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DETROIT REGION URBAN FOREST VULNERABILITY ASSESSMENT AND SYNTHESIS:

A Report from the Urban Forestry
Climate Change Response Framework



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Abstract

As the climate changes over the 21st century, the people, trees, and green spaces of Detroit, Michigan will face physical, biological, health, and indirect impacts. This assessment evaluates the vulnerability of the urban forest in the Detroit region. We synthesized and summarized information on the contemporary landscape, provided information on past climate trends and projected future climates, and illustrated climate impacts on a range of topics. We used models of habitat suitability for trees native to the Detroit area and used projected shifts in plant hardiness zones and heat zones to understand how less-common native species, nonnative species, and cultivars are projected to tolerate future conditions. We also assessed the adaptability of planted and naturally occurring trees to stressors that are not included in habitat suitability models such as drought, flooding, wind damage, and air pollution.

The summary of the contemporary landscape identifies major stressors currently threatening urban trees and natural areas in the Detroit region. Major current threats to the urban forest in the region include urban heat islands, invasive species and diseases, vacant land, soil and water contamination, air pollution, and social and economic inequality. Detroit has been warming at a rate of about 0.4 °F per decade since 1960 and the average temperature is projected to increase by 5 to 13 °F by the end of the century compared to the mean for 1980 through 2009. Precipitation in Detroit has been increasing by 0.95 inch per decade since 1960 and spring precipitation is projected to increase, while other precipitation projections vary by season and climate scenario. Extreme heat and heavy precipitation events are expected to increase in intensity and become more frequent. By the end of the century, Detroit is projected to shift from hardiness zone 6 to 7 or 8, and from heat zone 5 to a zone between 7 and 9, depending on the climate change scenario.

Species distribution modeling of native trees projects that suitable habitat will decrease for about a third of the tree species, increase for 13 percent of species, and remain stable for 13 percent of species, while 26 percent of native species evaluated for habitat suitability may be able to gain suitable habitat. In terms of adaptive capacity for planted or developed conditions, 27 percent of native species evaluated received a high adaptability score, 57 percent received a medium adaptability score, and 16 percent received a low adaptability score. For natural areas (both native and naturalized), 45 percent of species received a high adaptability score, 46 percent received a medium adaptability score, and 9 percent received a low adaptability score. Under the low climate change scenario, most Detroit tree species (51 percent) fell into the low-moderate vulnerability category. However, more species received higher vulnerability ratings under the high climate change scenario; 14 percent were categorized as low vulnerability, 21 percent as low-moderate vulnerability, 20 percent as moderate vulnerability, 35 percent as moderate-high vulnerability, and 10 percent as high vulnerability. 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, equity and environmental justice efforts, and long-term planning from partnerships to green infrastructure.

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

Cover Photo

Downtown Detroit, Michigan, with blooming trees in the foreground. Courtesy photo by Michigan Department of Natural Resources, used with permission.

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DETROIT REGION URBAN FOREST VULNERABILITY ASSESSMENT AND SYNTHESIS:

A Report from the Urban Forestry Climate Change Response Framework

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PREFACE

Context and Scope

This assessment is a fundamental component of the Urban Forestry Climate Change Response Framework project and builds on methods developed for the Chicago Wilderness region urban forest vulnerability assessment (Brandt et al. 2017) and the vulnerability assessment for the urban forest and natural areas of Austin, Texas (Brandt et al. 2020). This project incorporates lessons learned from the Climate Change Response Framework, which is a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects.

This assessment provides a synthesis of the best available scientific information. Its primary goal is to inform those who live among, work on, study, recreate in, and care about the urban forests and natural areas in the Detroit 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.

The scope of the assessment is the urban forest, broadly defined to include both developed and natural settings within the urban landscape.

Acknowledgments

We wish to thank our many collaborators on this project. Among them are our partners from American Forests™, Detroit Future City, Southeast Michigan Council of Governments (SEMCOG), The Greening of Detroit™, and the State of Michigan who served on the Detroit Reforestation team and met monthly to discuss and develop the workshop and this assessment.

We thank the municipal foresters, park district representatives, natural areas managers, and individuals from private, nonprofit, academic, and governmental organizations who participated in the vulnerability and adaptation workshops that contributed to this report. We are grateful to Asia Downtin (Michigan State University), Robert E. Grese (University of Michigan), and Christopher Hoving (Michigan Department of Natural Resources) for serving as peer reviewers and providing valuable insights.

EXECUTIVE SUMMARY

This assessment evaluates the vulnerability of urban trees and forests in the Detroit, MI, region 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 natural resource management. The scope of the assessment is the urban forest, broadly defined to include both developed and natural settings within the urban landscape.

The assessment summarizes current conditions and key stressors and provides an overview of past and projected trends in climate. Impacts of a changing climate on phenology shifts, physiological effects, tree pests and pathogens, wildfire risk, and urban flooding are discussed. Model projections of future habitat suitability under low and high climate change scenarios are considered alongside the adaptive capacity of tree species and local knowledge to estimate the vulnerability of Detroit tree species. Climate-related impacts on human health and the potential for urban trees to mitigate these effects are discussed. The overall vulnerability of the Detroit region urban forest is examined for each of the city's seven city council districts. A final chapter summarizes the implications of these impacts and vulnerabilities for urban forest management across the Detroit region.

Chapter 1: The Contemporary Landscape

This chapter describes the structure and function of the urban forest of Detroit, MI, the forces that shaped it, and current stressors and threats. This information lays the foundation for understanding how shifts in climate contribute to changes in the Detroit urban forests, and how climate interacts with other stressors present on the landscape.

Key Points

- Detroit is located in the Southern Great Lakes Forest ecoregion, defined by various forest, prairie, swamp, marsh, and wetland ecosystems.
- Black or African American residents make up most of the local population, and the overall population of the city has been declining since 1950.
- There are three watersheds within the Detroit city boundaries that empty into Lake St. Clair or the Detroit River. The eastern border of the city and southwest Detroit are more prone to flooding.
- Before Euro-American settlement, this region was classified as mesic southern forest, including a mosaic of different forest types and large areas dominated by beech and sugar maple communities. Today, Detroit and the surrounding areas have a greater diversity of species including oak, birch, beech, hickory, sugar maple, elm, and cottonwood.
- Urban trees in Detroit provide approximately \$24.3 million in benefits each year, including benefits from aesthetics, air quality, net total carbon sequestered and avoided, energy, and stormwater peak-flow reduction.
- Stressors and threats to urban trees in Detroit include drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant land, soil and water contamination, air pollution, and racial and economic inequality.
- Racial and economic inequality are prominent stressors that have led to disparities in tree cover and resources for urban forests and to issues regarding street tree acceptance and extreme heat and precipitation.
- The listed natural resource managers, nonprofit organizations, and community initiatives in the Detroit region are among those working to manage the Detroit region urban forest to ensure that it continues to provide benefits for the community.

Chapter 2: Climate Trends, Projections, and Physical Impacts

This chapter summarizes what we know about climate trends, how climate is projected to change over this century, and physical impacts to the Detroit region urban forest and natural areas.

Key Points

- The average temperature in Detroit has warmed by 0.4 °F per decade since 1960 and the average temperature is projected to increase in each season under a range of climate scenarios compared to the mean for 1980 through 2009.
- The average precipitation in Detroit increased by 0.95 inch per decade since 1960. Although precipitation projections vary by season and climate scenario, spring precipitation is generally expected to increase under all climate scenarios.
- Extreme heat and heavy precipitation events are expected to increase in intensity and become more frequent.
- The USDA hardiness zone for the region is projected to shift by one to two zones and the heat zones are projected to shift by three to five zones by end of century, depending on the climate scenario.

Chapter 3: Biological Climate Impacts

This chapter provides an overview of biological climate impacts in the Detroit region, from fruit production to fire risk.

Key Points

- Changes in carbon dioxide levels can affect plant productivity and species composition, but there are challenges and limitations with carbon dioxide fertilization.
- A changing climate may shift the timing of leaf-out, flowering, fruit production, and senescence in Michigan trees; urban trees in Detroit may be subject to frost and freeze damage.
- Climate change can alter nutrient cycling and rates of tree growth, photosynthesis, and transpiration (loss of water vapor). Trees may benefit from longer growing seasons and higher carbon dioxide concentrations, but can be limited by available moisture and nutrients.
- The abundance and range of pests and pathogens, such as emerald ash borer, oak borers, Asian longhorned beetle, spotted lanternfly, and oak wilt, are projected to increase under a changing climate due to increased temperatures and greater tree stress. Nonnative invasive species are projected to spread and become established as plants shift their range.
- Wildfire risk is projected to increase, but fire behavior is uncertain due to its connection with climatic shifts as well as various occurrence factors.
- Urban flooding is a major concern in the Detroit region. Flooding can lead to tree stress and secondary attacks, property damage, and shoreline erosion.

Chapter 4: Tree Species Vulnerability

This chapter summarizes expected changes in habitat suitability and the adaptive capacity of tree species in developed and natural areas of the Detroit region. Vulnerability is the susceptibility of a system to the adverse effects of climate change and is a function of potential climate change impacts and the adaptive capacity of the system.

Key Points

- **Projected habitat suitability for native trees:** Species distribution modeling of native species suggests that suitable habitat will decrease for 19 species (31 percent) and remain stable for 8 species (13 percent). Suitable habitat is expected to increase for 8 species (13 percent), and 16 species (26 percent) may be able to colonize new, suitable habitats. The rest of the species evaluated had mixed results (17 percent).
- **Projected shifts in hardiness zones, heat zones, and species ranges:** Under a low climate change scenario, the vast majority of the 187 evaluated species are projected to be in a suitable range (94 percent), while 6 percent are not projected to be in a suitable range. Under a high climate change scenario, 42 percent are projected to be in a suitable range, and 58 percent are not projected to be in a suitable range.
- **Adaptive capacity of urban trees:** Adaptive capacity of 187 species was evaluated using scoring systems for planted (187 species) and natural (92 species) environments. For natural areas (both native and naturalized), 41 species received a high adaptability score, 8 received a low adaptability score, and 43 received a medium adaptability score. For planted or developed conditions, 50 species received a high adaptability score, 30 received a low adaptability score, and the remaining 107 received a medium adaptability score.
- **Overall vulnerability of the trees in the Detroit region:** Under a low climate change scenario, most Detroit tree species fell into the low-moderate vulnerability category (51 percent). Twenty-three percent were categorized as low vulnerability, 20 percent as moderate vulnerability, 5 percent as moderate-high vulnerability, and 1 percent as high vulnerability. Under a high climate change scenario, more trees were considered vulnerable. Nearly 14 percent were categorized as low vulnerability, 21 percent as low-moderate vulnerability, 20 percent as moderate vulnerability, 35 percent as moderate-high vulnerability, and nearly 10 percent as high vulnerability.
 - Common species with moderate-high to high vulnerability under a high climate change scenario include boxelder, silver maple, sugar maple, common horse chestnut, northern catalpa, white mulberry, Callery pear, pin oak, and American linden.
 - Common species with low to low-moderate vulnerability under both climate change scenarios include red maple, green ash, honeylocust (thornless), American sycamore, London planetree, and Siberian elm.
 - Uncommon species with low to low-moderate vulnerability under both climate change scenarios include common persimmon, downy serviceberry, fringetree, mockernut hickory, Osage-orange, sourwood, southern hackberry, umbrella magnolia, and water locust.

