daily general circulation model (GCM) output and historical climate data (Stoner et al. 2013). This approach is advantageous because GCM and historical data do not need to be temporally correlated, and it is much better at capturing extreme temperatures and precipitation events than a linear regression approach.

This dataset was chosen for several reasons. First, the dataset covered the entire United States, and thus allowed a consistent dataset 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 to calculate hardiness and heat zones. Fourth, the statistical technique used is more accurate at reproducing extreme values at daily time steps than simpler statistical downscaling methods (Hayhoe 2010). Last, the resolution was fine enough to be useful for informing land management decisions.

To show projected changes in temperature and precipitation in Chapter 2, we calculated the average daily mean, minimum, and maximum temperature for each season and the entire year for three 30-year time periods (2010 through 2039, 2040 through 2069, 2070 through 2099) (Figs. 20-26). Mean cumulative precipitation was also calculated for each season and annually for the same time periods (Fig. 27). We then subtracted these values from the corresponding 1971 through 2000 averages to determine the departure from current climate conditions. Historical climate data used for the departure analysis were taken from ClimateWizard based on the PRISM dataset (see Appendix 2). This dataset was also used to develop hardiness and heat zone projections (see Chapter 2) and in the Tree Atlas model described in Chapter 3.

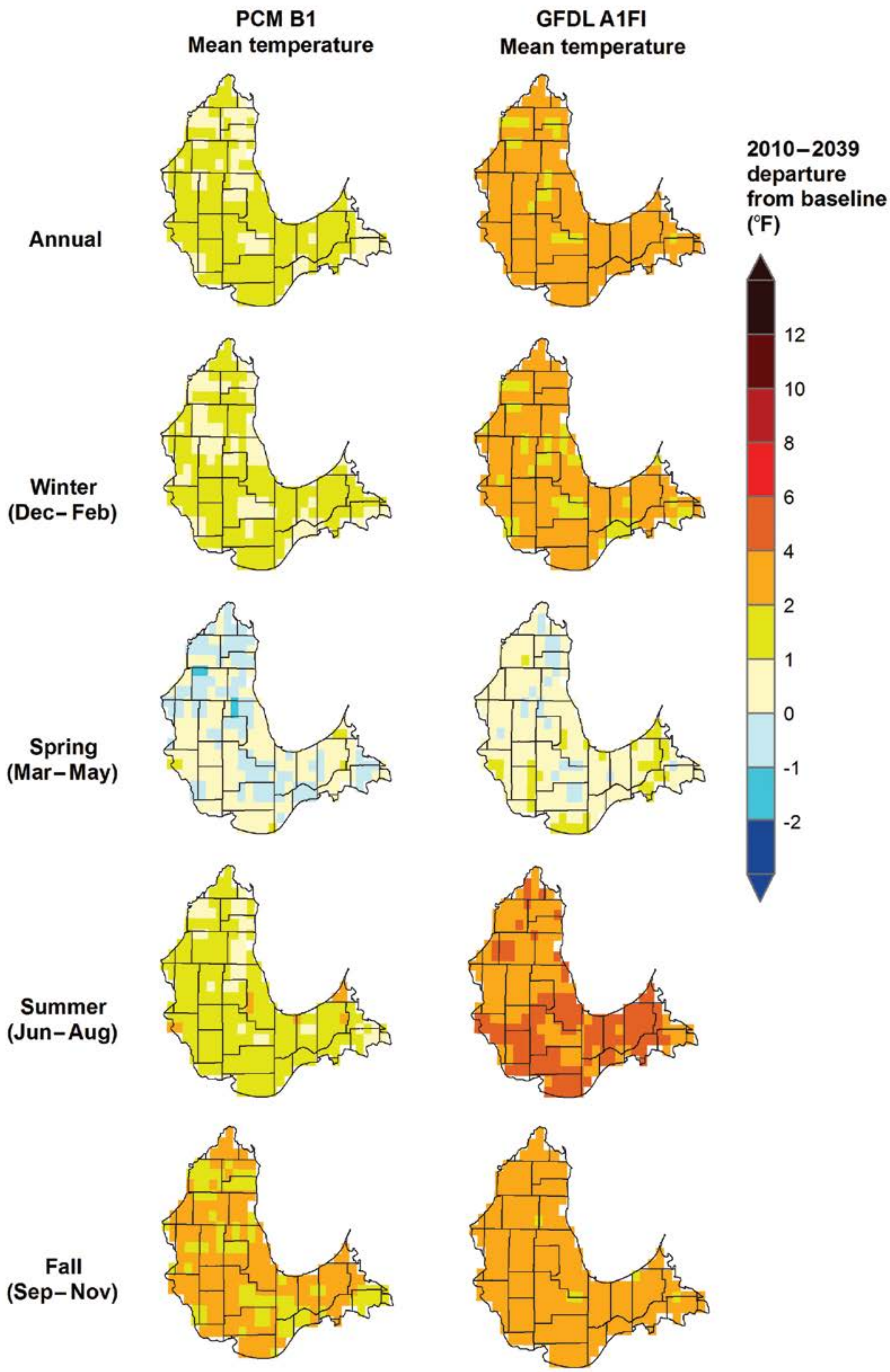

Figure 20.—Projected difference in mean daily mean temperature (°F) in the Chicago Wilderness region at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

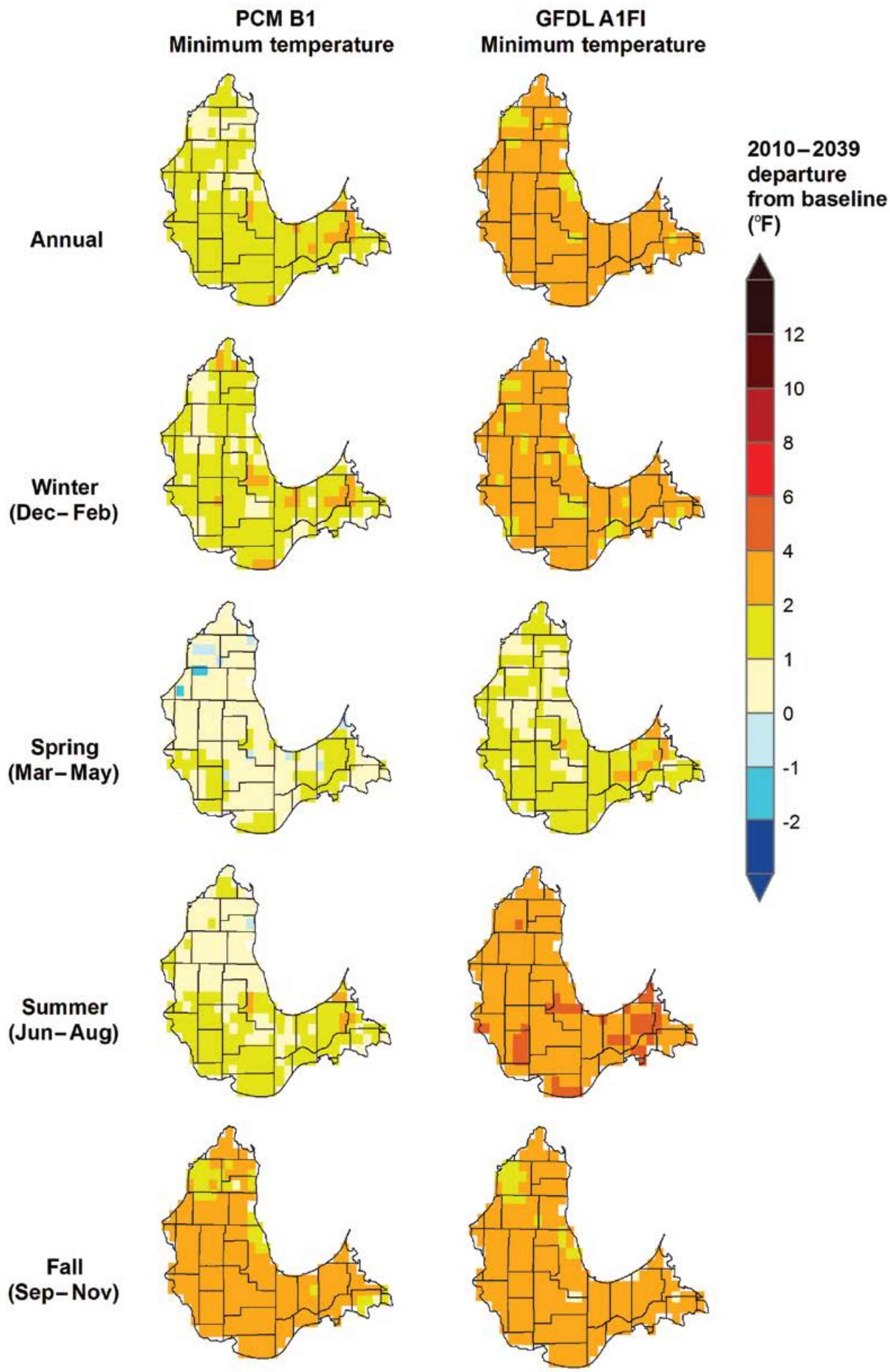

Figure 21.—Projected difference in mean daily minimum temperature (°F) in the Chicago Wilderness region at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

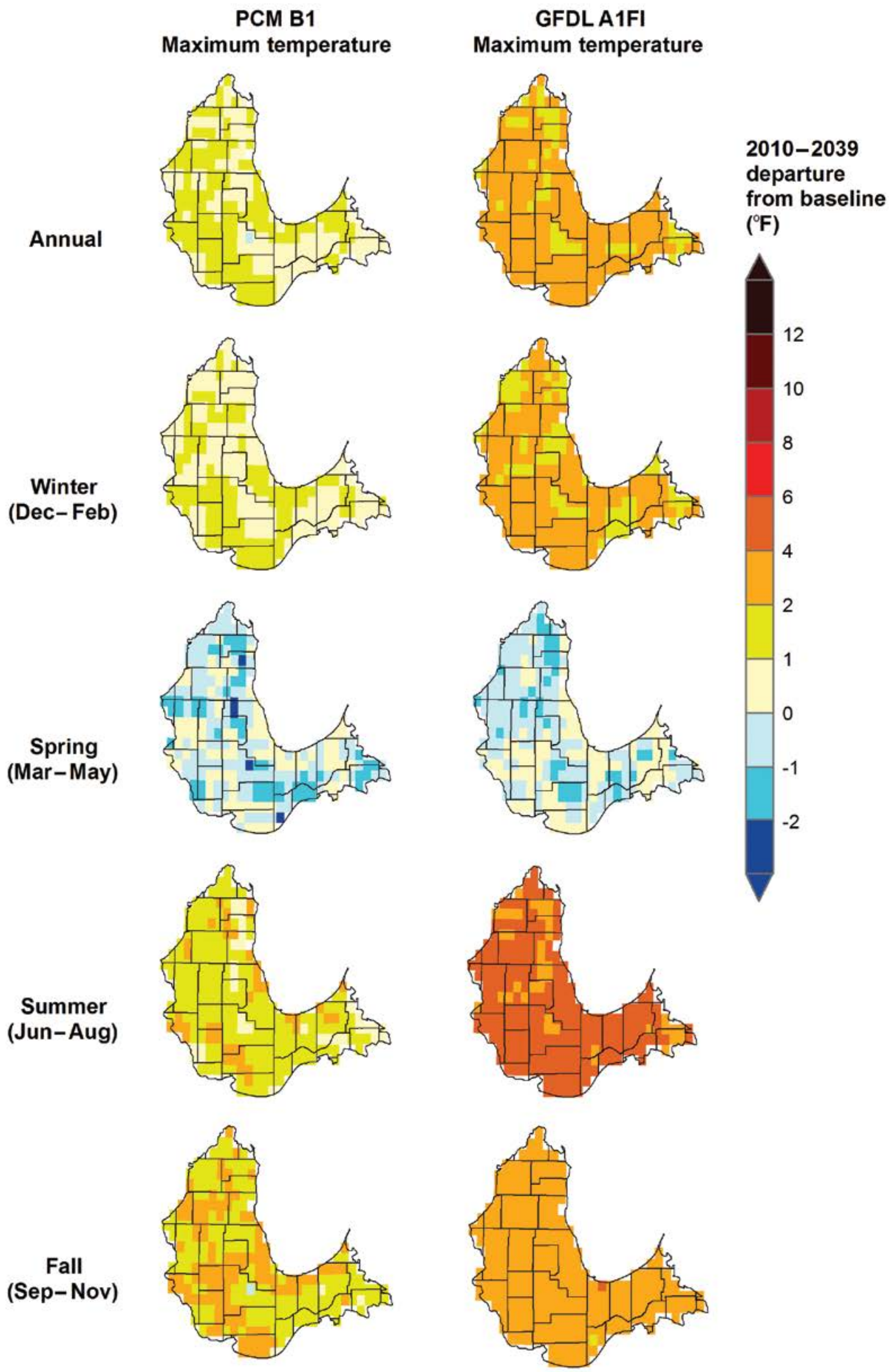

Figure 22.—Projected difference in mean daily maximum temperature (°F) in the Chicago Wilderness region at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

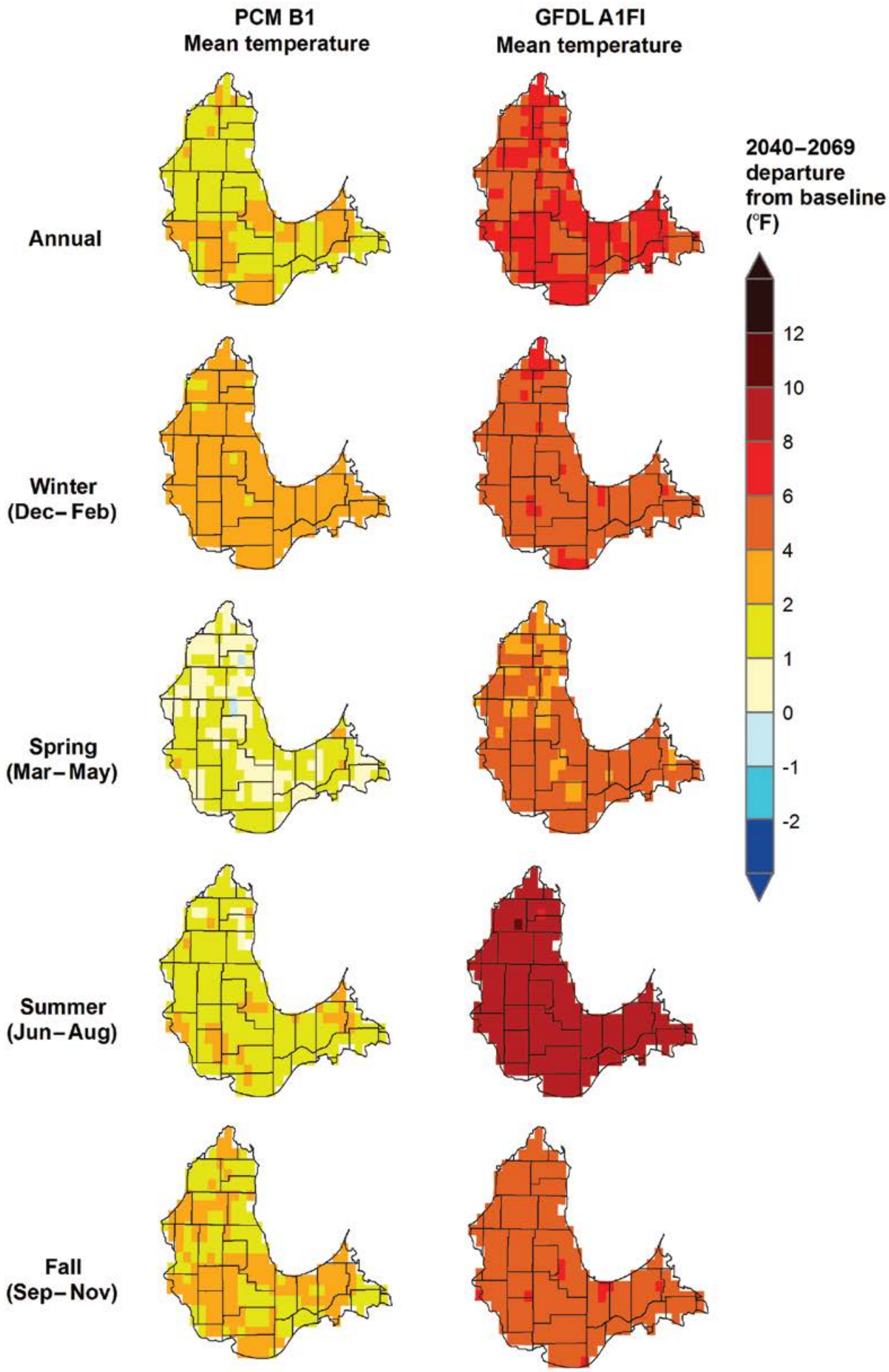

Figure 23.—Projected difference in mean daily mean temperature (°F) in the Chicago Wilderness region at mid-century (2040 through 2069) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

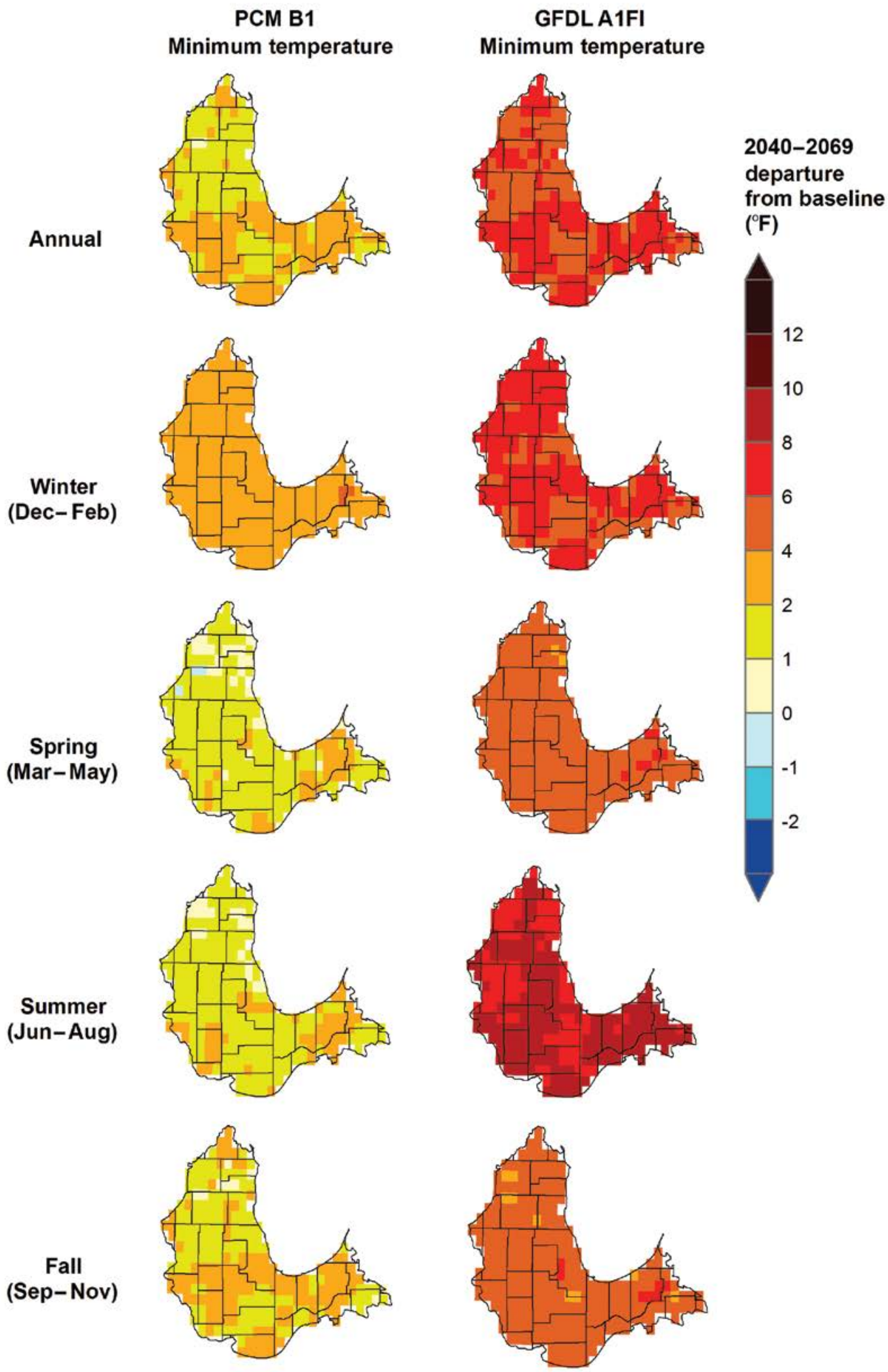

Figure 24.—Projected difference in mean daily minimum temperature (°F) in the Chicago Wilderness region at mid-century (2040 through 2069) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

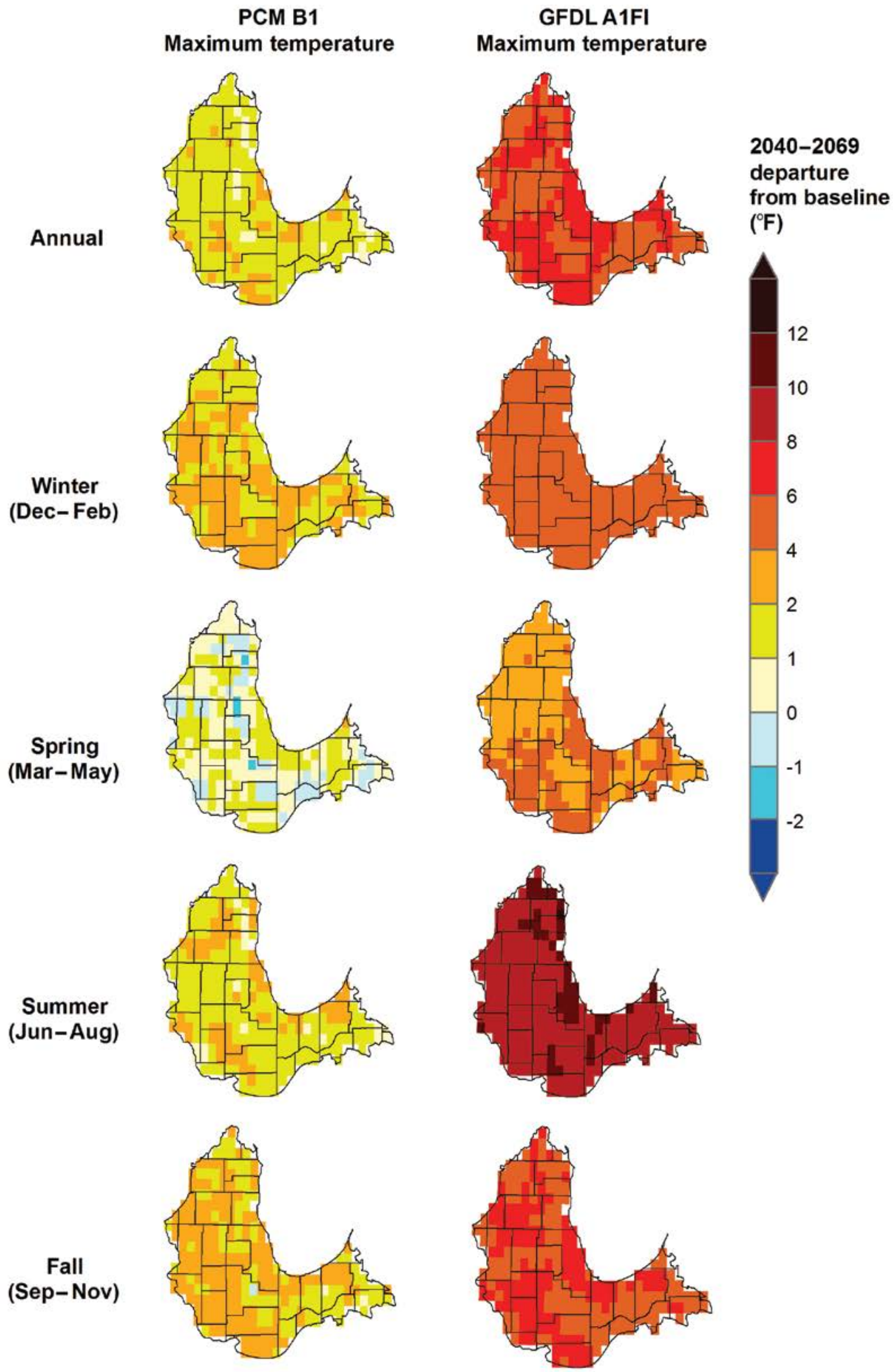

Figure 25.—Projected difference in mean daily maximum temperature (°F) in the Chicago Wilderness region at mid-century (2040 through 2069) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

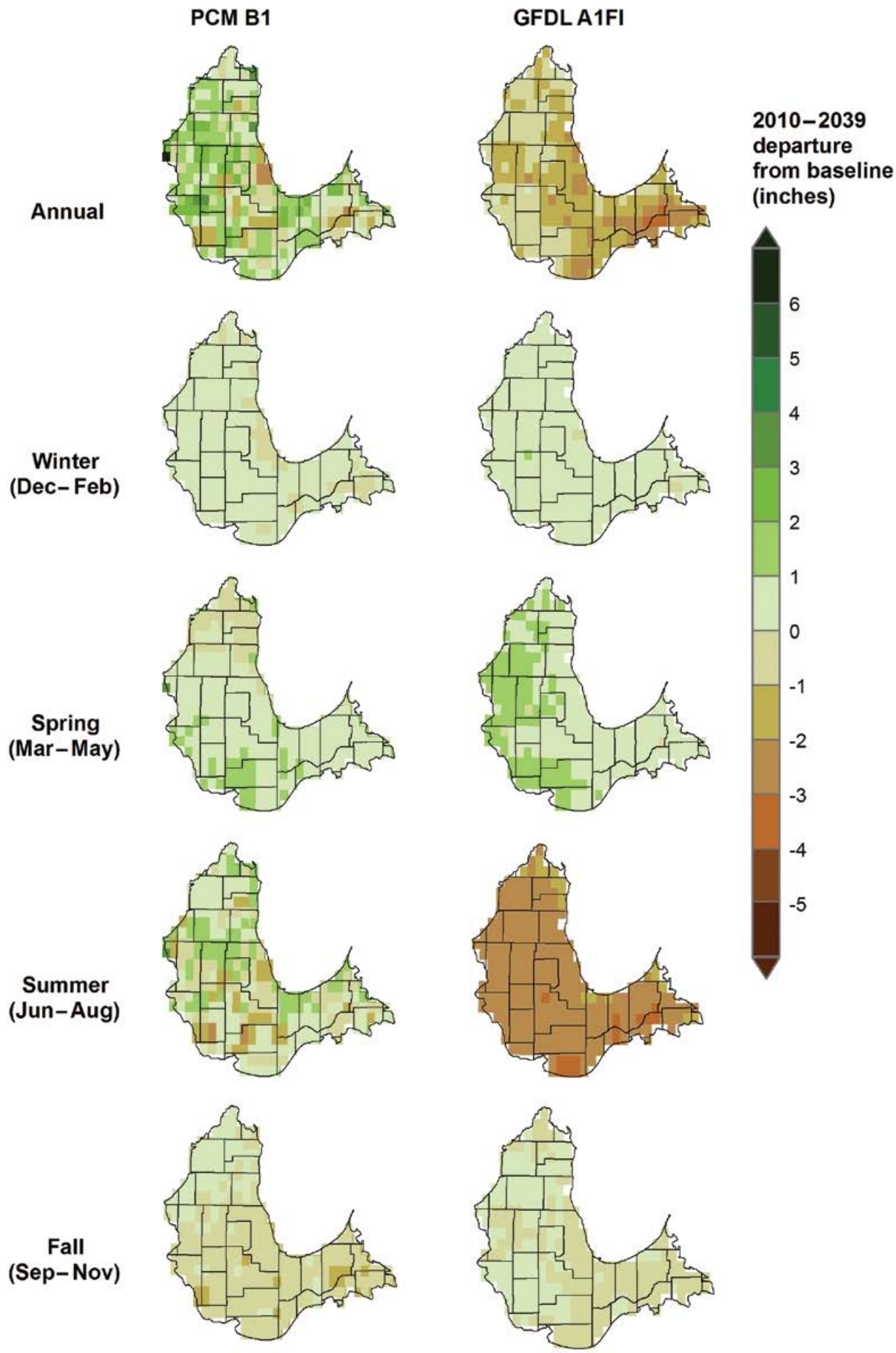

Figure 26.—Projected difference in mean annual and seasonal precipitation (inches) in the Chicago Wilderness region at the beginning of the century (2010 through 2039) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

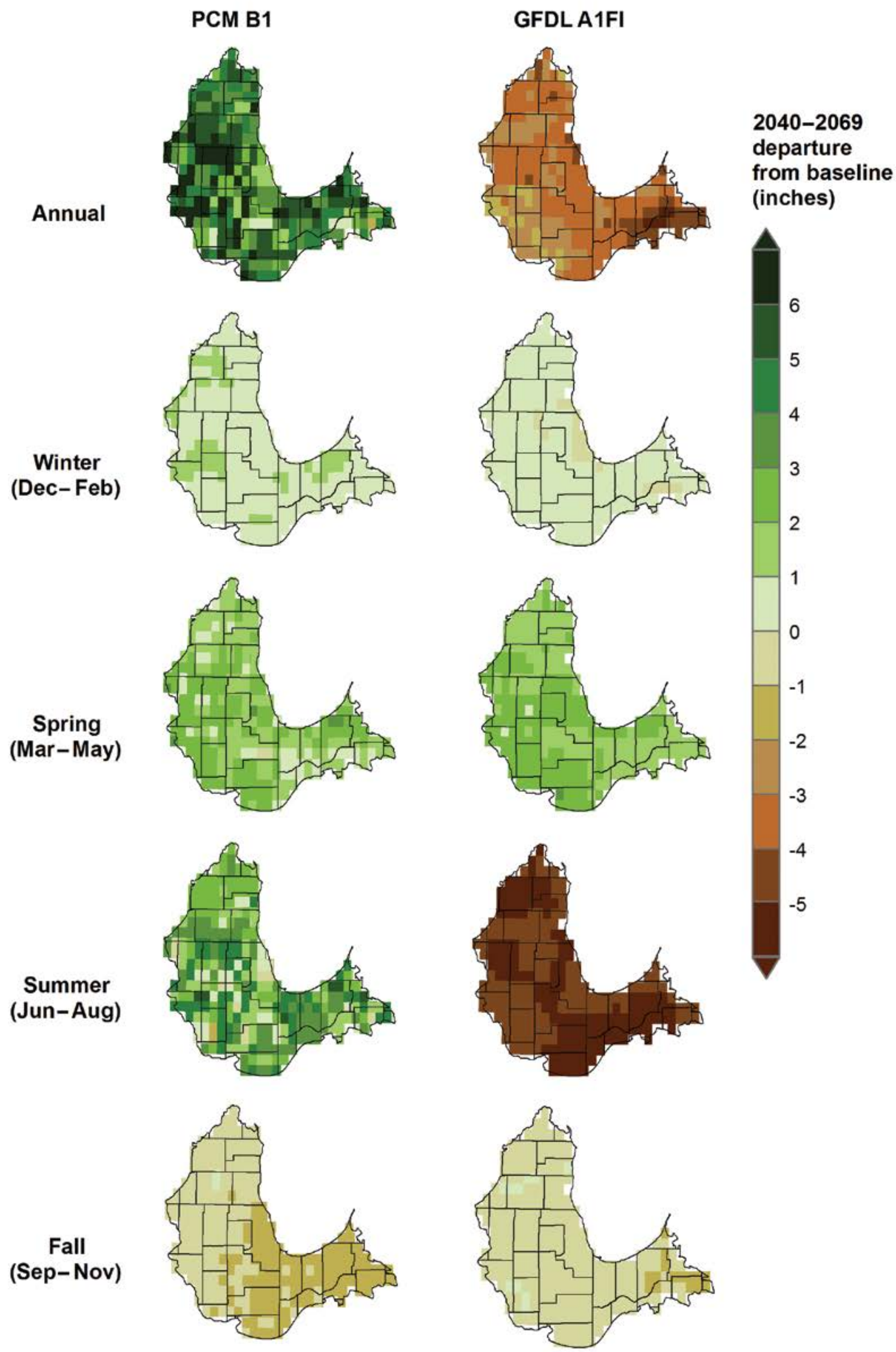

Figure 27.—Projected difference in mean annual and seasonal precipitation (inches) in the Chicago Wilderness region at mid-century (2040 through 2069) compared to baseline (1971 through 2000), for two climate model-emissions scenario combinations. Source: Stoner et al. (2013).

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APPENDIX 4

PLANT HARDINESS ZONE AND HEAT ZONE MAPPING

The plant hardiness zone map is based on minimum annual temperature and is used to guide gardeners and others on which plants may or may not be adapted to withstand winter cold temperatures. It was published in 1990 (Cathey 1990) and updated in 2003 (Ellis 2003) and 2010 (Daly et al. 2010). This approach differs from other approaches that use plant distributions to map hardiness zones (McKenney et al. 2007). The heat zone map, produced in 1997 by the American Horticultural Society (Cathey 1997), is based on number of days exceeding 86 °F (30 °C) and can be used as an indicator of heat stress on organisms.

Data used for the production of plant hardiness zones and heat zones were downscaled daily values of minimum and maximum temperature, as projected for 1980 through 2099 by Stoner et al. (2013) (see Appendix 3 for more information on downscaling methods and model-scenarios). Each modeled daily record for the 120-year period for each 1/8 degree (~8.6-mile × 8.6-mile) cell was evaluated by using R statistical software (R Development Core Team 2010). For plant hardiness zones, the code searched minimum temperatures and cataloged the absolute minimum temperature achieved for each year (June 1 through May 31 to ensure coldest day within annual cycle). The absolute minimum temperature for each year was averaged across each of four 30-year periods (1980 through 2009, 2010 through 2039, 2040 through 2069, and 2070 through 2099). Yearly and 30-year average data were imported into ArcGIS to prepare maps of plant hardiness zones and subzones (Fig. 28) according to the USDA definitions, which break subzones by increments of 5 °F (2.8 °C) from zone 1a (-60 to -55 °F; -51 to -48 °C) to zone 13b (65 to 70 °F; 18 to 20 °C) of annual extreme minimum temperature. For heat zones (Fig. 29), the maximum temperature of daily records was evaluated for the 86 °F threshold. Each day in a calendar year passing that threshold was tallied and summed for each year. The yearly data were again averaged over 30-year periods to obtain the average number of days per year greater than 86 °F for the same four 30-year periods.