Chapter 5: Human Health Impacts

This chapter provides an overview of climate-related impacts on human health in the Detroit region, from air pollution to mental health.

Key Points

- The population and urban forest in the Detroit region are both at risk from a changing climate, and urban forests can play a role in mitigating risks to human health from a changing climate.
- Climate change can increase ground-level ozone and particulate matter air pollution, which are associated with health issues such as asthma, diminished lung function, increased hospital visits, and premature deaths. Changing conditions can also shift biogenic VOC (volatile organic compound) emissions from plants and the production, allergenicity, distribution, and timing of aeroallergens, or airborne substances, such as tree, grass, and weed pollen.
- Oak, birch, and ragweed pollen are projected to increase under a changing climate and allergenicity is an important human health component to consider when selecting climate-adapted tree species.
- Human health is impacted by pests and pathogens such as emerald ash borer and ticks, which may shift their range, distribution, and abundance under changing conditions. Another concern is hazard trees, which may occur in the presence of tree pests and pathogens.

- Extreme heat is associated with heat-related diseases and mortality and poses a serious threat to Detroit residents, particularly those who are low-income, young, or socially isolated; lack air conditioning; or suffer from chronic illness.
- Changes in heavy precipitation events and lake temperatures can increase waterborne diseases, beach closings, and vulnerability to runoff and failure of septic or sewage treatment.
- Climate change is expected to cause food shortages and food insecurity, negatively impacting the community as food prices increase and availability decreases. Urban agriculture and food forests aid in food justice by increasing access to fresh foods, improving health, and building communities.
- While extreme weather events and natural disasters can cause secondary negative health effects, street trees and green spaces are linked to stronger social cohesion, stress relief, decreased crime, and an active lifestyle.

Chapter 6: Urban Forest Vulnerability

This chapter focuses on the overall vulnerability of the Detroit region urban forest, with attention given to each of the Detroit city council districts. Vulnerability is the susceptibility of a system to the adverse effects of climate change and is a function of potential climate change impacts and the adaptive capacity of the system.

Key Points

- Understanding district-level vulnerabilities can help guide resource allocation and climate adaptation strategies, and attention to the relationship between public health and inequality is critical in the planning and implementation process.
- Tree species diversity is largely comparable across Detroit, contributing to similar patterns of urban tree vulnerability across districts. All districts have a projected pattern of species vulnerability across low and high climate change scenarios.
- The most vulnerable neighborhoods are located in southwest Detroit. Vacant lots and impervious surfaces are an issue throughout the city. District 5 and district 6 have notable heat islands present, high poverty rates, and greater exposure to runoff. The higher runoff exposure reflects the location of these districts along the Detroit River.
- The Detroit region urban forest as a whole is vulnerable to temperature increases, more frequent and intense heavy rain events, and shifts in composition for native and nonnative invasive species, but the region has the capacity to adapt through its robust community urban forestry efforts.

Chapter 7: Management Implications

This chapter describes the management considerations and issues, summarized by theme, that urban foresters face.

Key Points

- Maintaining species diversity and selecting appropriate, adaptable species for the projected changes in habitat suitability will become more of a challenge for those managing green spaces in Detroit.
- Given the uncertainties around the effects of climate change, it will be important for land managers to continue to observe and document impacts on tree species and refine models and management strategies.
- Climate change challenges will present opportunities for land managers and other decision makers to further engage with their communities, develop new partnerships and programs, expand their volunteer base, and make investments in resilient landscapes.

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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, which is a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management (Swanston et al. 2016). Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects (Fig. 1). The Detroit assessment uses methods developed in the Chicago Wilderness region pilot (Brandt et al. 2017) and “Vulnerability of Austin’s Urban Forest and Natural Areas” (Brandt et al. 2020).

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—and stands of remnant forest (Nowak et al. 2001). The Urban project works across organizations, both public and private, toward this goal by accomplishing the following objectives:

- Engage with communities 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.

The tools and approaches developed in the Urban project were originally designed to be applied to areas in the Midwest and Northeast. This report expands that work to an additional area in the Midwest.

Current partners in the effort include:

- City of Detroit
- American Forests™
- USDA Forest Service
- The Greening of Detroit™
- USDA Northern Forests Climate Hub
- Southeast Michigan Council of Governments
- Northern Institute of Applied Climate Science

Scope and Goals

The primary goal of this assessment is to summarize potential changes to the urban forest of the Detroit region under a range of future climate scenarios and to determine the vulnerability of trees and natural and developed landscapes to those changes. It is intended to inform those who live among, work on, study, recreate in, and care about the urban forests and natural areas in the Detroit region. In addition, this assessment synthesizes information about the contemporary landscape and projections of physical and biological climate impacts used to assess these vulnerabilities. This assessment provides a synthesis of the best available scientific information. Uncertainties and gaps in information are also discussed throughout the assessment. 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.

This assessment covers the city of Detroit and the surrounding Southeast Michigan Council of Governments (SEMCOG) region (Fig. 2). Municipalities within this boundary are also included in the assessment. Across the SEMCOG region, there are 2.9 million acres of total land cover, 54 percent of which is considered green infrastructure; 56 percent of total green infrastructure is tree canopy coverage. Please refer to the Glossary starting on p. 111 for definitions of terms used in this report.



Figure 1.—Climate Change Response Framework components.

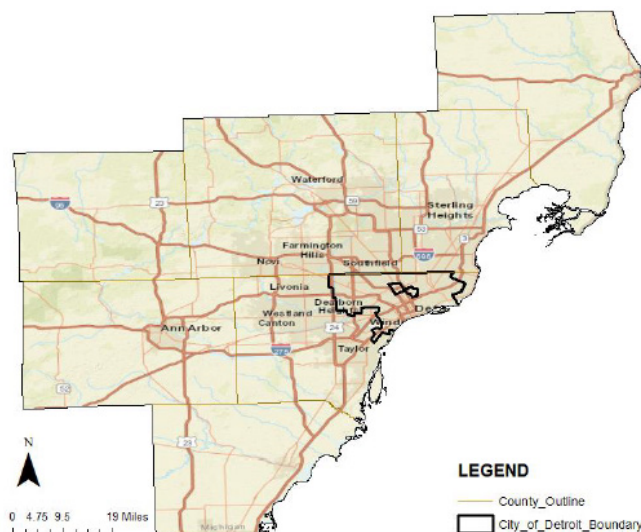


Figure 2.—Detroit region urban forest assessment area. The assessment area includes the area within the boundary of Detroit, MI, and the seven counties in the surrounding Southeast Michigan Council of Governments region.

Assessment Chapters

Chapter 1: The Contemporary Landscape

This chapter describes existing conditions, providing background on the physical environment, ecological character, and current management of urban forests of the Detroit region (Fig. 3).

Chapter 2: Climate Trends, Projections, and Physical Impacts

This chapter describes our current understanding of past and projected future changes in climate in the Detroit region: trends and projections in extreme weather, temperature, and precipitation; effects on soils and hydrology; and shifts in hardiness zones and heat zones.

Chapter 3: Biological Climate Impacts

This chapter describes phenology shifts, physiological effects, nutrient cycling, pests and pathogens, invasive plant species, species diversity, and wildfire risk in the Detroit region.

Chapter 4: Tree Species Vulnerability

This chapter describes modeled changes in habitat suitability for native tree species in Detroit and adaptive capacity scores in the region.

Chapter 5: Human Health Impacts

This chapter describes climate-related impacts on human health—allergenicity, pests and pathogens, biogenic VOCs (volatile organic compounds), heat-related illnesses and mortality, flooding and other extreme weather events, and increases in food prices—as well as social, mental, and physical impacts.

Chapter 6: Urban Forest Vulnerability

This chapter summarizes the vulnerability of the Detroit region and provides an overview of key climate impacts and adaptive capacity factors in each of the seven districts in Detroit.

Chapter 7: Management Implications

This chapter provides an overview of climate change impacts on decision making, management practices, and other issues related to urban and community forestry in the Detroit region (Fig. 4).



Figure 3.—Trained volunteers from The Greening of Detroit Citizen Forester program leading a tree planting demonstration for 20 volunteers in the Jefferson Chalmers neighborhood, Detroit, MI, October 2020. The volunteers planted 14 street trees during the public community event. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.



Figure 4.—Children and their teachers or guardians being trained in tree planting at Brightmoor Community Playground adjacent to the densely forested Eliza Howell Park, Detroit, MI, November 2020. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.

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—and stands of remnant forest (Nowak et al. 2001). The natural and glacial history of Detroit, Michigan shaped much of its current urban forest and forest composition. Southern Michigan is a part of the Southern Great Lakes Forest ecoregion, defined by various forest, prairie, swamp, marsh, and wetland ecosystems. In this section we describe the structure and function of the urban forest of Detroit, the forces that shaped it, and current stressors. This information lays the foundation for understanding how shifts in climate contribute to changes in the trees and urban forests of Detroit, and how climate interacts with other stressors present on the landscape

Landscape Setting

The assessment focus includes the city of Detroit and surrounding Southeast Michigan Council of Governments (SEMCOG) region, which consists of Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties (Figure 2 on p. 3). Detroit is a vibrant city, known as a major cultural center for its contributions to music and providing a home for art, design, and architecture. About 79 percent of its residents are Black or African American (U.S. Census Bureau 2019a). One of the unique features in the Detroit area is the Detroit River International Wildlife Refuge. The refuge was established in 2001 as the first international wildlife refuge in North America and one of the few urban refuges. It was the first project in the world to clean up an industrial brownfield site effectively and has been designated a Wetland of International Importance (U.S. Fish and Wildlife Service 2020). The site has 16 acres of restored wetlands and 25 acres of restored upland buffer habitat. Invasive plant species have been controlled on 50 acres of upland habitats. Through a partnership with the nonprofit organization The Greening of Detroit, more than 350 trees have been planted on the site.

Although the population of Detroit has declined since 1950, the decline has slowed in recent years. Meanwhile, development has continued to change the landscape. Between 1990 and 2000, land in the SEMCOG region was developed three times faster than the population grew (American Forests 2006). In a study examining the impacts of urban development on forest landscapes in southeast Michigan over a 30-year period (1985 to 2015), researchers found that development negatively impacted forested landscapes and that single-family housing was particularly damaging to the functionality of forested landscapes (Gounaridis et al. 2020). More than 300,000 new buildings were constructed over 30 years, with a sharp increase in development in Wayne, Oakland, and Macomb Counties on the urban periphery of Detroit. While there was no extensive deforestation, forests became more fragmented and less connected in areas with urban development.

Detroit and the surrounding SEMCOG region currently have a population of 4,750,123 (U.S. Census Bureau 2019a). Potential impacts from climate change on trees and green spaces are a prominent concern, as the city is projected to experience increased temperatures, more frequent and intense precipitation, and fluctuating lake levels, all of which threaten both human and environmental health (Gregg et al. 2012).

More Information on Trees in the Detroit Region

The following resources provide more information about the Detroit region urban forest.