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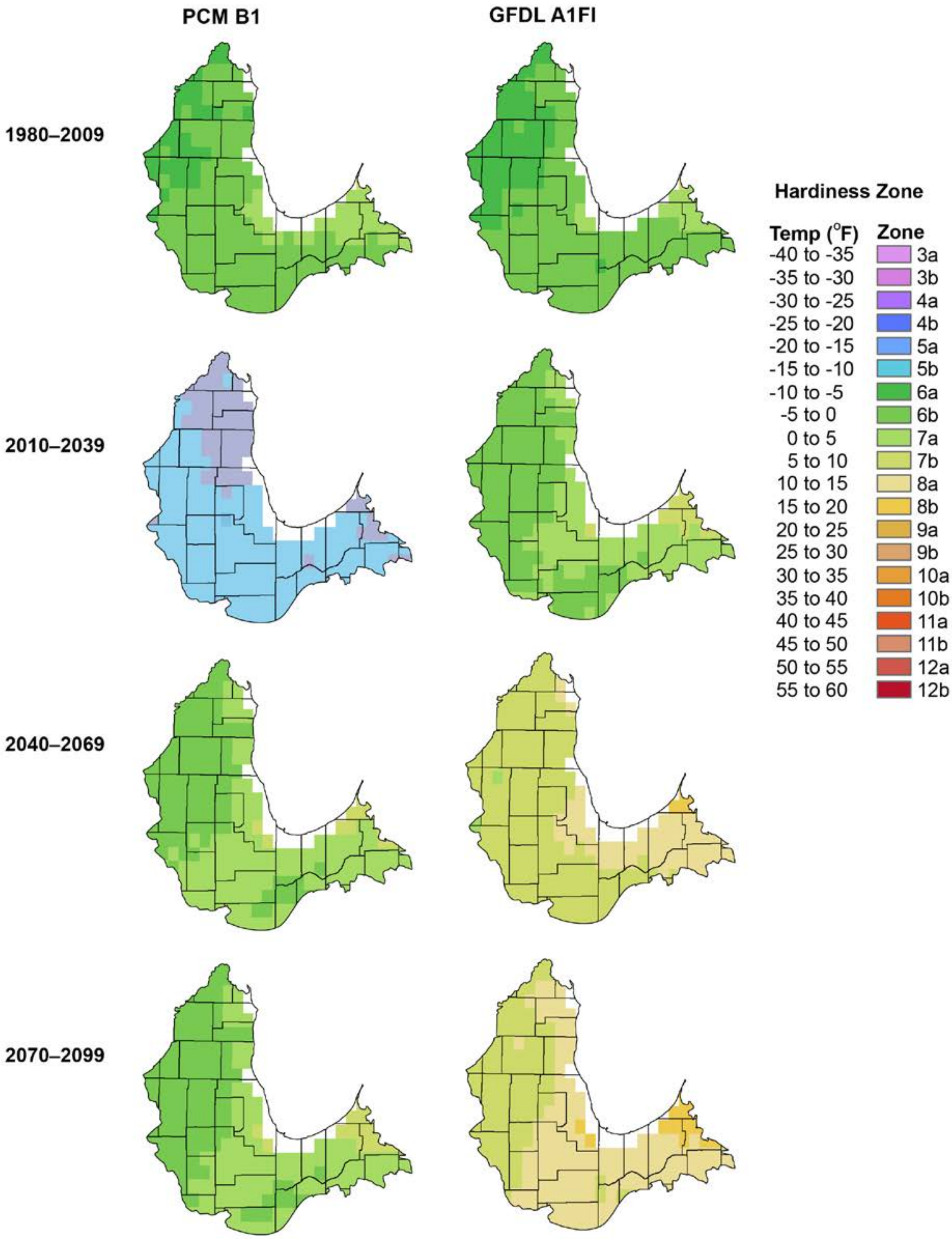

Figure 28.—Current and projected future plant hardiness zones for the Chicago Wilderness region under the PCM B1 and GFDL model-scenario combinations. Cartographers: Stephen Matthews, Louis Iverson, and Matthew Peters (U.S. Forest Service, Northern Research Station).

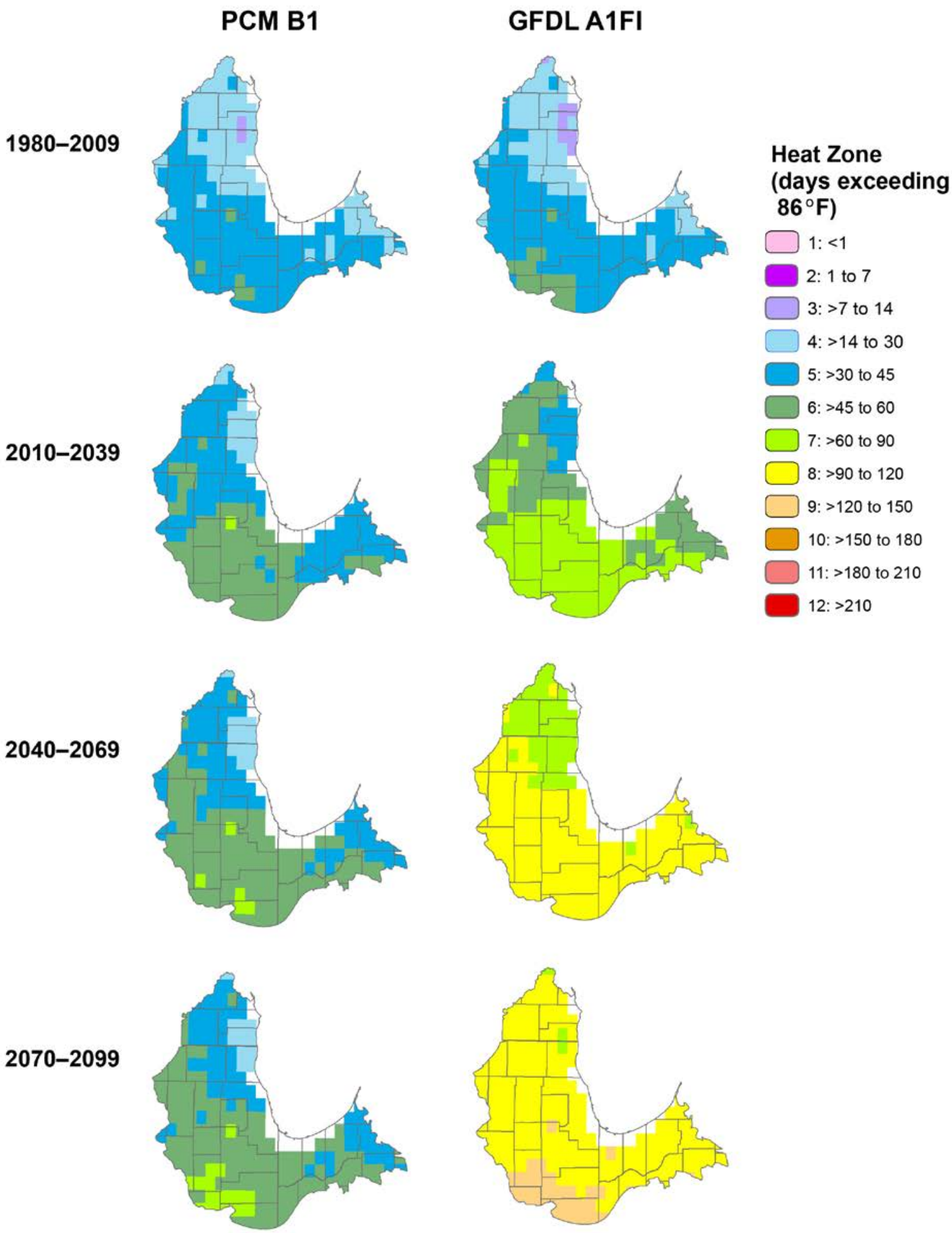

Figure 29.—Current and projected future plant heat zones for the Chicago Wilderness region under the PCM B1 and GFDL model-scenario combinations. Cartographers: Stephen Matthews, Louis Iverson, and Matthew Peters (U.S. Forest Service, Northern Research Station).

APPENDIX 5

ADDITIONAL TREE ATLAS INFORMATION

This appendix provides supplementary information to Chapter 3. The following pages contain additional model results and information from the Climate Change Tree Atlas (U.S. Forest Service, n.d.) (Table 19). Scientific names for all species are provided in Appendix 1.

The table shows results of the DISTRIB model used in the Tree Atlas for the Chicago Wilderness region. 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 IVs (2010 through 2039, 2040 through 2069, 2070 through 2099) from the DISTRIB models were calculated for each time period. One hundred thirty-four tree species were initially modeled. If a species never had an area-weighted IV (sum of IV for all 12.5-mile by 12.5-mile pixels in the assessment area) greater than 3 (FIA, current modeled, or future) across the region, it was deleted from the list because there were not enough data. Therefore, only a subset of 70 of the 134 possible species is shown.

A set of rules was established to determine change classes for the years 2070 through 2099, which was used to create the tables in Chapter 3. For most species, the following rules applied:

Future:Current modeled IV	Class
<0.5	large decrease
0.5 to 0.8	small decrease
>0.8 to <1.2	no change
1.2 to 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 0. A species' habitat was considered to have a large decrease if the future IV was zero and FIA values were greater than 0.

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. The change classes are calculated differently for these species because their current infrequency tends to inflate the amount of change that is projected. For this assessment, a species was considered rare if its current area-weighted importance value was less than 8. For rare species, the following rules applied:

Future:Current modeled IV	Class
<0.2	large decrease
0.2 to <0.6	small decrease
0.6 to <4	no change
4 to 8	small increase
>8	large increase (not used when current modeled IV ≤3)

Special rules also applied to species that were present (current FIA IV >0) but not modeled as present (current modeled IV = 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.

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Table 19.—Current and future modeled importance values, ratios, and change classes for two model-emissions scenario combinations, using the Climate Change Tree Atlas

				Modeled IV						Future:Current IV						Change class	
			Current	2010–2039		2040–2069		2070–2099		2010–2039		2040–2069		2070–2099		2070–2099	
Common name	Model reliability	FIA IV	modeled IV	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 (American linden)	medium	130	164	149	269	132	264	143	138	0.91	1.32	0.8	1.29	0.87	0.84	no change	no change
American beech	high	27	19	13	33	16	26	44	13	0.68	0.87	0.84	0.68	2.32	0.68	large increase	small decrease
American elm	medium	372	496	615	784	685	916	936	597	1.24	1.2	1.38	1.41	1.89	1.2	small increase	small increase
American hornbeam	medium	14	10	6	19	11	54	28	23	0.6	0.91	1.1	2.57	2.8	2.3	large increase	large increase
American plum	low	18	6	4	38	5	86	4	63	0.67	2.53	0.83	5.73	0.67	10.5	decrease	large increase
American sycamore	medium	5	25	40	76	72	94	110	100	1.6	2.17	2.88	2.69	4.4	4	large increase	large increase
Bigtooth aspen	high	12	10	0	4	1	0	2	0	0	0.1	0.1	0	0.2	0	large decrease	large decrease
Bitternut hickory	low	68	60	115	172	141	165	240	124	1.92	1.93	2.35	1.85	4	2.07	large increase	large increase
Black ash	high	69	90	40	56	26	83	17	47	0.44	0.51	0.29	0.75	0.19	0.52	large decrease	small decrease
Black cherry	high	752	596	370	372	328	116	467	77	0.62	0.5	0.55	0.16	0.78	0.13	small decrease	large decrease
Black hickory	high	0	0	0	5	0	12	2	26	NA	▲	NA	▲	▲	▲	▲	▲
Black locust	low	145	63	96	153	101	478	118	335	1.52	1.87	1.6	5.83	1.87	5.32	small increase	large increase
Black oak	high	206	220	226	316	225	273	255	188	1.03	1.02	1.02	0.88	1.16	0.85	no change	no change
Black walnut	medium	42	132	208	358	226	352	381	249	1.58	1.88	1.71	1.85	2.89	1.89	large increase	small increase
Black willow	low	90	103	135	165	117	225	142	184	1.31	1.27	1.14	1.73	1.38	1.79	small increase	small increase
Blackgum	high	22	10	12	19	12	18	20	14	1.2	0.83	1.2	0.78	2	1.4	small increase	small increase
Blackjack oak	medium	0	0	5	26	15	63	2	90	▲	▲	▲	▲	▲	▲	▲	▲
Boxelder	medium	452	295	377	465	327	772	288	537	1.28	1.31	1.11	2.18	0.98	1.82	no change	small increase
Bur oak	medium	403	352	384	479	325	508	238	375	1.09	1.11	0.92	1.18	0.68	1.07	small decrease	no change
Cedar elm	low	0	0	0	0	0	6	0	23	NA	NA	NA	▲	NA	▲	NA	▲
Chinkapin oak	medium	0	0	46	93	55	117	82	82	▲	18.6	▲	23.4	▲	▲	▲	▲
Common chokecherry	low	9	2	0	2	0	0	5	0	0	0.17	0	0	2.5	0	no change	large decrease
Common hackberry	medium	57	212	327	562	376	620	507	424	1.54	2.05	1.77	2.26	2.39	2	large increase	small increase
Common persimmon	medium	0	0	0	2	15	8	32	50	NA	NA	▲	▲	▲	▲	▲	▲
Eastern cottonwood	low	101	137	218	335	215	466	222	287	1.59	1.79	1.57	2.49	1.62	2.09	small increase	large increase
Eastern hophornbeam (ironwood)	medium	66	109	122	166	132	77	182	56	1.12	1.2	1.21	0.56	1.67	0.51	small increase	small decrease
Eastern redcedar	medium	3	25	109	169	112	252	133	170	4.36	3.93	4.48	5.86	5.32	6.8	large increase	large increase
Eastern redbud	medium	0	5	54	162	66	254	80	199	10.8	16.2	13.2	25.4	16	39.8	▲	▲
Eastern white pine	high	18	43	6	1	3	2	20	0	0.14	0.02	0.07	0.03	0.47	0	large decrease	large decrease
Flowering dogwood	high	15	16	16	29	17	29	64	38	1	1	1.06	1	4	2.38	large increase	large increase
Green ash	medium	166	233	257	402	276	541	332	368	1.1	1.38	1.18	1.86	1.42	1.58	small increase	small increase
Honeylocust	low	107	139	317	348	357	383	401	291	2.28	1.87	2.57	2.06	2.88	2.09	large increase	large increase
Jack pine	high	5	11	9	13	0	40	0	50	0.82	0.57	0	1.74	0	4.55	large decrease	large increase
Kentucky coffeetree	low	0	0	1	19	1	28	2	1	▲	4.75	▲	7	▲	▲	▲	▲
Longleaf pine	high	0	0	0	0	0	0	7	0	NA	NA	NA	NA	▲	NA	▲	NA
Mockernut hickory	high	1	9	12	76	22	91	50	92	1.33	3.17	2.44	3.79	5.56	10.22	large increase	large increase

(Continued)

Table 19.—*(Continued)* Current and future modeled importance values, ratios, and change classes for two model-emissions scenario combinations, using the Climate Change Tree Atlas

				Modeled IV						Future:Current IV						Change class	
			Current	2010–2039		2040–2069		2070–2099		2010–2039		2040–2069		2070–2099		2070–2099	
Common name	Model reliability	FIA IV	modeled IV	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
Northern pin oak (Hill's oak)	medium	66	33	16	23	12	31	8	13	0.48	0.56	0.36	0.76	0.24	0.39	large decrease	large decrease
Northern red oak	high	274	229	220	304	221	211	315	138	0.96	0.95	0.97	0.66	1.38	0.6	small increase	small decrease
Ohio buckeye	low	0	6	0	29	0	26	11	13	0	2.9	0	2.6	1.83	2.17	▲	▲
Osage-orange	medium	67	119	158	159	181	206	273	176	1.33	0.98	1.52	1.27	2.29	1.48	large increase	small increase
Paper birch	high	25	21	0	6	0	6	2	0	0	0.17	0	0.17	0.1	0	large decrease	large decrease
Pawpaw	low	0	0	0	3	0	3	18	1	NA	1.5	NA	1.5	▲	▲	▲	▲
Pecan	low	0	0	1	0	9	0	21	33	▲	0	▲	0	▲	▲	▲	▲
Pignut hickory	high	42	38	35	136	50	87	80	107	0.92	2.03	1.32	1.3	2.11	2.82	large increase	large increase
Pin oak	medium	63	49	77	168	90	310	139	197	1.57	2.07	1.84	3.83	2.84	4.02	large increase	large increase
Post oak	high	0	0	48	105	65	147	35	388	▲	▲	▲	▲	▲	▲	▲	▲
Quaking aspen	high	80	47	11	16	4	36	8	15	0.23	0.22	0.09	0.49	0.17	0.32	large decrease	large decrease
Red maple	high	148	159	113	209	122	311	156	197	0.71	0.87	0.77	1.29	0.98	1.24	no change	small increase
Red mulberry	low	129	101	175	233	193	297	231	228	1.73	1.6	1.91	2.03	2.29	2.26	large increase	large increase
Red pine	medium	70	61	25	55	18	57	22	39	0.41	0.61	0.3	0.63	0.36	0.64	large decrease	small decrease
River birch	low	20	2	11	15	12	27	23	20	5.5	3	6	5.4	11.5	10	small increase	small increase
Rock elm	low	4	0§	0	7	0	29	0	4	0	7	0	29	0	1	large decrease	no change
Sassafras	high	28	38	37	57	50	40	84	52	0.97	0.86	1.32	0.61	2.21	1.37	large increase	small increase
Scarlet oak	high	13	0§	7	7	6	4	7	3	0.54	1.17	0.46	0.67	0.54	0.23	small decrease	large decrease
Shagbark hickory	medium	214	197	251	325	287	259	367	215	1.27	1.3	1.46	1.04	1.86	1.09	small increase	no change
Shellbark hickory	low	1	0§	4	30	0	27	0	17	4	30	0	27	0	17	no change	small increase
Shingle oak	medium	1	0§	51	81	64	59	62	53	51	20.25	64	14.75	62	53	small increase	small increase
Shortleaf pine	high	4	0§	0	1	0	1	0	0	0	0	0	0	0	0	large decrease	large decrease
Silver maple	medium	70	210	340	545	341	687	406	464	1.62	1.94	1.62	2.45	1.93	2.21	small increase	large increase
Slippery elm	medium	107	126	153	257	168	265	232	156	1.21	1.42	1.33	1.46	1.84	1.24	small increase	small increase
Sugar maple	high	213	235	219	317	246	219	396	139	0.93	0.98	1.05	0.68	1.69	0.59	small increase	small decrease
Sugarberry	medium	0	0	0	3	0	75	0	84	NA	▲	NA	▲	NA	▲	NA	▲
Swamp white oak	low	26	12	39	83	43	99	56	62	3.25	2.59	3.58	3.09	4.67	5.17	large increase	large increase
Sweetgum	high	1	0§	0	0	0	2	8	0	NA	NA	NA	NA	8	▲	small increase	no change
Turkey oak	high	0	0	0	0	0	0	5	0	NA	NA	NA	NA	▲	NA	▲	NA
White ash	high	138	193	190	367	212	278	340	194	0.98	1.34	1.1	1.01	1.76	1.01	small increase	no change
White oak	high	431	367	416	584	396	279	421	178	1.13	1.15	1.08	0.55	1.15	0.49	no change	large decrease
White spruce	medium	5	0§	0	1	0	1	0	0	0	0.5	0	0.5	0	0	large decrease	large decrease
Winged elm	high	0	0	0	0	0	38	0	126	NA	NA	NA	▲	NA	▲	NA	▲
Yellow-poplar (tuliptree)	high	18	14	6	27	12	13	70	12	0.43	1	0.86	0.48	5	0.86	large increase	no change

▲ indicates new habitat

† GFDL values for 2010–2039 and 2040–2069 were calculated in a slightly different way, and ratios may have used slightly different values for the FIA and current modeled importance values. However, this should not affect the overall change class.