- Detroit’s “Tree Management Plan” (Davey Resource Group 2016) focuses on short- and long-term maintenance needs for public trees in the city’s inventory. Inventory data paired with analysis provided an understanding of the condition and needs of the Detroit tree population as well as a maintenance schedule recommendation to improve tree health, expand tree canopy, and manage risks posed by public trees.
- The USDA Forest Service provides state urban forest data including geographic information systems (GIS) files that can be downloaded on the scale of county, place, and county subdivision:
<https://www.nrs.fs.usda.gov/data/urban/state/?state=MI>.

Other resources and plans relevant to trees and vegetation in the Detroit area include the following.

- Michigan Department of Natural Resources provides information about urban forestry including grants, events, programs, tree care and maintenance, and various resources:
https://www.michigan.gov/dnr/0,4570,7-350-79136_79237_80942---,00.html.
- The Michigan Natural Features Inventory provides information about the plants, animals, invasive species, and natural communities in Michigan and provides resources, services, programs, projects, and publications related to the natural features of the state:
<https://mnfi.anr.msu.edu/>.
- The “Sustainability Action Agenda” is the city of Detroit’s first sustainability plan that outlines goals of developing an equitable, green, affordable, clean, and connected city: <https://detroitmi.gov/departments/general-services-department/office-sustainability/sustainability-action-agenda>.
- The Greening of Detroit is a nonprofit organization that influences green spaces, green infrastructure, tree planting, and education in the Detroit region:
<https://www.greeningofdetroit.com/>.
- Detroiters Working for Environmental Justice is a nonprofit organization focused on advocacy, community action, and green jobs, leading the development of the “Detroit Climate Action Plan”:
<https://detroitenvironmentaljustice.org/> and
<https://toolkit.climate.gov/reports/detroit-climate-action-plan-detroit-michigan>.
- The city of Detroit and Wayne County Forestry Office provide tree services to Detroit communities:
<https://detroitmi.gov/departments/general-services-department/tree-services>.
- The “Terrestrial Invasive Species Management Plan” for Michigan outlines terrestrial invasive species in the state, a statewide strategy to reduce environmental and economic impacts, and recommendations for action. The plan is available at:
<https://www.michigan.gov/invasives/stateresponse/terrestrial-invasive-species-management-plan>.
- The Huron River Watershed Council developed a tree resilience toolkit to aid land managers and decision makers in understanding the changing climate in southeast Michigan, the implications on the local forest and tree resources, and how to manage those resources for climate resilience:
<https://www.hrwc.org/what-we-do/programs/climate-change/climate-resilient-communities/tree-resilience-toolkit/>.

Geology, Soils, and Hydrology

The landscape of Michigan was shaped primarily during the last ice age. The movement of the last ice sheet, the Wisconsin Glacier, drastically affected the landscape when it retreated 14,000 years ago (Gregg et al. 2012). The Great Lakes are a product of this glacier, serving as large repository basins for much of the melted ice. Glacial processes determined many of the landscape characteristics we see today, such as soil types, hydrologic flows, and historical forest composition.

Soil types can highly influence the vulnerability of an urban forest to impacts such as drought and flooding. The size of soil particles determines the amount of water and nutrients that the soil can hold, affecting forest and plant dynamics and stormwater management in the Detroit region and surrounding areas. The most common soil types in the Detroit region (Fig. 5) are soils produced from glacial outwash and derived from deposited lake sediments.

Glacial outwash results in accumulation of fine-grained material (e.g., till) in ridges that outline the extent of glaciation. These ridges of glacial till have defined the watersheds in the area over time, determining the path of rivers and streams, in addition to controlling drainage dynamics. Sediments, including clay, silt, sand, and gravel, can also be carried by wind, rivers, and erosion to the lake. These sediments are made up of rock fragments or mineral particles and primarily differ by particle size, ranging from less than approximately 0.002 mm in diameter (clay), to 3 to 75 mm in diameter (gravel). Over time, sand and gravel can accumulate along the outer part of the lake. Meanwhile, finer silt and clay settle in the inner, deeper areas. Detroit and the surrounding areas have both soil types. However, silt and clay tend to be the prevalent types closer to the Detroit River.

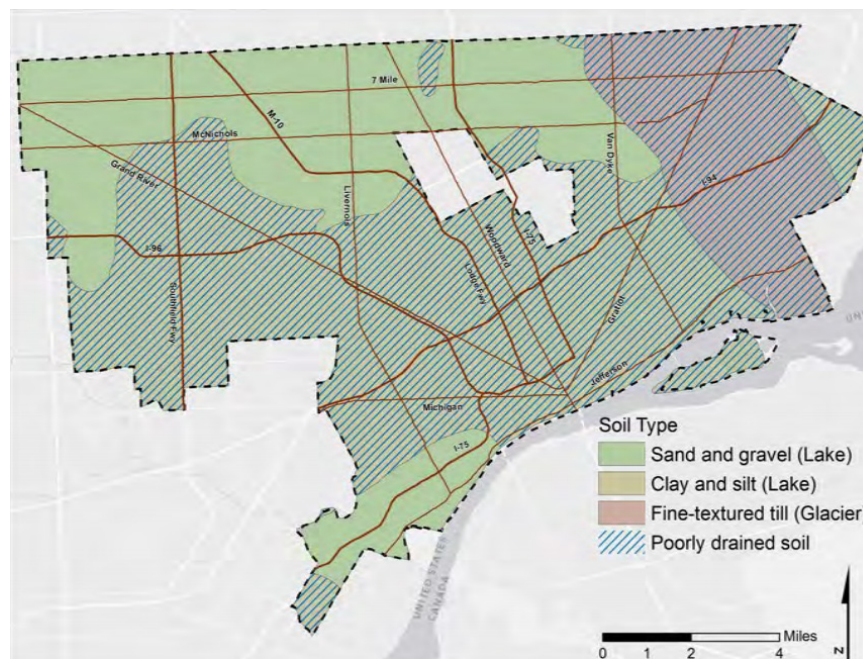


Figure 5.—Soil types underlying Detroit, MI, and associated drainage. “Lake” refers to soils from deposited lake sediments; “glacier” refers to soils produced from glacial outwash. Cartography: University of Michigan Detroit Climate Capstone; data source: Michigan Geographic Data Library, Michigan Quaternary Geology Map. From Gregg et al. (2012), used with permission.

Soil types influence the hydrology of the area. The dominant soil types in Detroit have different percolation rates. Soils that are poorly drained (clay, silt, and fine matter) cannot remove water as quickly, allowing runoff to occur more frequently (Gregg et al. 2012). Silt and clay are present in the east side of the city and toward the river. Sandy soil is more dominant in north and northeast Detroit. This soil type drains more quickly, resulting in less runoff.

The glacial processes in Michigan have influenced present watersheds in the Detroit area. Detroit is within the Great Lakes watershed, which moves water through Lake Superior, Lake Michigan, Lake Huron, the St. Clair River, Lake St. Clair, the Detroit River, Lake Erie, and Lake Ontario, to the St. Lawrence River, ultimately emptying into the Atlantic Ocean. There are three watersheds within the Detroit boundary, two of which emptying into Lake St. Clair (Lake St. Clair and Clinton watersheds) and one that empties into the Detroit River (Rouge watershed) (Fig. 6). The Huron watershed, to the west of Detroit, also plays a notable drainage role. This watershed passes through Wayne County and empties into Lake Erie.

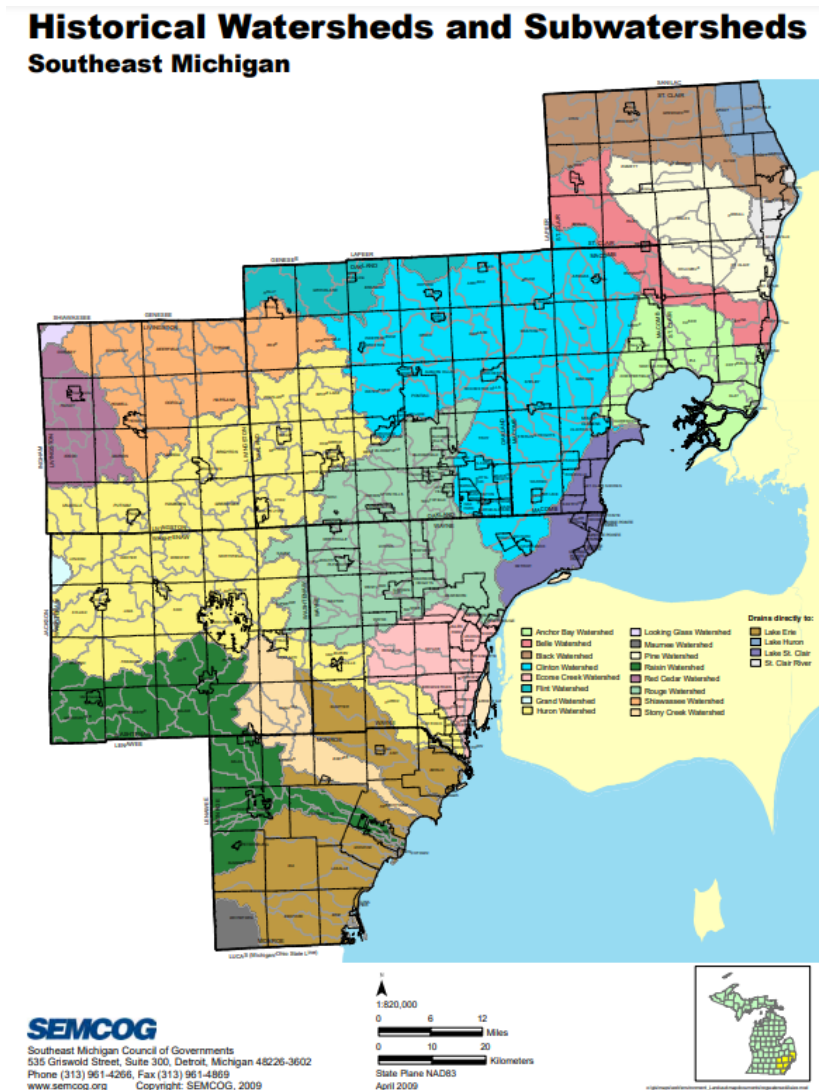


Figure 6.—Historical watersheds and subwatersheds in the Southeast Michigan Council of Governments (SEMCOG) region. Source: SEMCOG, used with permission.

As the city expanded, many streams and rivers within Detroit were routed into culverts and underground pipes. Understanding hydrologic processes in the area is important due to greater stressors on the system from increased storm events in a changing climate.

Ecological Context

The glacial and soil deposition processes, in addition to more general climate characteristics, have helped determine vegetation composition of the region. Classified as mesic southern forest, pre-Euro-American settlement Detroit was dominated by beech and sugar maple communities. (Please see Appendix 1 starting on p. 129 for common and scientific names of all species mentioned in this report.) These two species thrive on well-drained sandy lake plains and fine-textured glacial till. Soils in the area are typically fertile with high nutrient and soil organism content because of the decomposition of deciduous leaves and branches. Wetter habitats were formed where drainage was poor and seasonal pools were common. These conditions favor a combination of beech and black ash, while oak and hickory were found on drier uplands. The eastern border of the city and southwest Detroit remain more prone to flooding compared to other parts of the city because both were historically swamp and marsh.

Detroit and its surrounding region are located in the Midwest Broadleaf Forest Ecological Province. This ecological province features flat to hilly terrain associated with glaciation and vegetation including cold-deciduous, hardwood forests (Environmental Data Center 2020). Many species are able to tolerate mild, short, and occasional droughts during the late summer season. The USDA Forest Service's Forest Inventory and Analysis (FIA) program determined that surrounding areas have a diversity of species, predominantly the historical species of oak, birch, beech, hickory, and sugar maple, as well as elm and cottonwood (Gregg et al. 2012).

Natural Communities

The classification of communities in the Michigan Natural Features Inventory defines a natural community as an assemblage of interacting plants, animals, and other organisms that repeatedly occurs under similar environmental conditions across the landscape and is predominantly structured by natural processes rather than modern anthropogenic disturbances (Cohen et al. 2020). It emphasizes native ecosystems and therefore is a useful tool for identifying, conserving, and restoring important places that represent a broad range of ecological conditions. This classification of natural community types is based on a combination of data derived from statewide and regional surveys, ecological sampling and data analysis, literature review, and expert assessment.

Historical land cover of the SEMCOG region includes a mixture of upland and lowland forests along with nonforested wetlands. Mesic maple-beech forests were historically more common in the eastern portion of the region, while dry-mesic oak-hickory forests occurred more in the western portion (Fig. 7).

Currently, there are various forested communities in the landscape interspersed between developed areas, including floodplain forest, upland mesic forest/mesic southern forest, upland dry-mesic forest/dry-mesic southern forest, lakeplain oak openings, wet-mesic flatwoods, and southern hardwood swamp.

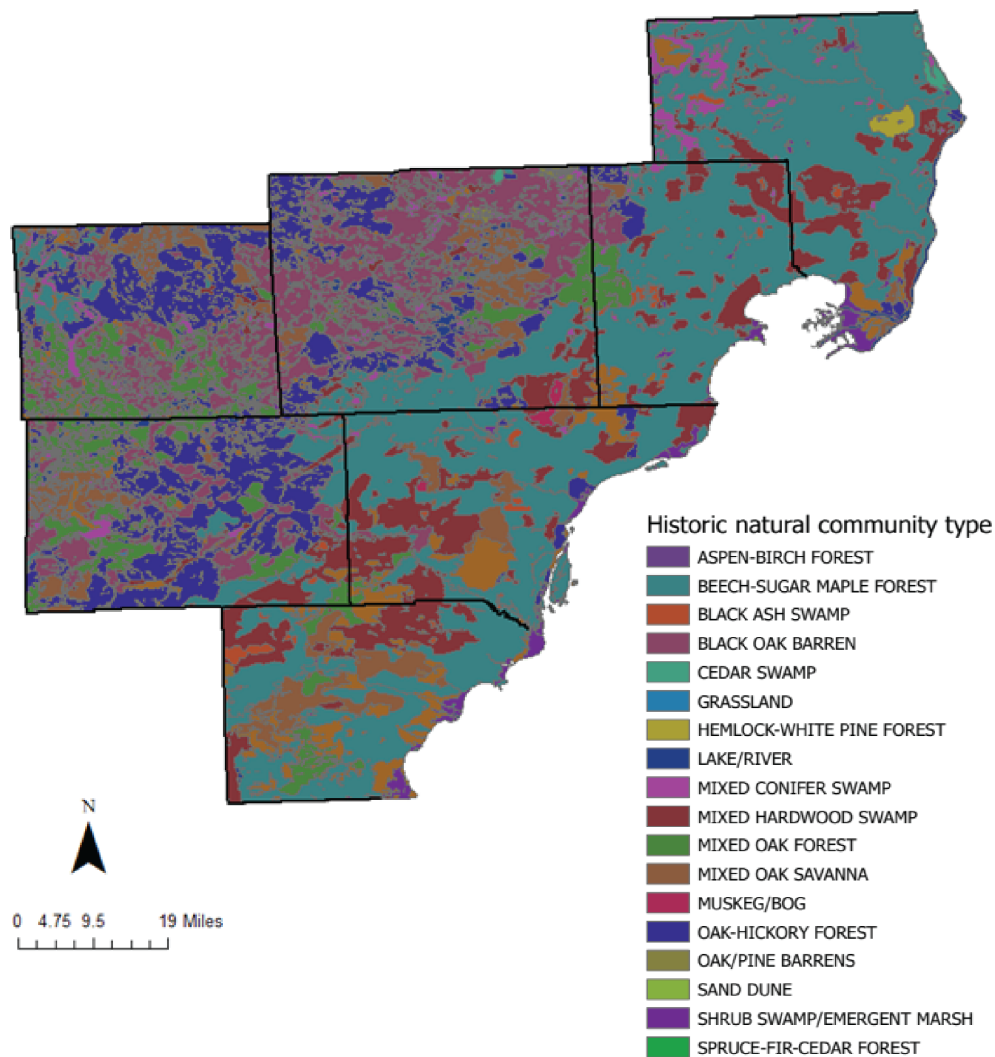


Figure 7.—Historical land cover of the Southeast Michigan Council of Governments region before Euro-American settlement. The scope of the natural communities list is terrestrial forested ecosystems, with a focus on dominant tree species. Adapted from Michigan State University (n.d.).

Floodplain Forest

Floodplain forest is a bottomland, deciduous or deciduous-coniferous forest community highly susceptible to nonnative species invasions (Cohen et al. 2020). Floodplain forests occupy low-lying areas next to streams and rivers and are subject to periodic over-the-bank flooding and to cycles of erosion and deposition. Though variable, soil texture is often sandy loam to loam and generally neutral to mildly alkaline. Floodplain soils are characterized by high nutrient availability and an abundance of soil water throughout much of the growing season. Over-the-bank flooding can directly cause treefall or indirectly lead to windthrow through increased soil saturation. Spring flood waters often carry ice floes and debris that can scour trees, leading to the development of multiple-stemmed canopy trees. Typical species include silver maple and green ash. Floodplain forests are prevalent in the SEMCOG region, where species richness is greatest in the southern Lower Peninsula (Cohen et al. 2020). In Detroit, this type of forest can be found in the Rouge River Corridor, including the area of the former Rogell Golf Course (City of Detroit 2018). Floodplain forests are classified as vulnerable in Michigan.

Upland Mesic Forest/Mesic Southern Forest

Mesic southern forest is a forest dominated by American beech and sugar maple and distributed on flat to rolling topography with predominantly well-drained, high nutrient, loam soils. The natural disturbance regime is frequent, small windthrow gaps allowing for the regeneration of shade-tolerant, canopy species and infrequent, intermediate- to large-scale wind events. In addition to wind disturbance, glaze or ice storms are an important source of intermediate disturbance, thinning the canopy and promoting tree regeneration. Dominant species of the canopy are American beech and sugar maple, which may account for more than 80 percent of the canopy composition. Prevalent in much of the SEMCOG region, mesic southern forest is classified as vulnerable in Michigan (Cohen et al. 2020).

Upland Dry-Mesic Forest/Dry-Mesic Southern Forest

Dry-mesic southern forest is a fire-dependent, oak or oak-hickory forest type (Cohen et al. 2020). It is generally present on dry-mesic sites south of the climatic tension zone in southern Michigan. Frequent fires maintain semiopen conditions, promoting oak regeneration and ground and shrub layer diversity. Fire, windthrow, and insect outbreaks and pathogens associated with oak defoliation and decline are the prevalent natural disturbance factors influencing dry-mesic southern forest. Dominant canopy species include white oak and black oak, with white oak being the more frequent dominant. Red oak can occur as a canopy species under the right conditions. Hickories such as pignut hickory, shagbark hickory, and bitternut hickory are often canopy codominants (Cohen et al. 2020). An example of this type of community can be seen as a remnant in the Rouge River-Rogell area of Detroit (City of Detroit 2018). Other examples are found in Palmer and Pitcher Parks (Weatherbee and Klatt 2004). Dry-mesic southern forest is prevalent in much of the SEMCOG region and is classified as vulnerable in Michigan (Cohen et al. 2020).

Lakeplain Oak Openings

Lakeplain oak openings are a fire-dependent savanna community, dominated by oaks and characterized by grass or a grasslike ground layer of species associated with both lakeplain prairie and forest communities (Cohen et al. 2020). Open conditions were historically maintained by frequent fire and, in depressions, by seasonal flooding. Soils are typically mildly alkaline, very fine sandy loams, loamy sands, or sands with moderate water-retaining capacity. In low areas, seasonally high water levels play an important role in maintaining the open condition of lakeplain oak openings. Dominant canopy species of droughty sand ridges are black oak and white oak. Bur oak, pin oak, and swamp white oak are prevalent on flat, poorly drained areas. Ground species include big bluestem, bluejoint grass, Pennsylvania sedge, blazing star, little bluestem, tussock sedge, sedge, twig-rush, switchgrass, Virginia mountain mint, cordgrass, and Indian grass. An example of this type of community can be seen as a remnant in the Rouge River-Rogell area of Detroit (City of Detroit 2018). Lakeplain oak openings are prevalent in Monroe and Wayne Counties and infrequent in Macomb, Oakland, and St. Clair Counties; they are classified as critically imperiled in the state (Cohen et al. 2020).

Wet-Mesic Flatwoods

The wet-mesic flatwoods community is a wet to mesic forest on mineral soils dominated by a highly diverse mixture of upland and lowland hardwoods. This community occurs on low relief, poorly drained glacial lakeplain characterized by the presence of an impervious clay layer, which allows for prolonged pooling of water and leads to a patchy, sparse ground layer (Cohen et al. 2020). Dominant trees include oaks, hickories, maples, ash, and American linden. Seasonal inundation is the primary natural disturbance factor influencing wet-mesic flatwoods. Surface soils are typically medium to slightly acid sandy loam to loam and overlie mildly to moderately alkaline sandy clay loam, clay loam, or clay. Seasonal water level fluctuations lead to mottling of the mineral soil layers. Water levels are typically highest in the late winter and spring, creating

many vernal pools. Strong water level fluctuations over the growing season favor species otherwise typical of river and stream floodplains. Seasonally dry mineral soils allow for greater tree-rooting depth than in wetlands on organic soils, reducing the prevalence of windthrow.

The wet-mesic flatwoods community is characterized by a highly diverse tree canopy that reflects variations in soil moisture as a response to slight changes in surface topography and mineral soil composition across most sites. Canopy tree species include both mesic and wetland species. Dominant trees are red oak, Shumard oak (State special concern species), white oak, swamp white oak, chinkapin oak, pin oak, bur oak, shagbark hickory, bitternut hickory, shellbark hickory, American beech, sugar maple, black maple, silver maple, red maple, green ash, white ash, pumpkin ash (State-listed as threatened), and American linden (Cohen et al. 2020). This type of community can be found on Belle Isle, an island in the Detroit River. This island has been impacted by altered hydrology due to development on the island, altered soils (fill), invasive species such as the emerald ash borer (EAB), invasive shrubs and grasses, and browse pressure from introduced European fallow deer (removed in 2004). Oak regeneration in the understory and low shrub layer is present but at low levels and has likely been impacted by deer browse pressure from the 10 or so native white-tailed deer known to inhabit the island (Cohen 2014). Wet-mesic flatwoods are found only in the southeastern part of the state, prevalent in Monroe, Wayne, and Macomb Counties in the SEMCOG region, and are classified as imperiled in Michigan (Cohen et al. 2020).