§ FIA importance values were used in place of current modeled values when the current modeled value was zero and the FIA value was greater than zero.

NA: no suitable habitat under current or projected climate conditions.

APPENDIX 6

MODIFYING FACTORS FOR ASSESSING THE ADAPTIVE CAPACITY OF TREE SPECIES IN URBAN AREAS

Modifying Factor scores, based on Matthews et al. (2011), were developed for 179 species that are either already present or being considered for planting in the Chicago area. The purpose of these scores is to provide regional information about individual species which will allow managers and policy-makers to consider potential suitable habitat distribution models in a local context based on specific variables within their jurisdiction. This approach will assist interpretation of modeled outputs as published for the Climate Change Atlas (U.S. Forest Service, n.d.) and other species distribution models.

Several assumptions associated with climate change over the next 50 years in the Chicago Wilderness region were made to develop the scores. We assume, based on the literature reviews in this assessment:

- More drought conditions throughout the region because growing season average temperatures are projected to be higher in the future with only minimal increases in precipitation during this time for most scenarios
- Higher exposure to fire events in natural areas due to higher average temperatures
- Higher incidence of flooding due to more extreme precipitation patterns
- Higher wind damage due to more-intense pressure differences
- An increase in ice storms at mid-century, followed by a reduction later in the century as temperatures warm
- Increases in several air and soil pollutants, which will be especially harsh in urban areas, over the next 50 years as the population, industry, and transportation increase in the area
- Increases in disease, insects, herbivory from deer (especially in natural and suburban areas), and invasive plants
- The use of harvesting primarily for restoration efforts and for new land development.

There are several limitations to these scores. Landscapes—natural, urban, and rural—contain many diverse interactions between processes and patterns that influence the species inhabiting them. Although this analysis uses common factors that influence habitat at the local level to modify large-scale projections, local managers are encouraged to consider, where applicable, some factors that are not included.

It is also important to understand that severe events can influence many factors used to modify habitat projections. A long drought can influence seed dispersal, fire, insect development, and seedling establishment. Therefore, these modifications are somewhat dynamic, and should be updated as needed by managers.

Scoring System

Each species was given a subscore for each modifying factor, which was then weighted and converted into overall disturbance, biological, and adaptability scores.

The definitions for the scoring system are as follows:

FactorType—One of two influential factor types (biological and disturbance) which describe the variables used to modify the outputs of individual species distribution models.

ModFactor—A modifying factor that is considered to affect the establishment, growth, mortality rate, and regeneration of a species which could reduce or increase the habitat suitability or future abundance for that species. See the following two sections for specific details relating to each Modfactor for naturally occurring and planted trees.

Score—A score, given as an integer ranging from -3 (negative effect on reproduction, growth, or survival) to +3 (positive effect on reproduction, growth, or survival), which relates to the potential influence of a ModFactor on the species throughout its range at the present.

Uncert—A default score (a multiplier to Score) reflecting the level of uncertainty about the ModFactor's influence on the distribution of the species. Scores are 0.5 = highly uncertain, 0.75 = somewhat uncertain, or 1.0 = low uncertainty that the ModFactor will provide the influence. These values are also assigned preliminarily by the modeling team based on literature research. For example, if there is contradictory information in the literature, the score would be 0.5.

FutureRelevance—A value (also a multiplier to Score) referring to the likely potential future relevance that a particular ModFactor could have on the distribution of a species over the next 50 years in a changing climate. Values range from 1 = not highly relevant over the next 50 years to 5 = likely to be an extremely important ModFactor.

Weighted—A weighted score based on multiplication of the three default values (Score × Uncert × FutureRelevance) for the species throughout its range.

Average Disturbance Score—The average of all the weighted disturbance factor scores; it indicates the relative overall impact of these factors.

Average Biological Score—The average of all the weighted biological factor scores; it indicates the relative overall impact of these factors.

Converted Dist Score—The average of all disturbance factor scores (unweighted) + 3 to remove negative values. Values can range from 0 to 6.

Converted Bio Score—The average of all biological factor scores (unweighted) + 3 to remove negative values. Values can range from 0 to 6.

Adapt Score—The hypotenuse of a right triangle created from the Converted Dist Score and Bio Score. Values can range from 0 to 8.5.

Adapt Class—Categories assigned based on Adapt Score. Low: less than 3.5. Moderate: 3.5 to 4.5. High: More than 4.5.

Factors for Naturally Regenerating Trees in Natural and Other Undeveloped Areas

Scores were developed for 75 species that are either native or naturalized in the Chicago Wilderness region. Scores for native species were primarily based on those developed by Matthews et al. (2011), with most information derived from Burns and Honkala (1990a, 1990b). For invasive species, information was gleaned from various sources, including the Natural Resources Conservation Service's PLANTS Database (Natural Resources Conservation Service 2015) and invasive species fact sheets developed by federal and state agencies. Additional information for wind and ice storm susceptibility was taken from Hauer et al. (2006) and Duryea et al. (2007).

Defaults were kept consistent with Matthews et al. (2011), with a few exceptions. Insect and disease scores were modified to account for local conditions.

Factors that received a weighted score of less than -4.5 or greater than 4.5 were listed in tables as contributing negatively or positively, respectively, to the overall adaptability score of the species. Weighted scores between these two values were not listed. Disturbance and biological factors are defined next; and default values for the associated Score, Uncert, and FutureRelevance are provided for each.

Disturbance Factors

Disease—Accounts for the number and severity of known pathogens that attack a species. If a species is resistant to many pathogens, it is assumed that it will continue to be so in the future. If the mortality rate is low, it is assumed that the species is not greatly affected by diseases. Thus, those species would receive positive scores. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 2.

Insect pests—Accounts for the number and severity of insects that may attack a species. If a species is resistant to attacks from known insect pests now or is adapted to cope with them, then it is assumed to be at least partially resistant in the future. This factor, although highly uncertain in overall effects, is likely to be very important over the next 50 years. Defaults for all species are: Score = -2, Uncert = 0.5, and FutureRelevance = 4.

Browse—The extent to which browsing (by deer or other herbivores) has an effect on the species, either a positive effect by promoting growth or by effective strategies for herbivory avoidance, or a negative effect by overbrowsing. Defaults for all species are: Score = -2 (+1 if promoted by browsing), Uncert = 0.75, and FutureRelevance = 1.

Invasive plants—The effects of invasive plants on a species, either through competition for nutrients or as a pathogen. This factor is not yet well researched as to effects on individual tree species, but could be very important in the future as invasive species are usually more readily adapted to changing environments, and can form monotypic stands that restrict regeneration. Defaults for all species are: Score = -3, Uncert = 0.5, and FutureRelevance = 4.

Drought—Extended periods without sufficient access to water. Certain species are better adapted to drier conditions, allowing them to survive more-frequent or prolonged droughts. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 4.

Flood—Frequent or prolonged periods of standing water. Species adapted to sustained flooding will be positively affected and species vulnerable to flooding will be negatively affected by the assumed greater exposure to flooding under climate change. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 3.

Ice—The damaging effects of ice storms and potential for ice heaving on a species. Defaults for all species are: Score = -1, Uncert = 0.5, and FutureRelevance = 2.

Wind—The damaging effects of wind storms and uprooting potential (and top breakage) of a species. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 2. If a species is susceptible to windthrow, Score = -2; if it is resistant to windthrow, Score = +1.

Fire topkill—The effects of fire or fire suppression on the larger stems of a species (poles and sawtimber). Species adapted to fire will be positively affected by the assumed greater exposure to fire under climate change, whereas species vulnerable to fire will be negatively affected. As a first approximation, bark thickness relates directly to this ModFactor. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 2.

Harvest—If the species is harvested by using best management practices, is the species generally enhanced or diminished through time? If the best management practice includes replanting, that is included in the ranking. If the species is not a target species currently being managed within a harvest context, managers may consider how the species responds when it is an incidental species in harvested stands. Harvesting is generally low in urban areas, so this disturbance factor defaults to 0 and is not factored in unless there is an active attempt at managing this species (e.g., removal of woody invasive species). Defaults for all species are: Score = 0, Uncert = 0.5, and FutureRelevance = 2.

Temperature gradients—The effects of variations in the temperature gradient associated with a species. Species that currently occupy regions with a wide range of temperatures are assumed to be better adapted to warmer and highly variable climates than species occupying regions with a narrow range of temperatures. Defaults for all species are: Score = 1, Uncert = 0.75, and FutureRelevance = 2.

Air pollution—Airborne pollutants, including acid rain and ozone, that affect, mostly negatively, the growth, health, and distribution of a species. Defaults for all species are: Score = -2, Uncert = 0.75, and FutureRelevance = 3.

Soil and water pollution—Pollutants in the soil and water that affect, mostly negatively, the growth, health, and distribution of a species. Defaults for all species are: Score = -1, Uncert = 0.5, and FutureRelevance = 1.

Salt—The sensitivity of a species to road salt and salt spray. This also would include tolerance of any alternative ice control substances (assuming that information is available). Defaults for all species are: Score = -1, Uncert = 0.5, and FutureRelevance = 1. If a species is particularly susceptible to salt, Score =-2; if it is resistant to salt, Score = +1.

Biological Factors

Competition-light—The shade tolerance of a species. Does the species grow better in full sun, partial shade, or shade? Default values depend on the tolerance level of the species; default for all species is: FutureRelevance = 3. Species intolerant to shade receive: Score = -3, Uncert = 0.75. Species with intermediate shade tolerance receive Score = -1, 0, or 1, where the default is 0, with flexibility to go +1 or -1; Uncert = 0.5. Shade-tolerant species receive Score = +3 and Uncert = 0.75.

Edaphic specificity—The specific soil requirements (e.g., pH, texture, organic content, horizon thickness, permeability) for a species to survive in a suitable habitat; includes long-term soil moisture capacities of the soil. Species that tolerate a range of soil properties have positive scores, and species with specific requirements have negative defaults. Unsuitable soils north of the current range of a species can be a barrier to migration. Defaults for all species are: Score = 0, Uncert = 0.75, and FutureRelevance = 2.

Environmental habitat specificity—Considers the range of non-edaphic environmental characteristics (e.g., slope, aspect, topographic position, climatic modulation, specific associates) that the species requires; also considers whether the species may be able to survive a changed climate in relatively small refugia (e.g., coves, north-facing slopes). Defaults for all species are: Score = 0, Uncert = 0.75, and FutureRelevance = 3.

Dispersal—The ability of the species to effectively produce and distribute seeds; considers viability, production, production intervals, seed banking, dispersing agents (even humans), and other factors related to moving seeds across the landscape. Defaults for all species are: Score = 1, Uncert = 0.5, and FutureRelevance = 3.

Seedling establishment—The ability of the species to regenerate with seeds to maintain future populations; considers the conditions required for establishment of seedlings and survival rates for seedlings, but not necessarily to the sapling stage. Defaults for all species are: Score = 1, Uncert = 0.75, and FutureRelevance = 4.

Vegetative reproduction—The ability of the species to regenerate by means of stump sprouts or cloning (not necessarily growing into a sapling size). Species that can reproduce vegetatively have positive defaults and those that cannot have negative defaults. Defaults assume some vegetative reproduction, so for all species they are: Score = 1, Uncert = 0.75, and FutureRelevance = 2.

Fire regeneration—The capability for the species to be enhanced in regeneration through fire, usually surface fires. This score will never be less than 0 as it is used only if there is an extra benefit in fire to regenerate the species, above seedling establishment and vegetative reproduction. Defaults are: Score = 0, Uncert = 0.75, and FutureRelevance = 2.

An example score for naturally regenerating boxelder in a natural setting is given in Table 20.

Table 20.—Example of Natural Modifying Factor scores generated for the species boxelder

FactorType	ModFactor	Score	Uncert	Future Relevance	Weighted
Disturbance	Disease	-1	0.75	4	-3
Disturbance	Insect pests	-1	0.5	4	-2
Disturbance	Browse	-1	0.75	1	-0.75
Disturbance	Invasive plants	-1	0.5	4	-2
Disturbance	Drought	3	0.75	4	9
Disturbance	Flood	2	0.75	3	4.5
Disturbance	Ice	-2	0.5	1	
Disturbance	Wind	-2	0.75	2	-3
Disturbance	Fire topkill	-2	0.75	2	-3
Disturbance	Harvest	0	0.5	2	0
Disturbance	Temperature gradients	3	0.75	2	4.5
Disturbance	Air pollution	-2	0.75	3	-4.5
Disturbance	Soil and water pollution	-1	0.5	1	-0.5
Disturbance	Salt	1	0.5	1	0.5
Biological	Competition-light	2	0.75	3	4.5
Biological	Edaphic specificity	2	0.75	2	3
Biological	Environmental habitat specificity	1	0.75	3	2.25
Biological	Dispersal	3	1	3	9
Biological	Seedling establishment	3	0.75	4	9
Biological	Vegetative reproduction	2	0.75	2	3
Biological	Fire regeneration	1	0.75	2	1.5
	Average Disturbance Score				-0.09
	Average Biological Score				4.61
	Converted Dist Score				2.71
	Converted Bio Score				5
	Adapt Score				5.69
	Adapt Class				high

Factors for Planted Trees in Developed Areas

Scores for 179 species that are currently planted, being considered for planting lists in the area, or are native to the area and could be planted were evaluated for adaptability in planted environments. Factors, scores, and weighting were modified from naturally occurring trees to account for the different environments present in more-developed areas. Many biological factors were also altered to account for the fact that dispersal and reproduction are not typically factors for planted trees. Most information for native species was derived from Burns and Honkala (1990a, 1990b), with supplementary material relevant to cultivated environments from Gilman and Watson (1993). Most information for cultivars and nonnatives was taken from Gilman and Watson (1993). Additional information for wind and ice storm susceptibility were taken from Hauer et al. (2006) and Duryea et al. (2007).

Factors that received a weighted score of less than -4.5 or greater than 4.5 were listed in tables as contributing negatively or positively to the overall adaptability score of the species. Weighted scores between these two values were not listed. Disturbance and biological factors are defined next; and default values for the associated Score, Uncert, and FutureRelevance are provided where they differ from those for naturally occurring trees ("natural scores").

Disturbance Factors

Disease—Same as for natural scores.

Insect pests—Same as for natural scores.

Browse—Same as for natural scores, but default Score is increased from -2 to -1 because it is assumed herbivory would be lower in planted environments.

Invasive plants—Same as for natural scores, but defaults go to 0 because it is assumed that for the most part planted trees will be shielded from competition from invasive species.

Drought—Same as for natural scores, but default FutureRelevance is reduced from 4 to 3 because it is assumed that many planted trees will be watered during drought periods.

Flood—Same as for natural scores.

Ice—Same as for natural scores.

Wind—Same as for natural scores.

Temperature gradients—Same as for natural scores, but default FutureRelevance is increased from 2 to 3 because of the urban heat island effect.

Air pollution—Same as for natural scores, but default Score is reduced from -2 to -3 to account for the increased air pollution in developed areas.

Soil and water pollution—Same as for natural scores, but default Score is reduced from -1 to -2 to account for greater pollution in developed areas.

Salt—Same as for natural scores, but default Scores are reduced from -1 to -2 and for susceptible species from -2 to -3 to account for the greater road salt and salt spray on street and residential trees.