Southern Hardwood Swamp

Southern hardwood swamp is a forested wetland occurring in shallow depressions on mineral or occasionally organic soils dominated by a mixture of lowland hardwoods (Cohen et al. 2020). Soils are neutral to mildly acidic, typically loam or silt loam. An underlying impermeable clay lens is often present and allows for prolonged pooling of water. The canopy is typically dominated by silver maple, red maple, green ash, and black ash. Water levels fluctuate seasonally, with standing water typically occurring throughout winter and spring. Due to anaerobic conditions associated with prolonged inundation and a high water table, trees are shallow rooted and prone to frequent blowdown. Windthrow creates a pit-and-mound microtopography along with variously sized canopy gaps, which promote regeneration of a diverse overstory. Before the introduction and spread of Dutch elm disease, American elm was an important canopy constituent but is now largely relegated to the subcanopy and sapling layers. Typical shrub species include spicebush, elderberry, winterberry, and buttonbush. The ground layer is characteristically sparse due to prolonged inundation during the early growing season (Cohen et al. 2020). In Detroit, this type of community can be found at Pitcher Park and Palmer Park. Another type of wetland forest community proposed by Weatherbee is the oak wetland forest dominated by oaks and found in Detroit at Baldock Park (Weatherbee and Klatt 2004). Other nonforested natural communities found in the SEMCOG region include Great Lakes marsh, submergent marsh, southern wet meadow, lakeplain wet and wet-mesic prairie, and southern shrub-carr. Southern hardwood swamp is prevalent in the southern part of the state including the SEMCOG region and is classified as vulnerable in Michigan (Cohen et al. 2020).

Current Conditions in the Detroit Region

Overview

The most recent data from the National Land Cover Database (Dewitz 2020) indicate that 36 percent of land in the SEMCOG region is developed, 28 percent is forested, and 30 percent is used for agriculture (Table 1). Most of the land cover in Detroit is developed (77 percent), which contributes to impervious surfaces. As reported by the city of Detroit's street tree inventory, most

of the city's trees are considered to be in fair or better condition (Davey Resource Group 2016). Much of the Detroit right-of-way is composed of three species: Norway maple (18 percent), thornless honeylocust (14 percent), and silver maple (13 percent). Maple species make up 41 percent of trees on the street right-of-way (Davey Resource Group 2016). The city currently lacks enough young trees for an ideal diameter size-class distribution.

Detroit has seen an increase in the number of vacant parcels since 2006, and a sizable portion of the budget for the city's General Services Department and Detroit Parks and Recreation Department goes toward managing vacant land (City of Detroit 2017). These two departments maintain 308 parks for active and passive recreation as well as properties such as boulevards, cemeteries, golf courses, greenbelts, miscellaneous lots, parkways, and park lots (City of Detroit 2017). Parks in Detroit range from 0.07 to 1,181 acres, for a total of 4,899 acres of park space (Fig. 8). Many neighborhoods with low percentages of canopy cover are in the downtown core, which is a high-priority planting area (Fig. 9).

Urban trees in Detroit provide about \$24.3 million in benefits each year, representing benefits in aesthetics, air quality, net total carbon sequestered and avoided, energy, and stormwater peak flow reductions (Davey Resource Group 2016). Increasing the urban tree canopy can reduce ambient temperatures, control stormwater, provide animal habitat, increase human health benefits, reduce crime, and provide aesthetic value and greater social cohesion (USDA Forest Service 2023). ParkScore®, an analysis based on five characteristics (rated out of 100) of an effective park system, determined that Detroit is 61st in the Nation in park access (71/100), acreage (21/100), amenities (35/100), investment (35/100), and equity (69/100) (The Trust for Public Land™ 2021). Although only 6 percent of the land area in Detroit is used for parks and recreation, 80 percent of residents live within a 10-minute walk to a park (the national average is 55 percent). The 2017 "Parks and Recreation Improvement Plan" notes that residents have started to use land in unforeseen ways by developing green spaces from open lots and rehabilitating parks, ultimately cultivating a great sense of community (City of Detroit 2017).

Table 1.—Land cover and use (percentage of total land area) in the Southeast Michigan Council of Governments (SEMCOG) region. Source: National Land Cover Database 2016 (Dewitz 2020).

County or region	Open water	Developed	Barren land	Forest	Nonforest vegetation	Agriculture	Wetlands
Livingston	2.9	20.9	0.4	43.9	0.4	30.4	1.1
Macomb	1.0	52.8	0.3	18.2	0.6	26.8	0.3
Monroe	2.5	17.2	0.8	14.6	0.6	62.4	1.9
Oakland	4.7	52.9	0.9	32.5	0.6	7.8	0.5
St. Clair	3.8	12.4	0.2	36.6	0.7	45.0	1.3
Washtenaw	2.0	20.6	0.3	33.9	0.5	42.0	0.7
Wayne	3.4	76.5	0.4	12.6	0.6	5.9	0.5
SEMCOG	3.1	36.2	0.5	28.4	0.6	30.3	0.9

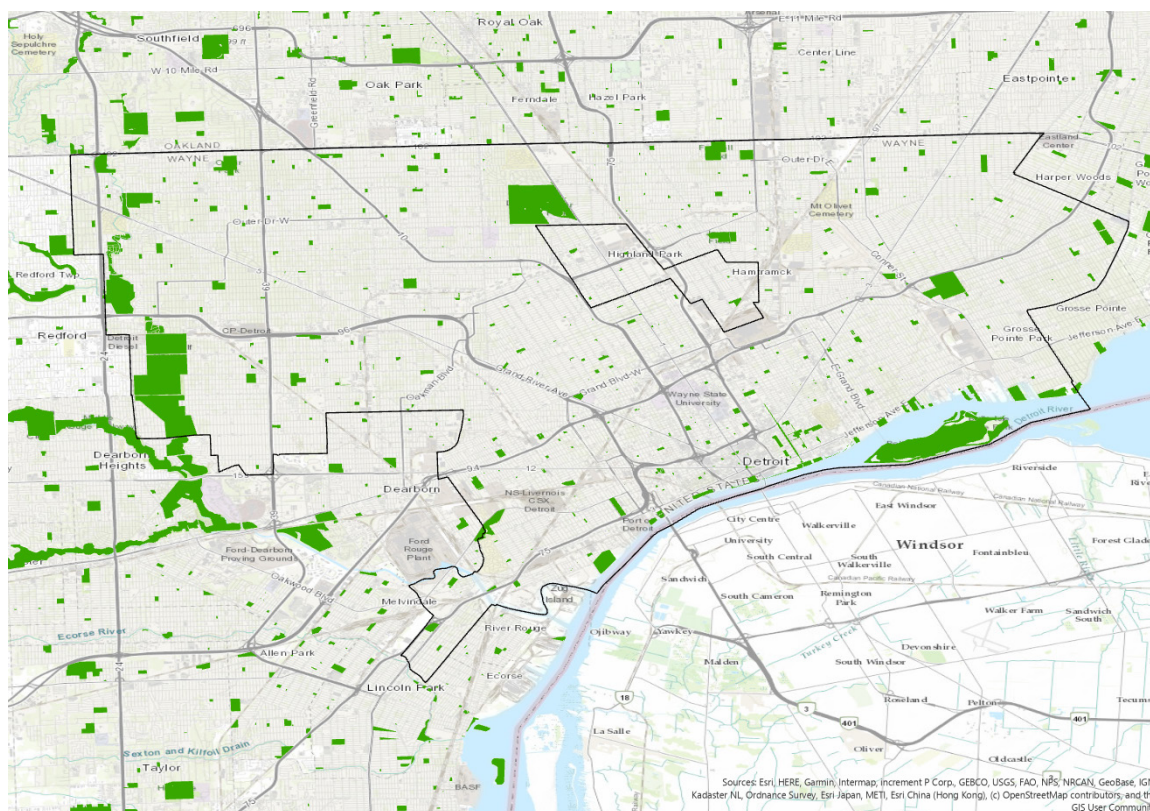


Figure 8.—Parks in Detroit, MI. Cartographer: Southeast Michigan Council of Governments (SEMCOG). Source: SEMCOG.

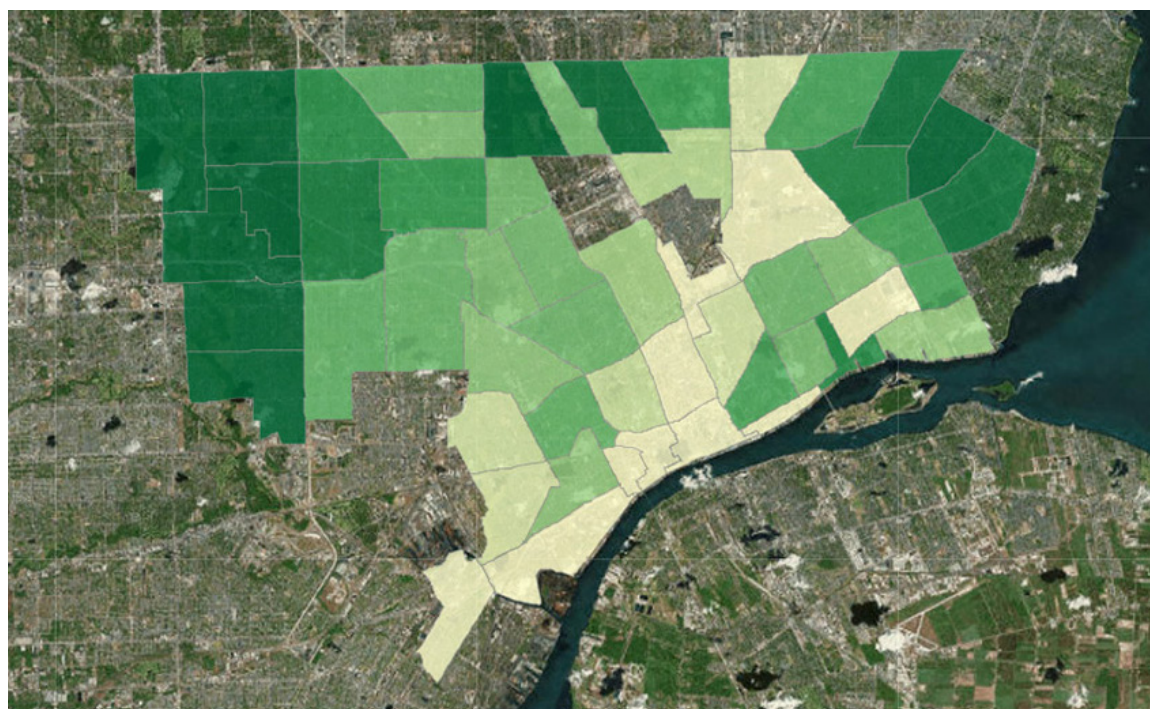


Figure 9—Detroit, MI, tree canopy cover by neighborhood. Lighter shades indicate lower canopy percentages. Credit: University of Vermont Spatial Analysis Laboratory.

Major Stressors and Threats

The Detroit region urban forest currently faces a variety of stressors including drought, flooding, strong storms, urban heat islands, invasive species and disease, vacant land, soil and water contamination, and air pollution, as well as racial and economic inequality. A changing climate interacts with these threats and amplifies their severity.

Urban Heat Islands

Exposure to heat can be substantially influenced by the geographic location within a region. For example, from 1980 to 2010, the average annual temperature in Detroit increased by 1.4 °F and the average annual temperature in Ann Arbor, MI increased by 0.2 °F (Gregg et al. 2012). Although this may not seem like a significant difference, a small increase in average annual temperature increases the likelihood of extreme droughts and heat events.