Biological Factors

Competition-light—Same as for natural scores.

Edaphic specificity—Same as for natural scores.

Land-use/Planting site specificity—The capability for the species to be planted in a variety of site types (street, residential, park, campus); also considers the range of non-edaphic environmental characteristics (e.g., slope, aspect, topographic position, climatic modulation, specific associates) that the species requires. Defaults for all species are: Score = 0, Uncert = 0.75, and FutureRelevance = 3.

Restricted rooting conditions and soil compaction—The ability of a species to grow and survive in narrow boulevards and other constrained spaces. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 3.

Nursery production potential—The ease and cost of producing the species in a nursery; also relates to how widely available it is. FutureRelevance is high for this factor because it will largely determine the extent to which the species is widely propagated and planted. Defaults for all species: Uncert = 0.75, and FutureRelevance = 4. If stock is widely available, Score = +2. If stock is not currently available, Score = -2.

Planting establishment—The ease with which the species establishes itself after planting; also relates to the amount of care required for the species to become established. Defaults for all species are: Score = 1, Uncert = 0.75, and FutureRelevance = 2. If the species is not easily established, Score = -1.

Maintenance required—The degree to which pruning or other maintenance is needed after establishment. Negative score indicates that maintenance is required. Defaults for all species are: Score = -1, Uncert = 0.75, and FutureRelevance = 2. If minimal maintenance is required, Score = 1.

Invasive potential—Likelihood that the species could become invasive if planted; applies to both native and nonnative species. Negative score indicates that a species is known to be or has the potential to be invasive. Defaults for all species are: Score = 0, Uncert = 0.75, and FutureRelevance = 3. If species is known to be invasive, Score = -3.

An example score for boxelder planted in a developed area is given in Table 21.

On the following pages are the resulting scores using the two scoring systems (Table 22).

Table 21.—Example of Planted Modifying Factor scores generated for the species boxelder

FactorType	ModFactor	Score	Uncert	Future Relevance	Weighted
Disturbance	Disease	-1	0.75	2	-1.5
Disturbance	Insect pests	-3	0.5	5	-7.5
Disturbance	Browse	-1	0.75	1	-0.75
Disturbance	Invasive plants	0	0.5	2	0
Disturbance	Drought	3	0.75	3	6.75
Disturbance	Flood	2	0.75	3	4.5
Disturbance	Ice	-1	0.5	2	-1
Disturbance	Wind	-1	0.75	2	-1.5
Disturbance	Temperature gradients	3	0.75	3	6.75
Disturbance	Air pollution	-2	0.75	3	-4.5
Disturbance	Soil and water pollution	-2	0.5	1	-1
Disturbance	Salt	1	0.5	1	0.5
Biological	Competition-light	2	0.5	1	1
Biological	Edaphic specificity	2	0.75	2	3
Biological	Land-use/Planting site specificity	1	0.75	3	2.25
Biological	Restricted rooting conditions	1	0.75	3	2.25
Biological	Nursery propagation	-1	0.75	4	-3
Biological	Planting establishment	2	0.75	2	3
Biological	Maintenance required	-1	0.75	2	-1.5
Biological	Invasive potential	-3	0.75	3	-6.75
	Average Disturbance Score				0.06
	Average Biological Score				0.03
	Converted Dist Score				2.83
	Converted Bio Score				3.38
	Adapt Score				4.41
	Adapt Class				medium

Table 22.—Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Accolade® elm	0	-0.48	2.59	4.76	high	TEM LPS NUP	--	n/a	n/a	n/a	n/a	--	--
'Accolade' flowering cherry	0	-0.92	1.5	4.21	medium	TEM NUP	FLO	n/a	n/a	n/a	n/a	--	--
Allegheny serviceberry	0	-1.67	1.88	4.66	high	LPS	DRO AIP	-1.88	2.36	4.57	high	COL	INPL DRO AIP
American basswood (American linden)	47	-0.79	0.28	4.01	medium	FLO TEM NUP	AIR RRC	-1.36	1.5	4.18	medium	FLO COL	INPL AIP SES
American beech	0	-1.58	-0.66	3.55	medium	--	FLO AIP LPS RRC	-1.89	1.5	4.25	medium	TEM	FLO FTK AIP COL
American elm	261	-1.94	0.94	3.92	medium	NUP	DISE DRO	-2.07	2.36	4.64	high	EHS	DISE DRO AIP
American hornbeam	1	-0.64	2.46	4.75	high	FLO TEM NUP	DRO AIP	-0.64	2.46	4.88	high	FLO COL SES	INPL DRO FTK
American plum	8	-1.02	1.63	4.33	medium	NUP	AIP	-1.11	0.64	3.96	medium	--	INPL AIP
American sycamore	0	-0.58	0.13	3.95	medium	TEM NUP	--	-0.88	0.75	4	medium	--	INPL
American witchhazel	11	-0.98	0.22	4.06	medium	TEM	INS AIP	-1.2	2.79	4.95	high	COL EHS	INS INPL AIP
Amur cherry	0	-2.25	2.31	4.57	high	LPS RRC	TEM AIP	n/a	n/a	n/a	n/a	--	--
Amur corktree	3	0.1	0.66	4.46	medium	TEM NUP	RRC INPO	-0.15	2.46	5.11	high	SES	COL
Amur honeysuckle	184	1.42	1.91	6.15	high	TEM AIP ESP LPS PLE MAR	INPO	0.86	5.14	4.5	high	TEM AIP COL ESP EHS DISP SES VRE	--
Amur maackia	0	0.56	2.34	4.85	high	DRO TEM LPS RRC NUP	FLO	n/a	n/a	n/a	n/a	--	--
Amur maple	36	-0.27	0.09	4.4	medium	TEM LPS	INPO	n/a	n/a	n/a	n/a	--	INS
Apple serviceberry	0	-2.06	3.13	5.06	high	LPS RRC NUP	DRO FLO AIP	n/a	n/a	n/a	n/a	--	--
Apple/crabapple species	105	-0.96	1.84	4.01	medium	TEM LPS RRC NUP	DISE INS AIP	n/a	n/a	n/a	n/a	--	--
Austrian pine	50	-0.65	0.72	3.91	medium	TEM RRC	DISE INS	n/a	n/a	n/a	n/a	--	--
Autumn-olive	10	-0.83	-0.59	4.06	medium	LPS	AIP NUP INPO	-0.48	2.89	5.09	high	EHS DISP	AIP
Baldcypress	2	0.02	2.28	4.9	high	FLO RRC NUP	AIP	n/a	n/a	n/a	n/a	--	--
Balsam fir	10	-2.19	1.13	4.22	medium	NUP	DRO TEM AIP	n/a	n/a	n/a	n/a	--	--
Bigtooth aspen	0	-0.92	-0.25	3.45	low	--	--	-1.07	1.14	4.57	high	VRE FRG	INPL DRO FTK AIP COL
Bitternut hickory	14	-0.5	-0.31	3.83	medium	DRO	AIP	-0.59	0.21	4.06	medium	DRO	INPL COL

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Black cherry	437	-1.58	-2.34	2.39	low	DRO TEM	AIP LPS RRC	-1.8	1.61	4.22	medium	DRO EHS SES	INPL FLO FTK AIP COL
Blackgum	0	-0.5	1.41	4.72	high	RRC	AIP	-0.05	2.79	5.31	high	COL	INPL
Blackhaw	2	-0.6	2.22	4.85	high	NUP TEM	INS	-0.91	2.25	4.73	high	EHS	INS INPL
Black Hills spruce	0	-1.65	1.03	3.92	medium	--	TEM AIP	n/a	n/a	n/a	n/a	--	--
Black locust	135	-1.23	-0.56	3.55	medium	DRO TEM	FLO AIP LPS RRC INPO	-1.29	2.04	4.66	high	DRO	INPL DRO AIP
Black maple	3	-1.71	0.38	4.06	medium	TEM	AIP	-2.02	2.89	4.78	high	COL EHS	INPL AIP INS
Black oak	4	-0.56	0.59	4	medium	DRO TEM	DISE INS	-0.88	1.61	4.61	high	DRO	DISE INS INPL
Black walnut	130	-1.02	0.32	3.97	medium	--	DRO AIP LPS RRC	-1.02	0.32	3.97	medium	SES	INPL DRO COL
Black willow	3	-1.58	-0.38	3.25	low	FLO	INS DRO AIP RRC	-1.7	-1.29	3.26	low	FLO	INS INPL DRO COL FTK AIP
Blue spruce	54	-1.4	0.75	3.95	medium	NUP	INS FLO AIP	n/a	n/a	n/a	n/a	--	--
Boxelder	481	0.06	0.03	4.41	medium	DRO FLO TEM	AIP INPO	-0.09	4.61	5.69	high	DRO FLO TEM COL DISP SES	AIP
Bur oak	87	0.58	0.84	4.54	high	DRO TEM AIP LPS NUP	DISE INSE FLO	0.25	1.39	4.77	high	DRO TEM AIP	DISE INS FLO
Callery pear	18	-0.73	1	4	medium	DRO TEM RRC NUP	INS INPO	n/a	n/a	n/a	n/a	--	--
Cherry plum	12	-1.48	1	3.82	medium	NUP	INS AIP	n/a	n/a	n/a	n/a	--	--
Chestnut oak	0	-1.04	1.94	4.7	high	LPS	INS AIP	-0.59	3.54	5.5	high	EHS SES VRE	INS INPL
Chinese catalpa	0	-0.94	1.06	4.12	medium	FLO TEM	AIP	n/a	n/a	n/a	n/a	--	--
Chinese chestnut	1	-0.52	-0.28	3.59	medium	TEM	--	n/a	n/a	n/a	n/a	--	--
Chinese fringetree	0	-1.04	2.06	4.77	high	LPS RRC	--	n/a	n/a	n/a	n/a	--	--
Chinese juniper	0	-0.31	1.69	4.5	high	DRO LPS NUP	FLO	n/a	n/a	n/a	n/a	--	--
Chinkapin oak	5	-0.42	1.22	4.4	medium	DRO TEM LPS	DISE INS AIP	-0.57	1.07	4.48	medium	DRO TEM	DISE INS INPL
Cockspur hawthorn	25	-1.02	2.5	4.59	high	DRO TEM LPS RRC NUP	INS AIP	n/a	n/a	n/a	n/a	--	--
Common chokecherry	7	-1.46	0.66	3.56	medium	NUP	DISE FLO AIP	-1.54	0.64	3.93	medium	--	DISE INPL FLO AIP COL

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Common elderberry	10	-0.23	0.34	3.91	medium	FLO TEM	AIP INPO	-0.14	2.57	5.16	high	FLO EHS DISP SES VRE	AIP COL
Common hackberry	53	0.31	1.66	4.7	high	DRO TEM LPS NUP	--	-0.38	2.36	4.96	high	DRO	INPL FTK
Common lilac	8	-1.69	1.69	3.88	medium	RRC NUP	FLO AIP	n/a	n/a	n/a	n/a	--	--
Common pear	17	-1.85	0.72	3.47	low	TEM NUP	DRO AIP	n/a	n/a	n/a	n/a	--	--
Common persimmon	0	0.69	1.97	4.76	high	DRO FLO TEM ESP RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Cornelian cherry dogwood	1	-0.81	0.13	4.06	medium	TEM	AIP	n/a	n/a	n/a	n/a	--	--
Crimean linden	0	-0.88	3.13	5.33	high	DRO TEM LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Cucumbertree	0	-1.48	0.34	3.8	medium	NUP	DRO AIP	n/a	n/a	n/a	n/a	--	--
Dawn redwood	0	0.1	1.03	4.35	medium	TEM	AIP	n/a	n/a	n/a	n/a	--	--
'Discovery' elm	0	-0.29	2.53	4.81	high	TEM LPS NUP	INS	n/a	n/a	n/a	n/a	--	--
Douglas-fir	5	-2.17	0.09	3.26	low	NUP	DRO FLO TEM LPS	n/a	n/a	n/a	n/a	--	--
Downy serviceberry	5	-0.5	2	4.97	high	TEM NUP	AIP	-1.25	4.39	5.76	high	COL EHS SES FRG	INPL FTK
Eastern cottonwood	98	-1.48	-0.38	3.1	low	TEM NUP	DISE INS AIP LPS RRC	-1.45	0.64	3.93	medium	TEM	DIS INS INPL AIP COL
Eastern hemlock	15	-2.54	-0.47	3.21	low	NUP	DRO AIP LPS	n/a	n/a	n/a	n/a	--	--
Eastern hophornbeam (ironwood)	44	-0.4	3	5.41	high	DRO TEM LPS RRC NUP	FLO AIP	-0.68	3.54	5.46	high	DRO TEM COL EHS	INPL FLO AIP
Eastern redbud	6	-0.5	1.38	4.31	medium	FLO TEM NUP	AIP	-0.5	2.36	4.96	high	FLO	INPL AIP
Eastern redcedar	35	0.08	1.75	4.71	high	DRO TEM LPS RRC	AIP	-0.32	-0.32	4.09	medium	DRO	INPL FTK COL
Eastern wahoo	4	-1.73	0.22	3.84	medium	--	AIP	-1.88	1.93	4.41	medium	COL	INPL AIP
Eastern white pine	99	-3.25	-0.59	2.9	low	NUP	DISE INS DRO TEM AIP LPS RRC	-3.07	1.29	3.75	medium	--	DISE INS INPL DRO FTK AIP
European alder	28	-0.35	0.13	4.25	medium	FLO	DISE AIP INPO	n/a	n/a	n/a	n/a	--	--
European beech	1	-2.04	0.44	3.76	medium	NUP	DRO LPS RRC	n/a	n/a	n/a	n/a	--	--

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
European buckthorn	2,595	2.02	0.72	5.86	high	DRO TEM ESP NUP	INPO	1.68	5.14	6.74	high	DRO TEM AIP COL ESP DISP SES VRE	--
European smoketree	1	-0.33	2.91	4.91	high	DRO LPS RRC NUP	FLO	n/a	n/a	n/a	n/a	--	--
European filbert	1	-1.48	0.66	3.71	medium	NUP	AIP RRC	n/a	n/a	n/a	n/a	--	--
European hornbeam	9	0.85	0.03	4.6	high	TEM	--	n/a	n/a	n/a	n/a	--	--
European larch	0	-1.77	0.44	3.67	medium	--	DRO TEM AIP	n/a	n/a	n/a	n/a	--	--
European mountain-ash	0	-1.65	2.81	4.51	high	LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Flowering dogwood	4	-2.13	1.5	4.3	medium	TEM LPS	DRO FLO AIP RRC	-2.32	3	4.86	high	COL	INPL DRO FLO AIP
Freeman maple	12	-0.23	2.25	4.91	high	TEM ESP LPS NUP	--	n/a	n/a	n/a	n/a	--	INS
'Frontier' elm	0	-0.15	2.5	4.91	high	DRO TEM LPS RRC	--	n/a	n/a	n/a	n/a	--	--
Glossy buckthorn	29	1.83	0.72	5.8	high	FLO TEM ESP NUP	INPO	1.63	5.14	6.74	high	FLO TEM AIP COL DIP SES	--
Gray alder	0	-1.73	1.09	4.17	medium	FLO	DRO AIP	-2.04	1.29	4.22	medium	FLO	INPL DRO FTK AIP
Gray birch	8	-2.27	-0.28	3.22	low	--	DISE INS AIP LPS	-2.54	1.39	4.16	medium	EHS	DISE INS INPL FTK AIP COL
Gray dogwood	5	-0.81	0.88	4.48	medium	TEM	--	-1.68	3	4.96	high	SES	INPL FTK
Green ash	413	-1.1	0.81	3.9	medium	FLO NUP	INS MAR	-1.27	1.18	4.48	medium	FLO	INS INPL COL
'Harvest Gold' linden	0	-0.92	1.31	4.27	medium	RRC	AIP	n/a	n/a	n/a	n/a	--	--
Hedge maple	0	-0.94	2.66	5.07	high	TEM LPS NUP	INS	n/a	n/a	n/a	n/a	--	INS
Heritage® oak	0	-0.21	2.78	5.19	high	DRO TEM LPS NUP	DISE INS	n/a	n/a	n/a	n/a	--	--
Higan cherry	0	-1.92	0.66	3.58	medium	--	FLO AIP RRC	n/a	n/a	n/a	n/a	--	--
Honeylocust	52	0.19	1.06	4.26	medium	DRO TEM RRC NUP	--	-0.09	1.61	4.72	high	DRO	INPL
Horse chestnut	3	-0.96	0.88	4.1	medium	TEM	AIP	n/a	n/a	n/a	n/a	--	--
Jack pine	2	-0.92	-0.38	3.4	low	DRO	AIP LPS RRC	n/a	n/a	n/a	n/a	--	--
Japanese maple	1	-1.6	1.84	4.25	medium	NUP	DRO AIP	n/a	n/a	n/a	n/a	--	INS
Japanese red pine	1	-1.6	-0.22	3.31	low	--	AIP	n/a	n/a	n/a	n/a	--	--

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Japanese tree lilac	1	-0.71	2.5	4.72	high	RRC LPS NUP	AIP	n/a	n/a	n/a	n/a	--	--
Japanese zelkova	1	0.17	1.94	4.6	high	TEM LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Katsura tree	1	-1.85	-0.41	3.31	low	DISE INS NUP	DRO WIN AIP RRC	n/a	n/a	n/a	n/a	--	--
Kentucky coffeetree	1	0.04	1.84	4.6	high	DRO LPS NUP	AIP	-0.23	0.32	4.26	medium	--	DRO INPL AIP COL
Korean mountain-ash	0	-1.88	1.22	3.65	medium	NUP	AIP	n/a	n/a	n/a	n/a	--	--
Korean Sun™ pear	0	-0.38	2.81	4.91	high	TEM LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Kousa dogwood	0	-1.94	1.88	4.63	high	NUP	DRO AIP	n/a	n/a	n/a	n/a	--	--
Leatherleaf viburnum	1	-1.75	1.72	4.51	high	NUP	AIP	n/a	n/a	n/a	n/a	--	--
Littleleaf linden	10	-0.94	1.81	4.59	high	LPS NUP	INS SAL	n/a	n/a	n/a	n/a	--	--
London planetree	0	-0.67	1.81	4.42	medium	DRO FLO TEM NUP	DISE AIP	n/a	n/a	n/a	n/a	--	--
Maidenhair tree	7	1.52	3	5.97	high	DRO TEM LPS RRC NUP	FLO	n/a	n/a	n/a	n/a	--	--
Miyabe maple	0	0.58	0.84	4.91	high	--	AIP	n/a	n/a	n/a	n/a	--	INS
Mockernut hickory	6	0.25	2.31	4.8	high	TEM	AIP	-0.79	1.18	4.44	medium	--	INPL FTK COL
Morden hawthorn	69	-1.17	0.91	4.29	medium	NUP	AIP	n/a	n/a	n/a	n/a	--	--
Nannyberry	3	-0.48	2.66	5.15	high	TEM RRC NUP	--	-1.05	2.25	4.73	high	COL	INPL
Northern catalpa	2	-0.65	-0.56	3.45	low	--	AIP	-1.05	-0.96	3.44	low	--	INPL AIP COL EHS
Northern pin oak (Hill's oak)	1	-1.5	0.84	3.77	medium	DRO LPS	TEM AIP	-1.27	1.07	4.22	medium	DRO	INPL
Northern red oak	170	-0.23	2.53	5.02	high	TEM LPS NUP	DISE INS INPL	-0.59	1.82	4.88	high	--	DISE INS INPL
Northern white-cedar (arborvitae)	133	-1.96	1.5	4.44	medium	NUP	DRO AIP	-2.23	2.04	4.38	medium	COL	INPL DRO SIP
Norway maple	106	-0.19	2.34	5.21	high	DRO FLO ESP RRC NUP	INS INPO	-0.14	4.71	5.97	high	DRO FLO COL ESP EHS SES	INS
Norway spruce	21	-1.67	0.72	3.61	medium	NUP	INS FLO AIP	n/a	n/a	n/a	n/a	--	--
Ohio buckeye	3	-1.81	0.38	3.88	medium	--	AIP	-1.68	-1.29	3.08	low	COL	NPL SES
Oriental spruce	0	-2.1	0.91	3.99	medium	--	AIP	n/a	n/a	n/a	n/a	--	--
Osage-orange	3	0.23	2.66	5.15	high	DRO TEM ESP RRC NUP	AIP	-0.2	2.04	4.95	high	DRO ESP EHS	INPL

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Pacific Sunset® maple	0	-0.54	2.75	5.22	high	DRO TEM LPS RRC	INS	n/a	n/a	n/a	n/a	--	INS
Pagoda dogwood	2	-1.73	1.66	4.29	medium	NUP	AIP	-2.2	2.14	4.46	medium	COL	INPL FTK
Paper birch	23	-2.42	1.03	3.65	medium	NUP	DRO TEM AIP	-2.91	1.61	4.36	medium	EHS FRG	INPL DRO FTK AIP COL
Peach	8	-1.42	0.38	3.61	medium	NUP	DRO FLO	n/a	n/a	n/a	n/a	--	--
Peachleaf willow	6	-1.75	0.09	3.32	low	FLO	AIP	-1.75	-1.07	3.49	low	FLO	INPL AIP COL SES
Pecan	0	-1.85	-0.31	3.15	low	NUP	AIP LPS RRC	n/a	n/a	n/a	n/a	--	--
Peking lilac	0	-1.04	2.03	4.67	high	LPS NUP	FLO TEM	n/a	n/a	n/a	n/a	--	--
Pignut hickory	0	-0.5	0.16	4.1	medium	TEM		-1.14	2.25	4.73	high	EHS	
Pin cherry	2	-1.71	-0.47	3.1	low	--	DRO AIP LPS	-1.8	0.86	4.06	medium	SES FRG	INLP DRO AIP COL
Pin oak	22	-0.94	1.31	3.91	medium	FLO TEM RRC NUP	DISE INS AIP	-0.82	-0.43	3.66	medium	FLO	DISE INS INPL FTK COL
'Prairie Gem' Ussurian pear	0	-0.63	2.34	4.57	high	TEM LPS NUP	AIP	n/a	n/a	n/a	n/a	--	--
Prickly ash	9	-0.5	-1.44	3.48	low	--	AIP LPS INPO	-0.68	2.68	5.05	high	EHS VRE	INPL AIP
Privet	1	-1.54	0.69	4.1	medium	TEM NUP	AIP INPO	-1.45	4.71	5.81	high	COL EHS DISP SES VRE	AIP
'Prospector' Wilson elm	0	-0.6	0.38	4.1	medium	DRO LPS		n/a	n/a	n/a	n/a	--	--
Pussy willow	5	-1.27	-0.19	3.3	low	FLO TEM NUP	DRO AIP LPS RRC	-1.13	0.75	4.24	medium	FLO DISP SES FRG	INPL DRO AIP COL EHS
Quaking aspen	17	-1.73	0.19	3.37	low	TEM NUP	INS DRO AIP RRC INPO	-2.52	1.82	4.41	medium	TEM EHS VRE	INS INPL DRO FTK AIP COL
Red maple	17	-1.23	1.25	4.25	medium	FLO TEM ESP LPS NUP	INS DRO AIP	-1.46	4.39	5.52	high	FLO COL ESP EHS SES VRE	INS INPL DRO
Red mulberry	4	-1.13	0.38	3.97	medium	TEM NUP	AIP	-1.63	1.93	4.44	medium	COL	INPL AIP FTK
Red pine	1	-2.04	-1.03	2.7	low	--	INS DRO AIP RRC	n/a	n/a	n/a	n/a	--	--
River birch	29	-0.9	1.22	3.85	medium	TEM LPS NUP	DISE INS DRO	-1.75	0.86	4.06	medium	--	DISE INS INPL DRO FTK COL

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Robusta poplar	0	-0.25	1.5	4.4	medium	DRO NUP	--	n/a	n/a	n/a	n/a	--	--
Rose-of-Sharon	3	-1.33	1.97	4.55	high	NUP	AIP	n/a	n/a	n/a	n/a	--	--
Russian -olive	3	0.77	1.41	4.89	high	DRO TEM NUP	INPO	0.61	2.89	5.67	high	DRO TEM DISP EHS SES	COL
Sargent cherry	5	-1.23	1.19	3.82	medium	TEM LPS RRC	WIN AIP	n/a	n/a	n/a	n/a	--	--
Sassafras	3	-1.08	2	4.12	medium	DRO NUP		n/a	n/a	n/a	n/a	--	--
Saucer magnolia	2	-0.83	2.06	4.63	high	TEM NUP	DRO FLO	n/a	n/a	n/a	n/a	--	--
Scarlet oak	0	-0.96	2	4.59	high	ESP LPS	AIP	-1.38	2.68	5.02	high	ESP EHS VRE	INPL AIP
Scholar tree	0	-0.08	1.94	4.5	high	DRO TEM LPS RRC NUP	FLO	n/a	n/a	n/a	n/a	--	--
Scotch pine	1	-0.79	1.97	4.42	medium	NUP	INS	n/a	n/a	n/a	n/a	--	--
Serbian spruce	4	0.1	1.88	4.06	medium	NUP	INS	n/a	n/a	n/a	n/a	--	--
Shagbark hickory	102	-1.08	-1.06	3.51	medium	TEM	AIP	-1.59	2.14	4.66	high	--	INPL AIP
Shantung maple	0	-0.31	3	5.41	high	DRO TEM LPS RRC NUP	INS	n/a	n/a	n/a	n/a	--	INS
Shellbark hickory	1	-2.04	-1.03	3.26	low	--	--	-2.14	1.18	3.99	medium	COL	INPL DRO AIP EHS
Shingle oak	1	-0.08	1.88	4.8	high	DRO NUP	DISE INS AIP	-0.45	0.75	4.33	medium	DRO EHS	DISE INS INPL AIP COL
Shumard oak	0	0.79	1.69	4.57	high	DRO FLO TEM LPS RRC NUP	--	0.29	0.11	4.3	medium	DRO FLO TEM	INPL COL
Siberian elm	122	-0.17	-1.25	3.51	medium	DRO	WIN INPO	-0.04	2.25	4.83	high	DRO EHS SES	WIN COL
Silver linden	0	-1.17	0.91	4.01	medium	TEM NUP	INS AIP	n/a	n/a	n/a	n/a	--	--
Silver maple	155	-0.33	0.13	4.05	medium	FLO TEM NUP	RRC	-1.05	3.32	5.18	high	FLO COL DISP SES	INS INPL
Slippery elm	37	-1.42	0.94	3.99	medium	TEM LPS	DISE	-1.93	1.61	4.22	medium	--	DISE INPL FTK AIP COL
Smoothleaf elm	0	-2.35	-0.47	3.02	low	--	DISE AIP	n/a	n/a	n/a	n/a	--	--
'Snow Goose' cherry	0	-1.19	2.59	4.85	high	NUP	--	n/a	n/a	n/a	n/a	--	--
Staghorn sumac	0	-0.08	-0.19	3.95	medium	DRO TEM	AIP RRC	-0.73	1.93	4.77	high	DRO TEM SES VRE FRG	INPL FLO FTK COL
Star magnolia	4	-1.85	1.84	4.37	medium	NUP	DRO AIP	n/a	n/a	n/a	n/a		

(Continued)

Table 22.—*(Continued)* Overall Disturb, Bio, and Adapt score, and adaptability class, for species in natural[1] and planted environments

Common name	Number of trees[2]	Planted Disturb Score	Planted Bio Score	Planted Adapt Score	Planted Adapt Class	Positive traits–planted[3]	Negative traits–planted[3]	Natural Disturb Score	Natural Bio Score	Natural Adapt Score	Natural Adapt Class	Positive traits–natural[3]	Negative traits–natural[3]
Sugar maple	213	-1.83	1.03	4.17	medium	NUP	INS FLO AIP	-2.07	3.21	4.78	high	COL	INS INPL FLO AIP
Sugarberry	0	-0.42	-0.59	3.81	medium	DRO FLO TEM	WIN AIP NUP	n/a	n/a	n/a	n/a	--	--
Swamp white oak	6	-0.58	1.84	4.57	high	TEM RRC NUP	AIP	-0.63	1.18	4.36	medium	--	INPL AIP
Sweetgum	1	-0.44	-0.28	3.74	medium	--	INS DRO RRC	n/a	n/a	n/a	n/a	--	--
Sycamore maple	0	-1.75	1.16	4.25	medium	NUP	INS AIP	n/a	n/a	n/a	n/a	--	INS
Tree of heaven	71	1.4	-1.88	4.54	high	DRO TEM AIP ESP	LPS NUP INPO	1.18	4.82	6.58	high	DRO AIP ESP EHS DISP SES VRE FRG	--
Triumph™ elm	0	-0.52	3	5.15	high	DRO TEM LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Turkish hazelnut	0	0.38	1.75	4.71	high	DRO TEM LPS RRC	--	n/a	n/a	n/a	n/a	--	--
Washington hawthorn	1	-1.25	1.97	4.32	medium	DRO TEM RRC NUP	DISE INS	n/a	n/a	n/a	n/a	--	--
Weeping willow	1	-0.5	-0.88	3.57	medium	FLO TEM NUP	INS AIP LPS RRC	n/a	n/a	n/a	n/a	--	--
White ash	234	-2.52	-0.28	3.22	low	TEM NUP	INS AIP RRC	-2.39	1.39	4.12	medium	--	INS INPL AIP COL
White fir	0	-0.63	-0.59	3.87	medium	--	DLO AIP	n/a	n/a	n/a	n/a	--	--
White fringetree	0	-1.08	2.47	4.92	high	LPS RRC	--	n/a	n/a	n/a	n/a	--	--
White mulberry	90	0.33	-0.22	4.06	medium	NUP	LPS INPO	0.13	2.46	4.99	high	EHS SES	
White oak	101	-0.81	0.53	4.25	medium	TEM ESP LPS	FLO AIP	-0.86	3.11	5.37	high	TEM ESP EHS	INPL AIP
White poplar	6	-0.29	-0.56	3.59	medium	DRO TEM ESP NUP	INS WIN LPS RRC	n/a	n/a	n/a	n/a	--	--
White spruce	91	-0.79	0.88	4.15	medium		INS	n/a	n/a	n/a	n/a	--	--
Willow oak	0	0.25	2.31	4.8	high	FLO LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Winged burningbush	9	-0.42	1.44	4.81	high	TEM NUP	INPO	-0.66	3.21	5.4	high	COL EHS	FTK
'Winter King' green hawthorn	0	-1.15	3.09	4.77	high	LPS RRC NUP	--	n/a	n/a	n/a	n/a	--	--
Yellow buckeye	0	-1.21	0.47	4.1	medium	--	DRO AIP	n/a	n/a	n/a	n/a	--	--
Yellow-poplar (tuliptree)	1	-1.92	0.09	3.47	low	NUP	DRO AIP RRC	-1.66	3.75	5.39	high	EHS SES FRG	INPL DRO AIP
Yellowwood	0	-0.33	1.47	4.51	high	TEM RRC	AIP	n/a	n/a	n/a	n/a	--	--

[1] The designation "n/a" means that this tree does not occur outside of cultivated settings in this area.
[2] Number of individuals in the most recent tree census (Nowak et al. 2013).
[3] See Table 5 for trait codes.

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APPENDIX 7

TREE SPECIES VULNERABILITY

Overall vulnerability of trees present in the Chicago Wilderness region and those being considered for planting was assessed by combining information about projected changes in habitat suitability and adaptive capacity (see Appendix 6 and Table 23).

For species where information was available from the Tree Atlas, the following matrix was used to determine vulnerability:

Projected Change in Habitat Suitability (Tree Atlas)	Adapt Class		
	Low	**Medium**	**High**
Decrease (both scenarios)	high	moderate-high	moderate
Mixed results	moderate-high	moderate	low-moderate
No effect	moderate-high	low-moderate	low
Increase (both scenarios)	moderate	low-moderate	low

For species where no model information was available, the following matrix was used to determine vulnerability:

Hardiness/Heat Zone Effect	Adapt Class		
	Low	**Medium**	**High**
Negative	high	moderate-high	moderate
No effect	moderate-high	low-moderate	low
Positive	moderate	low-moderate	low

Confidence ratings were generally based on the level of evidence to support the vulnerability rating and the level of agreement among that evidence (Intergovernmental Panel on Climate Change 2014). Reliable model projections that tended to agree across climate scenarios resulted in higher confidence ratings. If adaptive capacity was high and model projections were favorable for that species, this also resulted in a higher confidence rating. If model results were not available, confidence was higher if there was sufficient information on the adaptive capacity of the species and the hardiness and heat zones to make a determination. Species for which there was very little information on adaptive capacity and no model projections received a low vulnerability rating.