Heat exposure assessments using impervious surfaces and tree canopy as variables can determine vulnerable areas. Impervious surfaces (e.g., concrete and asphalt) absorb heat and radiate it into the air, which increases surface temperatures. Meanwhile, tree canopy and additional vegetation provide a cooling effect on the surrounding area. The interaction of these land covers results in areas of the city that are warmer in summer months and are thus more vulnerable to extreme heat events, creating the urban heat island effect (Fig. 10).

The average annual temperatures of urban heat island areas in Detroit are 1.8 to 5.4 °F warmer than adjacent areas and range from 70 to 85 °F (Geotab 2020, Gregg et al. 2012). CAPA Strategies conducted a “heat watch” in Detroit, providing maps of temperature distributions throughout the city on August 8, 2020, for the morning, afternoon, and evening. In the mornings, downtown Detroit and city council district 6 (see Table 12 in Chapter 6 for an overview of districts) experience significant urban heat island effects; islands are spread out around the city in the afternoons and dissipate more in the evenings (CAPA Strategies 2020). This study demonstrates where in the city there are significant urban heat islands, which often reflect characteristics of the land as well as its use.

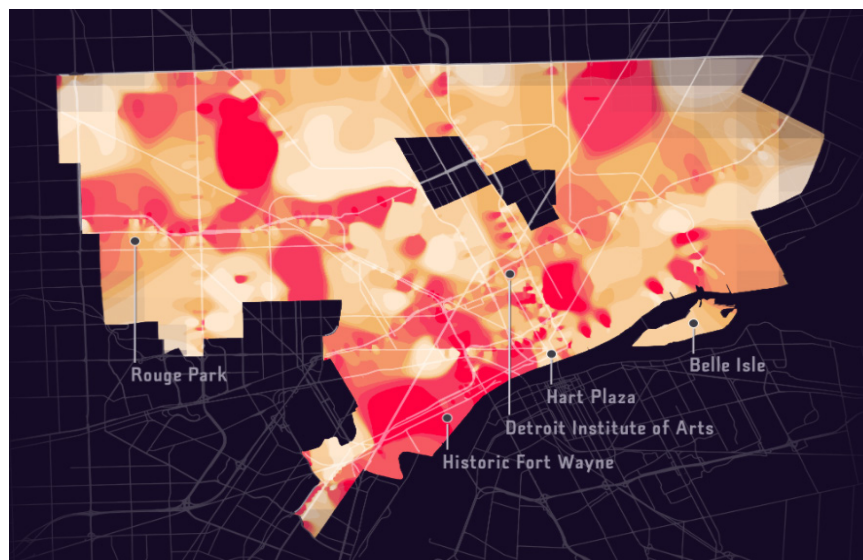


Figure 10.—Detroit, MI, urban heat islands. Maximum urban heat island effect is represented by red and the minimum is represented by white. Source: Geotab® (2020), used with permission.

Nonnative Insect Pests and Diseases

Detroit has lost extensive tree canopy because of insect pests and disease. Cooperative Invasive Species Management Areas (CISMAs) and various partners assist private landowners with invasive species control to reduce future losses. In Michigan, there are 17 CISMAs, including the Detroit and Western Lake Erie Cooperative Weed Management Area (CWMA), Lake St. Clair Cisma, Oakland County Cisma, Genesee, Lapeer, Livingston, and Shiawasee (GiLLS) Cisma, and Jackson, Lenawee, and Washtenaw Cisma in the SEMCOG region (State of Michigan 2023).

The first case of Dutch elm disease in Detroit occurred in 1950 and quickly spread throughout the city. The disease is caused by three species of ascomycete fungi and is spread by elm bark beetles—typically by the European elm bark beetle and sometimes by the American elm bark beetle. Its hosts include American elm, English elm, and winged elm trees. Many cities had planted elms as fast-growing shade trees in neighborhood streets, including 400,000 trees that quickly grew to 120 feet tall (The Detroit News 2001). Initially, Detroit tried to save the elm trees by spraying DDT. However, a combination of the disease, drought, and other stressors resulted in mass death and removal of elm trees in the city. The impact of Dutch elm disease has lingered for years. Although the disease is still present, researchers have found elm trees that may have genetic resistance (Bricault 2014). Detroit currently has 2,500 American elms inventoried. Following mass removal of elm trees, ash species were a common replacement. Tens of thousands of ash trees were planted and later wiped out by EAB, presenting a strong case for species diversity. Detroit has been planting a variety of species such as oaks, maples, lindens, and ginkgo in an effort to avoid these risks.

Emerald ash borer was discovered in Michigan near Detroit in 2002. Initial surveys found that EAB population densities and the associated tree mortality were higher in the greater Detroit area than in the rest of Michigan (Poland and McCullough 2006). EAB became established and was classified as an invasive pest in Detroit. Nonnative organisms are more likely to arrive in cities compared to rural or natural areas due to the high volume of international trade and commerce at urban ports of entry, which is suspected in the case of EAB. The larvae feed on the inner bark of ash trees, thereby disrupting the ability to transport water and nutrients. Adult beetles feed on ash foliage.

To manage the EAB infestation, the city of Detroit focused on addressing dead and dying ash trees. As of December 2020, more than 3,000 dead ash trees were scheduled for removal in the city's right-of-way. The Emerald Ash Borer Information Network (2018) states that EAB has killed more than 30 million ash trees in southeast Michigan. Although Michigan repealed its EAB internal quarantine in 2018, EAB has the potential to kill additional trees, as ash species have no immunity to the pest (Emerald Ash Borer Information Network 2018). To replace this loss in canopy, The Greening of Detroit planted more than 65,300 trees since 2002, in addition to hundreds of trees distributed through tree sales and giveaways. More than 50,000 volunteers contributed to planting and maintenance. Of these trees, 4,766 were funded primarily by EAB Great Lakes Restoration Initiative (GLRI) funding, as well as Reduce Runoff GLRI funding, as part of the larger effort to increase the urban forest.

The Asian longhorned beetle (ALB) also poses notable risk to city trees (Davey Resource Group 2016). Although ALB is not currently detected in Detroit, the city has more than 65,800 maple trees, the preferred host for ALB (State of Michigan 2021a). ALB can attack and kill additional tree species such as poplar, American sycamore, willow, and common horse chestnut. Populations are currently found in Ohio, Massachusetts, and New York and typically transported into new regions

by logs and firewood (State of Michigan 2021a). Populations in Illinois, New Jersey, and Toronto, Ontario have been successfully eradicated and early detection is crucial. If populations continue to spread, substantial economic and ecological impacts are expected.

Vacant Land

Detroit was once considered the center of the U.S. automobile industry. In the 1950s, the automobile industry began to disperse across the country and many jobs left the city. In response, the population declined and the city struggled with vacant and abandoned land. A sizable portion of housing parcels in Detroit are still vacant today, including abandoned buildings, vacant lots, and empty houses. In 2010, former Detroit Mayor Bing put forth a plan to demolish 10,000 vacant houses during his term, concentrating the population in a smaller area to improve city services. Although this effort was successful, the city still had tens of thousands of vacant homes standing.

Vacant land once again became an important topic in the 2013 Detroit mayoral election. At the time, more than 10 public agencies owned vacant land, creating difficulties for redevelopment. The Detroit Land Bank Authority (DLBA) was created to consolidate control and make vacant land available for purchase and redevelopment to productive use. The DLBA first-quarter report for fiscal year 2021 indicates an inventory of 85,159 properties and an economic value of more than \$676.5 million to Detroit neighborhoods (DLBA 2020).

There are 15,855 vacant, DLBA-owned structures, of which 2,514 are for sale, 4,765 are candidates for salvage, and 8,576 are demolition candidates. The department recently launched the new Land Reuse Programs team, developed to implement the Vacant Land Policy. The team manages DLBA's vacant land inventory, which entails creating vacant lot listings (see Figure 11 for current vacant property registrations), preparing land for sale, responding to purchase inquiries, and coordinating with the city. DLBA has been developing vacant land programs and the Land Reuse Programs team is coordinating with Disposition, Operations, and Research and Analysis to create internal infrastructure for the programs.

Although there continues to be notable vacant land in the city, vacant lots also offer opportunities for developing community green space and increasing canopy cover in the region. The Greening of Detroit has targeted vacant lots by replacing pavement with greenery and replanting trees, shrubs, and wildflowers (American Forests 2012). Individuals and communities in the city are focusing on vacant land, which can be transformed into gardens, orchards, tree nurseries, pocket parks, and other green spaces and productive landscapes that provide community benefits.

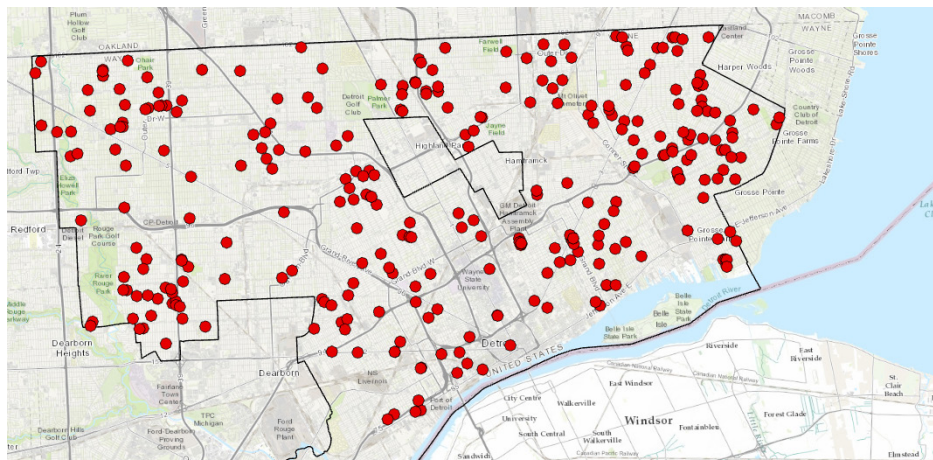


Figure 11.—Detroit, MI, vacant property registrations in 2020. Source: City of Detroit (2021).

Soil, Water, and Air Pollution

Soil Contamination—Detroit is a postindustrial city that has a high residential density and has historically been adjacent to industry, making soil contamination a concern. Lead hazards and contamination are due to lead paint in housing stock built before 1978, as well as existing pollution from factories, car exhaust, and industrial smelters (CLEARCorps/Detroit 2004). More than half of the housing in Detroit was built before 1950, when most homes used lead-based paint. Now-outmoded home demolition processes have demolished structures into basements or released unabated lead paint onto vacant land. Lead also occurs naturally in soils at low concentrations, but larger concentrations can pose both an environmental and a physiological threat. In 2019, the U.S. Department of Housing and Urban Development awarded the city of Detroit \$9.7 million in grants to help remove lead paint from low-income households starting as early as spring 2020 (Williams 2019).

Phytoremediation, a green technology that uses trees to remediate contaminated soils, has been used by The Greening of Detroit to clean up vacant lots in the city (Zalesny et al. 2020). It allows specialized trees to stabilize soil pollutants, trap or break down contaminants, and prevent the movement of pollutants into groundwater and other waterways.