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Table 23.—Overall vulnerability, and associated information, for tree species in the Chicago Wilderness region

Common name	Origin	Estimated number of trees	Planted Adapt Class	Natural Adapt Class[1]	Projected change: Tree Atlas	Heat/ Hardiness zone effect	Overall vulnerability	Confidence
Accolade® elm	cultivar	0	high	n/a	not modeled	positive	low	medium
'Accolade' flowering cherry	cultivar	0	medium	n/a	not modeled	positive	low-moderate	low-medium
Allegheny serviceberry	native	0	high	high	not modeled	no effect	low	low-medium
American basswood (American linden)	native	822,780	medium	medium	no change	not evaluated	low-moderate	medium
American beech	native	0	medium	medium	mixed results	not evaluated	moderate	medium
American elm	native	5,363,030	medium	high	increase	not evaluated	low-moderate	medium-high
American hornbeam	native	26,130	high	high	increase	not evaluated	low	high
American plum	native	150,100	medium	medium	mixed results	not evaluated	moderate	low-medium
American sycamore	native	7,970	medium	medium	increase	not evaluated	low-moderate	medium
American witchhazel	native	206,360	medium	high	not modeled	no effect	low-moderate	low
Amur cherry	nonnative	0	high	n/a	not modeled	•	low	low
Amur corktree	invasive	7,970	medium	high	not modeled	no effect	low-moderate	low
Amur honeysuckle	Invasive	3,370,400	high	high	not modeled	no effect	low	low
Amur maackia	nonnative	744,480	high	n/a	not modeled	negative	moderate	low
Amur maple	invasive	36	medium	n/a	not modeled	negative	moderate-high	low
Apple serviceberry	nonnative	0	high	n/a	not modeled	negative	moderate	low
Apple/crabapple species	cultivar	1,724,980	medium	n/a	not modeled	no effect	moderate	low
Austrian pine	nonnative	983,160	medium	n/a	not modeled	positive	low-moderate	low
Autumn-olive	invasive	228,040	medium	high	not modeled	no effect	low-moderate	low
Baldcypress	native	26,030	high	n/a	not modeled	positive	low	medium
Balsam fir	native	205,390	medium	n/a	not modeled	negative	high	medium
Bigtooth aspen	native	0	low	high	decrease	not evaluated	high	medium-high
Bitternut hickory	native	186,540	medium	medium	increase	not evaluated	low-moderate	medium-high
Black cherry	native	7,737,030	low	medium	decrease	not evaluated	high	medium-high
Blackgum	native	0	high	high	increase	not evaluated	low	high
Blackhaw	native	68,650	high	high	not modeled	no effect	low	low
Black Hills spruce	native	0	medium	n/a	not modeled	negative	moderate-high	low
Black locust	native	2,972,090	medium	high	increase	not evaluated	low	high
Black maple	native	69,910	medium	high	not modeled	no effect	moderate	low
Black oak	native	53,670	medium	high	no change	not evaluated	low	medium
Black walnut	native	2,469,240	medium	medium	increase	not evaluated	moderate	medium
Black willow	native	44,830	low	low	increase	not evaluated	moderate	medium
Blue spruce	native	1,107,240	medium	n/a	not modeled	no effect	moderate	low
Boxelder	native	8,597,890	medium	high	increase	not evaluated	low	high
Bur oak	native	1,603,410	high	high	no change	not evaluated	low	medium-high
Callery pear	invasive	257,690	medium	n/a	not modeled	positive	low-moderate	low
Cherry plum	nonnative	157,440	medium	n/a	not modeled	positive	low-moderate	low
Chestnut oak	native	0	high	high	not modeled	no effect	low	low
Chinese catalpa	nonnative	0	medium	n/a	not modeled	•	moderate	low
Chinese chestnut	nonnative	11,090	medium	n/a	not modeled	no effect	moderate	low
Chinese fringetree	nonnative	0	high	n/a	not modeled	positive	low	low
Chinese juniper	nonnative	0	high	n/a	not modeled	no effect	low	low
Chinkapin oak	native	79,770	medium	medium	new habitat	not evaluated	moderate	medium
Cockspur hawthorn	native	320,200	high	n/a	not modeled	negative	moderate	low
Common chokecherry	native	114,910	medium	medium	decrease	not evaluated	moderate-high	low-medium
Common elderberry	native	197,340	medium	high	not modeled	no effect	low-moderate	low
Common hackberry	native	1,020,060	high	high	increase	not evaluated	low	high

(Continued)

Table 23.—*(Continued)* Overall vulnerability, and associated information, for tree species in the Chicago Wilderness region

Common name	Origin	Estimated number of trees	Planted Adapt Class	Natural Adapt Class[1]	Projected change: Tree Atlas	Heat/ Hardiness zone effect	Overall vulnerability	Confidence
Common lilac	nonnative	109,050	medium	n/a	not modeled	no effect	moderate	low
Common pear	nonnative	266,140	low	n/a	not modeled	no effect	moderate-high	low
Common persimmon	native	0	high	n/a	new habitat	not evaluated	low	high
Cornelian cherry dogwood	cultivar	11,090	medium	n/a	not modeled	no effect	moderate	low
Crimean linden	nonnative	0	high	n/a	not modeled	negative	moderate	low
Cucumbertree	native	0	medium	n/a	not modeled	no effect	moderate	low
Dawn redwood	nonnative	0	medium	n/a	not modeled	positive	moderate	low
'Discovery' elm	cultivar	0	high	n/a	not modeled	•	low	low
Douglas-fir	native	108,410	low	n/a	not modeled	negative	high	low
Downy serviceberry	native	57,460	high	high	not modeled	no effect	low	low
Eastern cottonwood	native	2,198,060	low	medium	increase	not evaluated	moderate	high
Eastern hemlock	native	268,660	low	n/a	not modeled	no effect	high	low-medium
Eastern hophornbeam (ironwood)	native	602,120	high	high	mixed results	not evaluated	low-moderate	medium
Eastern redbud	native	110,420	medium	high	new habitat	not evaluated	low-moderate	medium-high
Eastern redcedar	native	563,500	high	medium	increase	not evaluated	low-moderate	medium-high
Eastern wahoo	native	46,320	medium	medium	not modeled	•	moderate	low
Eastern white pine	native	1,525,970	low	n/a	not modeled	negative	high	high
European alder	invasive	382,610	medium	n/a	not modeled	positive	moderate-high	low
European beech	nonnative	20,240	medium	high	not modeled	no effect	low-moderate	low
European buckthorn	invasive	44,281,470	high	n/a	not modeled	no effect	low	low
European filbert	nonnative	17,440	medium	n/a	not modeled	no effect	moderate	low
European hornbeam	nonnative	99,760	high	n/a	not modeled	negative	low	low
European larch	nonnative	0	medium	n/a	not modeled	negative	moderate-high	low
European mountain-ash	nonnative	0	high	n/a	not modeled	positive	moderate	low
European smoketree	nonnative	13,070	high	high	increase	not evaluated	low	low
Flowering dogwood	native	81,590	medium	n/a	not modeled	no effect	low-moderate	medium-high
Freeman maple	cultivar	280,470	high	n/a	not modeled	•	low	low-medium
'Frontier' elm	cultivar	0	high	high	not modeled	no effect	low	low
Glossy buckthorn	invasive	500,900	high	medium	not modeled	negative	low	low
Gray alder	native	0	medium	medium	not modeled	negative	moderate-high	low
Gray birch	native	145,590	low	high	not modeled	no effect	high	low
Gray dogwood	native	68,010	medium	medium	increase	not evaluated	moderate	low
Green ash	native	8,657,000	medium	n/a	not modeled	negative	moderate	medium-low
'Harvest Gold' linden	cultivar	0	medium	n/a	not modeled	positive	moderate-high	low
Hedge maple	nonnative	0	high	n/a	not modeled	•	low	low
Heritage® oak	cultivar	0	high	n/a	not modeled	positive	low	low
Higan cherry	cultivar	0	medium	high	increase	not evaluated	low-moderate	low
Honeylocust	native	997,510	medium	n/a	not modeled	no effect	low-moderate	medium-high
Horse chestnut	nonnative	40,250	medium	n/a	mixed results	not evaluated	moderate	low
Jack pine	native	25,720	low	n/a	not modeled	no effect	high	medium
Japanese maple	nonnative	36,060	medium	n/a	not modeled	negative	moderate	low
Japanese red pine	nonnative	11,090	low	n/a	not modeled	negative	high	low
Japanese tree lilac	nonnative	19,020	high	n/a	not modeled	positive	moderate	low
Japanese zelkova	nonnative	11,090	high	n/a	not modeled	no effect	low	low
Katsura tree	nonnative	11,090	low	medium	new habitat	not evaluated	high	low
Kentucky coffeetree	native	33,380	high	n/a	not modeled	positive	low	medium-high
Korean mountain-ash	nonnative	0	medium	n/a	not modeled	•	low-moderate	low

(Continued)

Table 23.—*(Continued)* Overall vulnerability, and associated information, for tree species in the Chicago Wilderness region

Common name	Origin	Estimated number of trees	Planted Adapt Class	Natural Adapt Class[1]	Projected change: Tree Atlas	Heat/ Hardiness zone effect	Overall vulnerability	Confidence
Korean Sun™ pear	nonnative	0	high	n/a	not modeled	positive	low	low
Kousa dogwood	nonnative	0	high	n/a	not modeled	positive	low	low
Leatherleaf viburnum	nonnative	17,440	high	n/a	not modeled	no effect	low	low
Littleleaf linden	nonnative	789,950	high	n/a	not modeled	•	low	low
London planetree	nonnative	0	medium	n/a	not modeled	no effect	moderate	low
Maidenhair tree	nonnative	199,650	high	n/a	not modeled	no effect	low	low
Miyabe maple	cultivar	0	high	medium	new habitat	not evaluated	low	low
Mockernut hickory	native	6	high	n/a	not modeled	no effect	low-moderate	medium
Morden hawthorn	cultivar	121,430	medium	high	not modeled	no effect	moderate	low
Nannyberry	native	69,310	high	low	not modeled	no effect	low	low
Northern catalpa	native	59,440	low	medium	decrease	not evaluated	moderate-high	low
Northern pin oak (Hill's oak)	native	20,240	medium	high	mixed results	not evaluated	high	high
Northern red oak	native	3,087,850	high	medium	not modeled	negative	low-moderate	medium
Northern white-cedar (arborvitae)	native	2,457,220	medium	high	not modeled	negative	moderate-high	low
Norway maple	invasive	1,858,800	high	n/a	not modeled	no effect	moderate	low
Norway spruce	nonnative	377,510	medium	low	new habitat	not evaluated	moderate	low
Ohio buckeye	native	64,160	medium	n/a	not modeled	no effect	moderate	medium
Oriental spruce	nonnative	0	medium	high	increase	not evaluated	moderate	low
Osage-orange	native	80,910	high	medium	not modeled	no effect	low	high
Pacific Sunset® maple	cultivar	0	high	medium	increase	not evaluated	low	low
Pagoda dogwood	native	34,590	medium	medium	decrease	not evaluated	moderate	low
Paper birch	native	352,400	medium	n/a	not modeled	positive	high	high
Peach	nonnative	107,320	medium	low	not modeled	no effect	low-moderate	low
Peachleaf willow	native	77,720	low	n/a	new habitat	not evaluated	moderate-high	low
Pecan	native	0	low	n/a	not modeled	negative	moderate	medium
Peking lilac	nonnative	0	high	high	increase	not evaluated	moderate	medium
Pignut hickory	native	0	medium	medium	not modeled	•	low-moderate	medium
Pin cherry	native	40,550	low	medium	increase	not evaluated	moderate-high	low
Pin oak	native	360,430	medium	n/a	not modeled	•	low-moderate	medium
'Prairie Gem' Ussurian pear	cultivar	0	high	high	not modeled	no effect	low	low
Prickly ash	native	207,940	low	high	not modeled	positive	low	low
Privet	invasive	7,940	medium	n/a	not modeled	•	low-moderate	low
'Prospector' Wilson elm	cultivar	0	medium	medium	not modeled	no effect	moderate	low
Pussy willow	native	55,420	low	medium	decrease	not evaluated	moderate	low
Quaking aspen	native	230,070	low	high	increase	not evaluated	high	high
Red maple	native	340,290	medium	medium	increase	not evaluated	low-moderate	medium-high
Red mulberry	native	66,440	medium	n/a	decrease	not evaluated	low-moderate	medium-high
Red pine	native	15,010	low	medium	increase	not evaluated	high	high
River birch	native	552,800	medium	n/a	not modeled	•	low-moderate	medium-high
Robusta poplar	cultivar	0	medium	n/a	not modeled	positive	moderate	low
Rose-of-Sharon	nonnative	77,240	high	high	not modeled	no effect	low	low
Russian-olive	invasive	54,970	high	n/a	not modeled	no effect	low	low
Sargent cherry	cultivar	80,070	medium	n/a	increase	not evaluated	moderate	low
Sassafras	native	47,370	medium	n/a	not modeled	positive	low-moderate	medium-high
Saucer magnolia	cultivar	26,030	high	high	decrease	not evaluated	low	low
Scarlet oak	native	0	high	n/a	not modeled	positive	moderate	low-medium
Scholar tree	nonnative	0	high	n/a	not modeled	negative	low	low

(Continued)

Table 23.—*(Continued)* Overall vulnerability, and associated information, for tree species in the Chicago Wilderness region

Common name	Origin	Estimated number of trees	Planted Adapt Class	Natural Adapt Class[1]	Projected change: Tree Atlas	Heat/ Hardiness zone effect	Overall vulnerability	Confidence
Scotch pine	nonnative	23,500	medium	n/a	not modeled	no effect	moderate-high	low
Serbian spruce	nonnative	78,160	medium	high	increase	not evaluated	moderate	low
Shagbark hickory	native	1,711,410	medium	n/a	not modeled	no effect	low-moderate	medium
Shantung maple	nonnative	0	high	medium	increase	not evaluated	low	low
Shellbark hickory	native	9,750	low	medium	increase	not evaluated	moderate	low-medium
Shingle oak	native	23,500	high	medium	not modeled	positive	low-moderate	medium
Shumard oak	native	0	high	high	not modeled	no effect	low-moderate	low
Siberian elm	invasive	2,240,590	medium	n/a	not modeled	•	low-moderate	low
Silver linden	nonnative	0	medium	high	increase	not evaluated	moderate	low
Silver maple	native	3,209,940	medium	medium	increase	not evaluated	low-moderate	medium-high
Slippery elm	native	453,470	medium	n/a	not modeled	positive	low-moderate	medium-high
Smoothleaf elm	nonnative	0	low	n/a	not modeled	positive	moderate	low
'Snow Goose' cherry	cultivar	0	high	high	not modeled	no effect	low	low
Staghorn sumac	native	0	medium	n/a	not modeled	no effect	low-moderate	low
Star magnolia	nonnative	69,320	medium	high	mixed results	not evaluated	moderate	low
Sugar maple	native	4,457,170	medium	n/a	new habitat	not evaluated	moderate	medium
Sugarberry	native	0	medium	n/a	not modeled	no effect	low-moderate	medium
Swamp white oak	native	104,750	high	n/a	increase	not evaluated	low-moderate	medium-high
Sweetgum	native	17,090	medium	n/a	not modeled	positive	low-moderate	low-medium
Sycamore maple	nonnative	0	medium	high	not modeled	positive	low-moderate	low
Tree of heaven	invasive	1,830,940	high	n/a	not modeled	no effect	low	low
Triumph™ elm	cultivar	0	high	n/a	not modeled	negative	low	low
Turkish hazelnut	nonnative	0	high	n/a	not modeled	no effect	moderate	low
Washington hawthorn	native	23,100	medium	n/a	not modeled	no effect	moderate	low
Weeping willow	nonnative	11,090	medium	medium	increase	not evaluated	moderate	low
White ash	native	4,025,410	low	n/a	not modeled	negative	moderate-high	low-medium
White fir	native	0	medium	n/a	not modeled	no effect	moderate-high	low
White fringetree	nonnative	0	high	high	not modeled	no effect	low	low
White mulberry	invasive	1,584,250	medium	high	decrease	not evaluated	low-moderate	low
White oak	native	1,857,380	medium	medium	decrease	not evaluated	moderate-high	low-medium
White poplar	nonnative	95,600	medium	n/a	not modeled	no effect	moderate	low
White spruce	native	1,786,850	medium	n/a	decrease	not evaluated	high	high
Willow oak	native	0	high	n/a	not modeled	positive	low	low
Winged burningbush	invasive	148,650	high	high	not modeled	no effect	low	low
'Winter King' green hawthorn	cultivar	0	high	n/a	not modeled	negative	moderate	low
Yellow buckeye	native	0	medium	n/a	not modeled	no effect	moderate	low
Yellow-poplar (tuliptree)	native	17,440	low	high	increase	not evaluated	moderate	low-medium
Yellowwood	native	0	high	n/a	not modeled	no effect	low	low

[1] The designation "n/a" means that this tree does not occur outside of cultivated settings in this area.

A "0" indicates that no trees of this species or cultivar were detected in the most recent tree census (Nowak et al. 2013).

• indicates insuffcient information.

APPENDIX 8

URBAN FOREST VULNERABILITY WORKSHEET AND INSTRUCTIONS

Case Study Process

Representatives from four municipalities, three park districts, and three forest preserve districts in the Chicago Wilderness region were selected to participate in a 1-day workshop at The Morton Arboretum in November 2014. Participant selection was based on a combination of participants' interest/availability and the need for a range of levels of development (urban-rural), economic means, and geographic locations. We recruited participants through phone calls and in-person conversations at local urban forestry-related events in the Chicago region.

Participants were given presentations on past and projected climate change, model projections for tree species, and the adaptive capacity of trees. After presentations were completed, each participant was given instructions and a worksheet (see following sections). When available, additional information such as soil drainage class and inventory data was also provided. Each participant completed his or her own worksheet, but was grouped with like organizations to share ideas (e.g., all municipalities were together). Each group had a facilitator to walk group members through worksheet questions and a note-taker to record group discussion. Participants were given about 3 hours to complete the worksheet and were asked to rely primarily on their personal knowledge about the place they manage.

After all participants in the group had completed their worksheets, the facilitator asked the following questions within each group:

- As you look over the worksheet factors, are there some that you don't feel will have a large influence on tree growth or survival?
- Which of the factors stand out as having the largest influence and should be given the greatest weight?
- Are there other factors that we're missing?
- Which factors most strongly contributed to your ratings?
- Are there factors which may interact in such a way that the effects cancel each other out or multiply the effect?
- In what areas did you have the most confidence in your determination, and in what areas did you have the least?
- For those who completed worksheets for more than one area, did some areas stand out as more or less vulnerable, and what factors contributed to that outcome?

After the smaller group discussion, all participants joined in a large-group discussion to compare results, and anonymous written evaluations were also collected from each participant.

We collected all completed worksheets from participants and summarized their responses in narrative form. We sent the completed narrative summaries back to each participant for review of accuracy and tone and made revisions accordingly.

Worksheet Instructions

A. Read through the list of regional impacts and adaptive capacity factors and their accompanying questions. These questions will prompt you to consider local factors that may modify regional impacts or affect local capacity to adapt to climate change.

B. For each impact or adaptive capacity factor:

1. Answer **yes or no** to the question based on any data you have or your personal knowledge/experience (if you aren't sure, you can give a lower confidence rating). If the question simply does not apply to your area (e.g., a question about residents' tree care and there are no residents), please write N/A.
2. Write down your **explanation** about whether and how you would expect this to affect your impacts or adaptive capacity to climate change in your area (see glossary).
3. Record the **overall effect** of the factor on your area's trees and/or forests.