Research continues into the use of trees to remediate the “Michigan 10” metals (arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc) and polycyclic aromatic hydrocarbons (PAHs) on several brownfield sites in the city. These sites were established by The Greening of Detroit between 2011 and 2015 to apply current research findings to local site conditions. Native and hybrid poplar and willow species have been chosen for phytoremediation because of their unique soil remediation abilities. These species also thrive in saturated soil conditions. Environmental benefits include a reduction in stormwater runoff, reduced blight, and an increase in curbside appeal. A newly developing partnership with the Forest Service will collect and analyze soil, tissue, and leaf samples to determine the uptake of contaminants and evaluate benefits to local communities. The increase in wet weather could potentially increase soil remediation by this treatment.

Water Contamination—The drinking water for Detroit comes from the Detroit River, within the Lake St. Clair, Clinton River, Detroit River, Ecorse River, and Rouge River watersheds in the United States, as well as parts of the Thames River, Little River, Turkey Creek, and Sydenham watersheds in Canada (City of Detroit 2020). The drinking water is currently deemed clean and safe to drink, meeting or exceeding all State and Federal regulatory standards (City of Detroit 2019b). The Detroit Water and Sewerage Department (DWSD) tested drinking water in 2019 for lead using the strictest rule in the Nation, the Michigan Lead and Copper Rule (LCR, enacted in June 2018; State of Michigan, n.d.), and found that all samples were below the U.S. Environmental Protection Agency [EPA] action level. However, lead can contaminate drinking water due to corrosion in service lines and in household plumbing that contains lead. DWSD customers are provided a corrosion inhibitor to reduce the corrosion of pipe materials that could enter their drinking water.

Additional contaminants that may be present in the source water for Detroit include microbial contaminants (viruses and bacteria), inorganic contaminants (salts and metals), organic chemical contaminants (synthetic and volatile organic compounds [VOCs]), pesticides and herbicides, and radioactive contaminants (City of Detroit 2020). While small amounts of these contaminants may be found in drinking water, the accepted level is regulated by the U.S. EPA.

As the climate changes, storms and extreme flooding events can result in increased stormwater runoff (U.S. EPA 2016). Increased runoff can create new pollution problems or exacerbate existing ones, and can also wash nutrients, sediment, and other pollutants into water sources. More frequent and intense precipitation events can overwhelm municipal stormwater management systems, leading to backup that causes localized flooding or runoff of contaminants into nearby waterways. These events can also challenge combined stormwater and wastewater drainage systems, resulting in more combined sewer overflows into waterways and a reduction in water quality.

A prominent topic concerning water quality is stormwater management. Stormwater management is commonly improved by green stormwater infrastructure, which reduces runoff volume, filters pollutants, and cuts down on flooding. DWSD has built 16 green stormwater infrastructure projects in recent years, managing a total of 24.5 million gallons of stormwater each year (City of Detroit 2020). In June 2019, the city announced a \$500 million program to upgrade aging water infrastructure. As part of the program, DWSD has upgraded 43 miles of water main, replaced 559 lead service lines, and lined 40 miles of sewer collection piping.

Air Pollution—Air pollutants such as ground-level ozone (O_3), sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter (PM) can inflict harm on urban trees both directly and indirectly. Elevated O_3 concentrations can cause visible damage to foliage, reduce plant reproduction and growth rates, and reduce tree survival rates. Elevated SO_x and NO_x concentrations also cause direct injury to vegetation, with indirect impacts on ecosystems due to deposition in the environment. Urban trees improve air quality and provide additional benefits by reducing temperature, removing air pollutants, and reducing energy use by shading buildings and blocking winds (Nowak 2002). Some tree species can also emit VOCs, contributing to ozone and carbon monoxide formation. Emission rates of VOCs vary by species and atmosphere. For example, in atmospheres containing low NO_x concentrations, VOCs have the potential to remove ozone (Nowak 2002).

Air quality has continued to improve throughout the region over the past 20 years, and as of mid-2023, the SEMCOG region now meets the U.S. EPA (2016) ozone standard of 70 parts per billion (ppb). This standard was lowered from 75 ppb in 2015. Some environmental and public health advocates have criticized the new designation. One criticism is that the U.S. EPA did not demonstrate that the improved air quality reflected largely “permanent and enforceable” reductions in pollution levels (Cwiek 2023).

Social and Economic Inequality of the Urban Forest

The urban forest provides many benefits to Detroit communities—from stormwater control to air pollutant uptake. However, trees and their associated services are not distributed equally. Variations in the extent of forest canopy cover result in neighborhood disparities in tree benefits, leading to disproportionate health issues from extreme heat and increased precipitation. In addition, there are notable social and political dynamics in Detroit stemming from issues of racial and economic inequality (Carmichael and McDonough 2019). Lack of public acceptance of street tree planting efforts has further exacerbated the variability in forest canopy cover in Detroit neighborhoods.

Extreme Heat and Precipitation

Urban forest canopy cover and urban heat islands vary among Detroit neighborhoods, which can cause disproportionate vulnerability to increasing temperature and precipitation. Heat-related health implications include asthma, allergies, chronic obstructive pulmonary disease, and fatalities

due to heat waves and severe weather events. Poverty, lower educational attainment, and lack of household access to a vehicle are three significant factors that contribute to an increased risk of heat-related illness (Gregg et al. 2012). Along with age, these factors can aid in determining human sensitivity to extreme heat. Heat-related mortality is associated with two indicators of community-level socioeconomic status: the percentage of the population living in poverty, and the percentage without a high school diploma (Smoyer 1998). These indicators often serve as measures of quality of life, occupation, and living conditions. More favorable levels of these characteristics help mitigate heat-related death risk by increasing access to opportunities such as air conditioning to avoid heat (Gregg et al. 2012).

Research has shown that heat health warning systems, emergency preparedness plans, and associated interventions may not be reaching the most heat-vulnerable individuals or support their behavior change when heat events arise (Sampson et al. 2013). The words and perspectives of community members who represent vulnerable populations as well as the leaders who work with them can be helpful in disseminating this information. Although many tend to recognize health threats, many also overlook or disconnect themselves from risk factors. Resources to aid in decision making are often culturally, physically, or financially inaccessible (or a combination thereof).

A study examining heat-related intervention strategies found that political will and resource access are crucial components of implementing heat-related health programming in urban, low-income areas (White-Newsome et al. 2014). In Detroit, one of the noted challenges is receiving multiple heat-related messages from a variety of sources without coordinated communications via government offices. Media outlets (radio and television) were most commonly used to publicize heat information to the public, along with pathways such as the Community Emergency Response Team (CERT). The CERT program provides education on disaster preparedness and training on basic disaster response skills. CERT members can also assist when professional responders are not immediately available and are encouraged to participate in emergency preparedness projects in their community. In Detroit workshops with governmental and nongovernmental organizations, recommendations included climate change education for grade-school students, investments in public relations campaigns on heat and health, and developing the framing and messages of heat warnings that connect to everyday life.

Inland urban flooding paired with disinvestment, aging infrastructure, and a changing climate is a prominent issue in Detroit (Sampson et al. 2019). As the frequency and intensity of precipitation events increase, Detroit also becomes more vulnerable to precipitation-related health impacts from stormwater overflow and water pollution (Sampson et al. 2014). Health effects include mold, asthma, respiratory diseases, diseases from raw sewage, and harmful algal blooms. In interviews with 18 Detroit residents experiencing recurrent household flooding, residents discussed exposure to risk factors for chronic and infectious diseases as well as economic loss and uncertainty (Sampson et al. 2019). As Detroit continues to undergo increased temperatures and extreme precipitation events, it is important to understand how to address climate change impacts while limiting the social, health, and economic disparities that residents experience (Sampson et al. 2014). It is also important to incorporate the concerns and priorities of community members to help ensure more-equitable outcomes.

Street Tree Acceptance

A history of insufficient municipal services, investment, and opportunity for some Detroit residents has affected their relationship with and perceptions of trees and the urban forest. There is a spectrum of uncertainty in terms of how much residents blame climate change, built

infrastructure, and government management for health risks. Historical trauma has caused tension, lack of trust, and feelings of neglect—all of which are barriers to implementing strategies and opportunities in the region. Historical experiences are often associated with the time in Detroit's history following the 1967 Detroit Riot, which coincided with the large-scale removal of diseased elms in residential neighborhoods.

Although it is clear to many residents that trees can provide aesthetic value, shade, and other benefits, they are also aware of the costs associated with an enhanced tree canopy. For example, trees can result in a “mess” of leaves and fruits, root-clogged sewer systems, raised sidewalks, and increased rodent populations. Many residents express the feeling of being left with an enormous burden resulting from negative externalities associated with the long-term maintenance of trees.

Nonprofit organizations can play a key role in urban and community forestry programs, but these efforts have in some cases been resisted by residents (Carmichael and McDonough 2019). Including residents in the planning and decision-making process can help improve trust and engagement in urban forestry efforts. When the city partnered with a local nonprofit organization to reforest its streets and organize tree planting on city-owned property, nearly a quarter of Detroit residents eligible for a free street tree declined tree planting offers, submitting a “no-tree request” between 2011 and 2014 (Carmichael and McDonough 2018). A lack of acceptance of street trees imposes a barrier to improving urban tree canopy in the city.

The primary reason for resistance to tree planting may be the power dynamics among stakeholders. Here, the nonprofit organization was the decision maker in terms of which trees to plant and where, causing residents to feel as though their values were not integrated into the program (Carmichael and McDonough 2019). After interviewing those who rejected street trees, researchers found that rejections were due more to distrust of the city government and the tree planters themselves, rather than their views about trees. Those who did submit a “no-tree request” were aware of the benefits of trees, but their response was ultimately rooted in historical experiences in Detroit, or “heritage narratives” (Carmichael and McDonough 2018). In addition, residents expressed concerns about tree maintenance and a desire for a greater role in selecting species. Residents who wanted more decision-making power also assumed they would ultimately be responsible for stewardship, an assumption that reflects their historical experiences. Negative experiences with trees were often attributed to the lack of tree maintenance by the city. Residents noted the importance of neighborhood upkeep, mentioning economic decline, an increase in vacant properties, and a decrease in city services. In addition, there were many large hazard trees such as ash and silver maples that were in danger of falling on houses and blocking accessibility for senior citizens.

Current Management

Community Initiatives

Community planting initiatives have been an important element in the reforestation efforts in Detroit. A key figure in this work has been The Greening of Detroit, which has helped combat the effects of Dutch elm disease, EAB, and the decline of city-funded reforestation. Since its inception, The Greening of Detroit has engaged volunteers to plant more than 133,000 trees in Detroit, Hamtramck, and Highland Park. It has worked with Detroit district managers, the Office of Sustainability within the city's Department of General Services, the Planning and Development Department, and DWSD to determine tree planting locations (American Forests 2012). When

a community begins planting, residents often express interest in other urban projects, such as gardens. Planting efforts are focused in areas with the greatest ecosystem benefits by reclaiming brownfields, filtering pollution, or absorbing stormwater runoff. The Greening of Detroit also works on educating the next generation and implementing green infrastructure, such as the transformation of vacant lots into plantings of shrubs, trees, or wildflowers (Fig. 12).