   ↓ **Negative effect:** You expect this factor to increase mortality, physical damage, or disease/pest susceptibility of your trees or reduce growth and vigor.

   ↔ **Neutral effect:** You do not expect this factor to have a negative or positive effect on your trees, or the positive and negative factors will balance out.

   ↓ **Positive effect:** You expect this factor to reduce mortality, physical damage, or disease/pest susceptibility of your trees and/or enhance growth and vigor.
4. Record your **confidence** in the direction of the effect you determined in step 3.

   Low: You do not have much information to support your conclusion and/or the information is conflicting.

   Medium: You have some information which seems to support your conclusion.

   High: Your conclusion is supported by area-specific data that all support your conclusion.

   Example:

Regional Impact	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Heavy rain events could increase flooding, especially in the spring.	Is all or part of the area currently susceptible to flooding (in a flood plain and/or has high number of flood-related insurance claims)?	*Yes*	*According to FEMA, only the area within 100 feet of the Chicago River is at risk for flooding. Flood maps are not up-to-date, however.*	↔	*Medium*

C. Blank spots are left at the end of each section for additional impacts and factors not listed. Feel free to add to the list.

Example:

Regional Impact	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Increased temperatures and late-season droughts could increase susceptibility to wildfire.	Does the area have a high density of fuels or other factors that put it at risk for wildfire?	Yes	Area is heavily forested and overstocked with many declining trees.	↓	High

D. Go through your responses and circle the factors you think would have the greatest influence on your area.

Example:

Regional Impact	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Heavy rain events could increase flooding, especially in the spring.	Is all or part of the area currently susceptible to flooding (in a flood plain and/or has high number of flood-related insurance claims)?	Yes	According to FEMA, only the area within 100 feet of the Chicago River is at risk for flooding. Flood maps are not up-to-date, however.	↔	Medium
Increased temperatures and late-season droughts could increase susceptibility to wildfire.	Does the area have a high density of fuels or other factors that put it at risk for wildfire?	Yes	Area is heavily forested and overstocked with many declining trees.	↓	High

E. For each factor (e.g., physical, biological, human):

Review the circled positive/negative effects. Determine an overall impact or adaptive capacity rating by placing a mark along a continuous line.

Use your best judgment for the final determination based on the relative weight given to each factor, but as a general guideline:

For impacts:

- **Negative Impact:** Negative effects outweigh positive effects.
- **Moderate Impact:** Negative effects are approximately equal to positive effects or most factors are neutral.
- **Positive Impact:** Positive effects outweigh negative effects.

For adaptive capacity:

- **Low Adaptive Capacity:** Negative effects outweigh positive effects.
- **Moderate Adaptive Capacity:** Negative effects are approximately equal to positive effects or most factors are neutral.
- **High Adaptive Capacity:** Positive effects outweigh negative effects.

Example:

Overall influence of human factors (place mark along line):

Negative X **Moderate** **Positive**

F. For each section:

Review the overall effects for all factor types to determine an overall rating of impacts and adaptive capacity by placing a mark along a continuous line. In general, this will be an average of all factor types within the section, but use your best judgment for the final determination based on the relative weight given to each factor type.

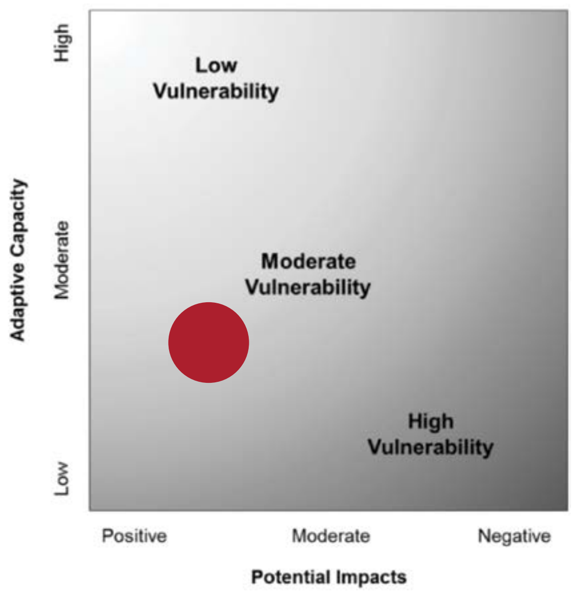
Example:

Overall impacts (place mark along line):

Negative X **Moderate** **Positive**

G. Evaluate overall vulnerability:

Based on your determination of impacts and adaptive capacity, plot your assessment of vulnerability for your area on the figure (as shown in the example below).



Urban Forest Vulnerability Worksheet

Name ____________________ Organization/Municipality ________________________________

Area assessed ____
(e.g., neighborhood, community, county, quadrant, or zone)

Section 1: Impacts

Impacts are the direct and indirect consequences of climate change on systems. Impacts are a function of a system's exposure to climate change and its sensitivity to any changes. Impacts could be beneficial or harmful to a particular forest or ecosystem type.

Physical Factors

Regional Impact	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Heavy rain events could increase flooding, especially in the spring.	Is all or part of your area currently susceptible to flooding (in a flood plain and/or has high number of flood-related insurance claims)?				
Increases in precipitation could lead to increased soil moisture in the winter and spring.	Are the soils in your area well or poorly drained compared to the rest of the region?				
Decreases in summer or fall precipitation could lead to decreases in soil moisture.	Are the soils in your area well or poorly drained compared to the rest of the region?				
Heavy storm events may increase and tornado seasons may shift.	Is your area particularly susceptible to wind or tornadoes compared to the rest of the region?				
Temperatures have increased more dramatically in the counties directly adjacent to Lake Michigan over the past 100 years.	Is your area along the shores of Lake Michigan?				
Snow may increase on the east side of Lake Michigan.	Is your area on the east side of Lake Michigan?				

Overall influence of physical factors (place mark along line):

Negative **Moderate** **Positive**

Biological Factors

Regional Impact	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Many trees, especially at the southern end of their natural or planted range, are expected to experience a reduction in habitat suitability.	Based on the model projections, are many of the dominant trees in your area expected to have a reduction in habitat suitability and/or be otherwise vulnerable to climate change and associated stressors?				
Many trees, especially at the northern end of their natural or planted range, are expected to experience an increase in habitat suitability.	Based on the model projections, are many of the dominant trees in your area expected to have an increase in habitat suitability and/or have low vulnerability to climate change?				
Many pests and pathogens are expected to benefit from longer growing seasons and warmer temperatures.	Is your area currently experiencing a pest or disease outbreak of one or more pests/pathogens that could benefit from projected changes in climate?				
Some pests or pathogens that prefer cool, wet conditions may decrease.	Is your area currently experiencing a pest or disease outbreak of one or more pests/pathogens that could see a reduction in favorable conditions from projected changes in climate?				
Warmer winters could be beneficial to some herbivores.	Is your area particularly vulnerable to herbivory from deer or other wildlife?				
As temperatures increase, suitable habitat for many invasive species could increase.	Are invasive plant species outcompeting native and/or desired planted species in your area?				
Temperatures are projected to increase.	Tree canopy cover can reduce local temperatures by creating shade and contributing to evaporative cooling. Are tree cover and/or density at or near desired levels for your area?				
Winter storms may become more intense.	Are a large percentage of trees in the area susceptible to winter storm damage?				
Severe thunderstorms with straight-line winds may become more frequent in the future.	Are a large percentage of trees in the area susceptible to wind damage?				
Winter freeze-thaw cycles are expected to see seasonal shifts to later in the fall and earlier in the spring.					

Overall influence of biological factors (place mark along line):

Negative **Moderate** **Positive**

Human-Influenced Factors

Regional Impact	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Temperatures are projected to increase.	Does your area experience a strong urban heat island effect that could make it warmer than the surrounding area?				
Increased temperatures and longer growing seasons could lead to increased ozone pollution.	Does your area have higher levels of air pollution from automobiles or industry compared to the region as a whole?				
Increased heavy precipitation events could increase runoff, leading to shifts in local soil and water pollution.	Does your area have relatively high levels of soil or water pollution (e.g., from agricultural or industrial sources)?				
Increased heavy precipitation events could increase runoff and flooding, especially in the spring.	Does the area have a large amount of impervious cover that could reduce soil infiltration and increase runoff, reducing soil moisture in some areas and flooding in others?				

Overall influence of human factors (place mark along line):

Negative **Moderate** **Positive**

Section 2: Adaptive Capacity

Adaptive capacity is the ability of a system to accommodate or cope with potential climate change impacts with minimal disruption. This could be intrinsic to the organism (ability to acclimate).

Biological Factors

Adaptive Capacity Factor	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Species-rich communities have exhibited greater resilience to extreme environmental conditions and greater potential to recover from disturbance.	Is there a high level of diversity of tree species in your area (e.g., no more than 20% from one family, 10% of one genus, 5% of one species)?				
Greater genetic diversity may help species adjust to new conditions or sites by increasing the likelihood that some individuals within a species will be able to withstand climate-induced stressors.	Is there a high level of genetic/ seed source diversity within the tree species planted in your area?				
Reduced concentrations of one species or genotype in a particular area can reduce the spread of pests and/or pathogens.	Are species or genotypes arranged spatially (either naturally or artificially) across your area to reduce high concentrations of one type in a particular location (e.g., alternating street tree species within a block or between blocks)?				
Older trees can be more vulnerable to breakage from wind storms or susceptible to pests and/or pathogens as they reach the end of their lifespan.	Are many trees in your area reaching the end of their lifespan?				
Younger trees may be more vulnerable before their root systems are well-established.	Are many trees in your area newly planted (e.g., under 5 years old)?				
Damaged trees can be susceptible to infection and other stressors.	Have trees in your area recently (within the past year) experienced damage from a storm or other disturbance event?				

Overall biological adaptive capacity (place mark along line):

Low **Moderate** **High**

Organizational/Technical Factors

Adaptive Capacity Factors	Local considerations	Yes or no	Explanation	Overall effect	Confidence
Trained forestry professionals may be more likely to recognize potential problems and identify appropriate solutions.	Is your area currently overseen by a tree board and/or department staffed with forestry professionals?				
Tree care ordinances can be helpful in ensuring best practices when followed unless they are not updated in light of new information.	Is a tree care ordinance or planting list in place that is sufficiently flexible to allow for adjustments in species in light of climate change?				
A diverse mix of species and genotypes relies on the availability of young trees for planting.	Are current nursery suppliers able to provide a wide mix of species and cultivars?				
Knowing the mix of species, age classes, and conditions of trees can help determine how many trees could be vulnerable.	Does your area have a current and comprehensive tree inventory?				
Long-term plans can be helpful in identifying goals and objectives, as long as they can be adjusted given new information.	Does your area have a long-term plan (such as a tree management plan, or similar) that is sufficiently flexible to allow for adjustments in species in light of climate change?				
A disaster response/recovery plan can help ensure that damaged trees are properly managed and replaced with a resilient mix of trees that are properly planted and maintained.	Does your area currently have a disaster recovery/response plan?				
Trees that are properly watered and fertilized are less likely to experience disease, mortality, and drought stress.	Are the majority of trees in the area receiving routine care and maintenance?				
Proper pruning can reduce the susceptibility of trees to damage or mortality from storms.	Are the majority of trees pruned routinely (every 5-7 years) to reduce storm-related damage?				
Sharing resources can help with recovery and response following extreme storms.	Is your area part of a mutual aid network?				
Conducting risk and hazard assessments can help reduce vulnerability to extreme storm events.	Does your organization conduct tree risk/hazard tree assessments?				

Overall organizational/technical adaptive capacity (place mark along line):

Low **Moderate** **High**

Economic Factors

Adaptive Capacity Factor	Local considerations	Yes or no	Notes	Overall effect	Confidence
As trees die, planting new trees presents an opportunity to increase diversity and plant more resilient species.	Is there sufficient funding to purchase and plant new trees to replace each one that is lost (excluding recent EAB-related funding issues)?				
Proper care and maintenance can reduce the vulnerability of existing trees.	Is there sufficient funding to maintain existing street trees and those on public lands?				
Proper care and maintenance can reduce the vulnerability of existing trees.	Do private landowners (homeowners, businesses) in your area have sufficient financial resources to plant and care for trees?				

Overall economic adaptive capacity (place mark along line):

Low **Moderate** **High**

Social Factors

Adaptive Capacity Factor	Local considerations	Yes or no	Climate change considerations	Overall effect	Confidence
Residents who value trees are more likely to care for them.	Do residents in your area value trees as an important resource?				
Even if funding is limited, a large volunteer base can help reduce costs and increase awareness about trees and tree care.	Is there a sufficient volunteer base to aid in the planting and care of trees in the area?				
Organizations can help find and pool resources to help care for and plant trees.	Is there an active network of organizations engaged in caring for forest resources in your area?				
Incentives can increase public participation and interest.	Are any public incentive programs in place to encourage the planting and/or care of trees?				

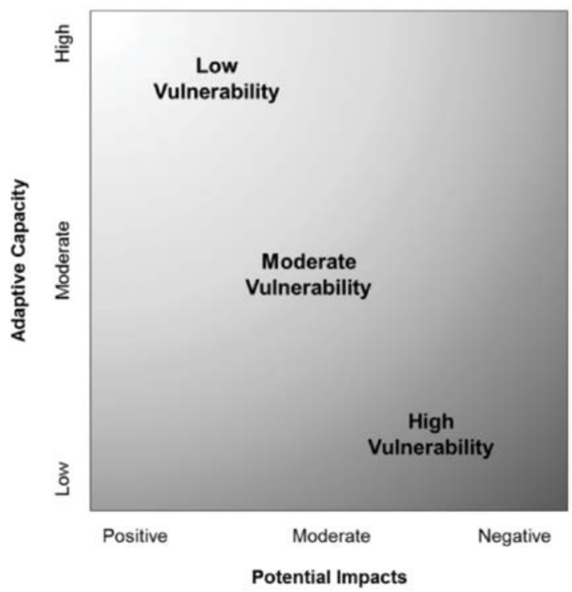
Overall social adaptive capacity (place mark along line):

Low **Moderate** **High**

Section 3: Vulnerability

Vulnerability is the susceptibility of a system to the adverse effects of climate change. It is a function of its potential impacts and its adaptive capacity.

Based on your determination of impacts and adaptive capacity, plot your assessment of vulnerability for your area on the figure.



Brandt, Leslie A.; Derby Lewis, Abigail; Scott, Lydia; Darling, Lindsay; Fahey, Robert T.; Iverson, Louis; Nowak, David J.; Bodine, Allison R.; Bell, Andrew; Still, Shannon; Butler, Patricia R.; Dierich, Andrea; Handler, Stephen D.; Janowiak, Maria K.; Matthews, Stephen N.; Miesbauer, Jason W.; Peters, Matthew; Prasad, Anantha; Shannon, P. Danielle; Stotz, Douglas; Swanston, Christopher W. 2017. **Chicago Wilderness region urban forest vulnerability assessment and synthesis: a report from the Urban Forestry Climate Change Response Framework Chicago Wilderness pilot project.** Gen. Tech. Rep. NRS-168. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 142 p. https://doi.org/10.2737/NRS-GTR-168.

The urban forest of the Chicago Wilderness region, a 7-million-acre area covering portions of Illinois, Indiana, Michigan, and Wisconsin, will face direct and indirect impacts from a changing climate over the 21st century. This assessment evaluates the vulnerability of urban trees and natural and developed landscapes within the Chicago Wilderness region to a range of future climates. We synthesized and summarized information on the contemporary landscape, provided information on past climate trends, and illustrated a range of projected future climates. We used this information to inform models of habitat suitability for trees native to the area. Projected shifts in plant hardiness and heat zones were used to understand how nonnative species and cultivars may tolerate future conditions. We also assessed the adaptability of planted and naturally occurring trees to stressors that may not be accounted for in habitat suitability models such as drought, flooding, wind damage, and air pollution.

The summary of the contemporary landscape identifies major stressors currently threatening the urban forest of the Chicago Wilderness region. Major current threats to the region's urban forest include invasive species, pests and disease, land-use change, development, and fragmentation. Observed trends in climate over the historical record from 1901 through 2011 show a temperature increase of 1 °F in the Chicago Wilderness region. Precipitation increased as well, especially during the summer. Mean annual temperature is projected to increase by 2.3 to 8.2 °F by the end of the century, with temperature increases across all seasons. Projections for precipitation show an increase in winter and spring precipitation, and summer and fall precipitation projections vary by model. Species distribution modeling for native species suggests that suitable habitat may decrease for 11 primarily northern species and increase or become newly suitable for 40 species. An analysis of tree species vulnerability that combines model projections, shifts in hardiness and heat zones, and adaptive capacity showed that 15 percent of the trees currently present in the region have either moderate-high or high vulnerability to climate change, and many of those trees with low vulnerability are invasive species.

We developed a process for self-assessment of urban forest vulnerability that was tested by urban forestry professionals from four municipalities, three park districts, and three forest preserve districts in the region. The professionals generally rated the impacts of climate change on the places they managed as moderately negative, mostly driven by the potential effects of extreme storms and heavy precipitation on trees in the area. The capacity of forests to adapt to climate change ranged widely based on economic, social, and organizational factors, as well as on the diversity of species and genotypes of trees in the area. These projected changes in climate and their associated impacts and vulnerabilities will have important implications for urban forest management, including the planting and maintenance of street and park trees, management of natural areas, and long-term planning. will have important implications for urban forest management, including the planting and maintenance of street and park trees, management of natural areas, and long-term planning.

KEYWORDS: climate change, vulnerability, adaptive capacity, urban forests, Climate Change Tree Atlas, expert elicitation, climate projections, impacts

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