The efforts of nonprofit groups, volunteers, and State and Federal agencies have aimed to fill forestry gaps that result from Detroit's limited municipal budget. American Forests, a nonprofit forest conservation organization, has partnered with organizations such as The Greening of Detroit, SEMCOG, Michigan Department of Natural Resources, the Forest Service, DWSD, and Michigan Department of Environmental Quality to inventory and reforest trees in Detroit. By cooperating among various public and private entities, Detroit can strengthen the effectiveness and reach of its urban forestry efforts.

These organizations have documented important outcomes such as number of trees planted, tree survival, and number of volunteer participants. Although these data are important, more-qualitative measures of success (e.g., indicators of trust) can help nonprofit organizations integrate findings more meaningfully into their work and incorporate voices of the community. Taking more-qualitative measures into account may help the community to pilot big ideas, engage residents in stewardship, and develop policies from inside the community.



Figure 12.—Trained volunteers with The Greening of Detroit Citizen Forester program giving a tree planting demonstration in a residential neighborhood, Detroit, MI, April 2021. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.

Street Tree Acceptance

In response to “no-tree requests” by some Detroit residents, nonprofit groups such as The Greening of Detroit have made changes to their programming, actively involving residents in the planning and planting process. The dynamics of tree planting needs and desires vary from neighborhood to neighborhood. How residents interact with trees in the Warrendale, Winship, Hubbard Farms, and Morningside communities can differ greatly, and it is important to recognize and honor these differences. A community tree planting application continues to be a useful tool to demonstrate a community group’s need for trees. At any one time, there is an ongoing backlog of trees due to limited funding. Targeting larger geographic neighborhood areas anchored by city parks allows for the flexibility of offering street trees with tailored community engagement. Because of the neighborhood size and presence of city park trees, this strategy reduces the pressure of having to “convince” residents to accept trees that they are not interested in, and also serves those who are ready for trees. Matching tree plantings with a larger scale tree removal schedule is an area for future growth and better coordination.

Tree acceptance has been higher when there is robust community engagement with relatable information that is tailored to specific audiences. For a typical resident who does not think about trees, it is important to provide options for tree species, easy-to-understand information, the choice to accept or decline, the ability to be heard and responded to by a city representative, and a clear account of the public health benefits of trees and potential for saving money by reducing energy costs. Creative approaches that engage residents of all ages, particularly youth, through multiple channels could be explored further (Fig. 13). Campaigns that are tied to the city, nonprofit groups, schools, institutions, public events, partnerships, and social media could increase interest among Detroit residents.



Figure 13.—A woman and her twin grandsons beside a sapling that they have just planted in a residential neighborhood, Detroit, MI. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.

Detroit Climate Action Plan and Sustainability Action Agenda

Detroiters Working for Environmental Justice, an organization working to improve the economic and environmental health of Detroit, established the Detroit Climate Action Collaborative in 2011 (GLISA 2023). The collaborative is composed of universities, State agencies, private organizations, environmental organizations, community-based nonprofit groups, and the city of Detroit (Gregg et al. 2012). It has provided expert advice to identify short- and long-term actions for greenhouse gas emissions reductions and to ready Detroit residents for the impacts of climate change (GLISA 2023). This effort led to the development of the “Detroit Climate Action Plan” (Detroiters Working for Environmental Justice 2017).

The climate action plan is focused on solutions for five primary areas: solid waste; public health; businesses and institutions; parks, public spaces, and water infrastructure; and homes and neighborhoods (Detroiters Working for Environmental Justice 2017). Workgroups from each area developed a plan to advance Detroit as a climate-resilient city—one that is safer, healthier, economically extensive, and joyous for all. Each section was represented by stakeholders including nonprofit groups, businesses, academic institutions, and government organizations. Detroiters Working for Environmental Justice also commissioned an economic report and three studies examining the impact of the “Detroit Climate Action Plan”: a vulnerability study, Detroit climatology study, and greenhouse gas inventory.

The city’s “Sustainability Action Agenda” is the result of a yearlong process incorporating research, community engagement, and interdepartmental collaboration (City of Detroit 2019a). It was released in summer 2019 as the first sustainability plan for the city. It aims to create a more equitable, green city where Detroit residents have access to affordable, high-quality homes; live in clean, more connected neighborhoods; and work together to manage resources.

There are various action items in the action agenda related to climate adaptation and preparedness. In action 8, the goal is to increase tree plantings in vulnerable areas. The city aims to plant 5,000 trees by 2024, and 15,000 by 2029, in the 20 census tracts that have vulnerable populations most impacted by pollution and heat island effects. Additional action items include improving infrastructure and operations to enhance resilience to climate impacts, creating neighborhood-scale, distributed green infrastructure projects, incorporating green stormwater infrastructure into street redesign and greenway projects, and integrating climate change impacts into hazard mitigation planning.

Summary

The Detroit region urban forest, shaped in part by its natural and glacial history, still contains various forested communities in the landscape interspersed between developed areas. Current stressors and threats to the Detroit region urban forest include drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant land, soil and water pollution, air quality, and social inequity. Detroit’s “Tree Management Plan” (Davey Resource Group 2016) was developed to focus on short- and long-term maintenance needs for public trees in the city’s inventory. The “Detroit Climate Action Plan” and “the Detroit Sustainability Action Agenda” focus on equitable and sustainable climate solutions. In addition, various partners manage natural systems in the Detroit region to protect and expand urban forest and develop strategies to mitigate climate change impacts.

Key Points

- Detroit is located in the Southern Great Lakes Forest ecoregion, defined by various forest, prairie, swamp, marsh, and wetland ecosystems.
- Black or African American residents make up most of the local population, and the overall population of the city has been declining since 1950.
- There are three watersheds within the Detroit city boundaries that empty into Lake St. Clair or the Detroit River. The eastern border of the city and southwest Detroit are more prone to flooding.
- Before Euro-American settlement, this region was classified as mesic southern forest, including a mosaic of different forest types and large areas dominated by beech and sugar maple communities. Today, Detroit and the surrounding areas have a greater diversity of species including oak, birch, beech, hickory, sugar maple, elm, and cottonwood.
- Urban trees in Detroit provide approximately \$24.3 million in benefits each year, including benefits from aesthetics, air quality, net total carbon sequestered and avoided, energy, and stormwater peak-flow reduction.
- Stressors and threats to urban trees in Detroit include drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant land, soil and water contamination, air pollution, and racial and economic inequality.
- Racial and economic inequality are prominent stressors that have led to disparities in tree cover and resources for urban forests and to issues regarding street tree acceptance and extreme heat and precipitation.
- The listed natural resource managers, nonprofit organizations, and community initiatives in the Detroit region are among those working to manage the Detroit region urban forest to ensure that it continues to provide benefits for the community.

CHAPTER 2: CLIMATE TRENDS, PROJECTIONS, AND PHYSICAL IMPACTS

Climate, the average weather over a long-term period for a particular location, can change substantially on the scale of thousands of years. After the last ice sheet retreated 14,000 years ago, the climate in the Detroit region shifted from cool and moist to hot and dry, before eventually becoming the climate that we experience today (Gregg et al. 2012). The climate in Detroit is heavily influenced by the Great Lakes. Winters tend to be cold and accompanied by moderate snowfall. Summers are hot with moderate to high humidity. Although the climate has changed in the past, the current rapid rate of change is particularly stressful to humans and ecosystems alike. Temperature and precipitation are changing quickly at a global scale and the rate is projected to increase in the coming decades (Intergovernmental Panel on Climate Change [IPCC] 2018). These changes will impact different areas in different ways. Thus, the changes are best summarized at a local level for informed decision making. To assist in evaluating these local changes, this chapter provides information on our current understanding of past and projected changes in climate in the Detroit region.

Meteorological observations and climate models can help us understand how the climate has changed and is projected to change in the Detroit region. Unless otherwise noted, climate observations were retrieved from GRIDMET and future projections were retrieved from MACAv2-METDATA (daily and monthly summaries) (Abatzoglou 2013). Model outputs included annual and seasonal observations, projections of temperature and precipitation, and extreme events (temperatures 0 °F or below, or 90 °F or above; precipitation 1 inch or greater and precipitation 2 inches or greater). The GRIDMET and MACAv2-METDATA datasets were processed using Google Earth Engine (Gorelick et al. 2017) to obtain various indices. A 30-year baseline period of 1980 through 2009 and three future periods (2010 through 2039, 2040 through 2069, and 2070 through 2099) from the HadGEM2-ES (Jones et al. 2011) and IPSL-CM5A-MR (Dufresne et al. 2013) general circulation models under the representative concentration pathways (RCPs; Moss et al. 2008) 4.5 and 8.5 represent a range of potential warming and precipitation changes.

Representative concentration pathways describe different pathways of greenhouse gas emissions and atmospheric concentrations as well as air pollutant emissions and land use (IPCC 2022). RCP 4.5 represents an intermediate climate scenario where atmospheric carbon dioxide levels remain below 550 parts per million (ppm); the RCP 8.5 scenario includes continued increases in greenhouse gas emissions and is considered the “high end” scenario (high emissions, high concentrations, and large temperature increase) (Avery et al. 2018). The HadGEM2-ES model represents a warm-dry scenario under RCP 4.5 and a hot-wet scenario under RCP 8.5. The IPSL-CM5A-MR model represents a warm-wet scenario under RCP 4.5 and a hot-dry scenario under RCP 8.5. Climate projections were statistically downscaled using the delta method to remove bias among the simulated historical periods from the different models and between the observed data. For each climate scenario, the potential change in temperature and precipitation from the simulated baseline period to the future periods was used to adjust observed data prior to calculating the climate indices. It is important to note that each model contains uncertainty. More uncertainty is associated with precipitation and timing of conditions.

Historical climate trends were retrieved from the National Oceanic and Atmospheric Administration (NOAA) Climate at a Glance tool (NOAA National Centers for Environmental Information 2020). This tool was developed to facilitate near real-time analysis of monthly temperature and precipitation data across the contiguous United States and intended for the study of climate variability and change.

Observed Trends

Temperature Observations

Historical trends demonstrate that temperature has been increasing in Detroit. Since 1998, all but 2 years (2003 and 2014) have been above the average for 1960 through 1990, which is a standard baseline period of comparison for examining climate trends (NOAA National Centers for Environmental Information 2020). The last two decades, 2000 to 2010 and 2010 through 2019, have been the warmest on record for the contiguous United States and for Detroit. Recent years have been increasingly hot and 7 of the hottest 10 years in Detroit have occurred between 2000 and 2019.

When we compare the period 1961 through 1990 to the period 1981 through 2010, the 30-year average annual temperature has increased by 1.4 °F (GLISA 2023). From 1959 to 2011, average overnight temperatures increased by 4.3 °F. During that same period, the number of hot, humid summer days increased by 3.5 (172 percent) and the number of hot, dry summer days increased by 3 (338 percent). Conversely, the number of cool, dry days has decreased by 10.5 (70 percent).

The average annual temperature in Detroit has increased from 1960 through 2019 by 0.4 °F per decade, and the average annual minimum and maximum temperatures follow a similar trend (Fig. 14) (NOAA National Centers for Environmental Information 2020). When we examine the average temperature (1960 through 2019) in the seven-county SEMCOG region, the temperature has increased in all four seasons (December to February, March to May, June to August, and September to November) (see Appendix 2). The trend varies by season, increasing the most in December to February (0.7 °F per decade) and the least in September to November (0.3 °F per decade).

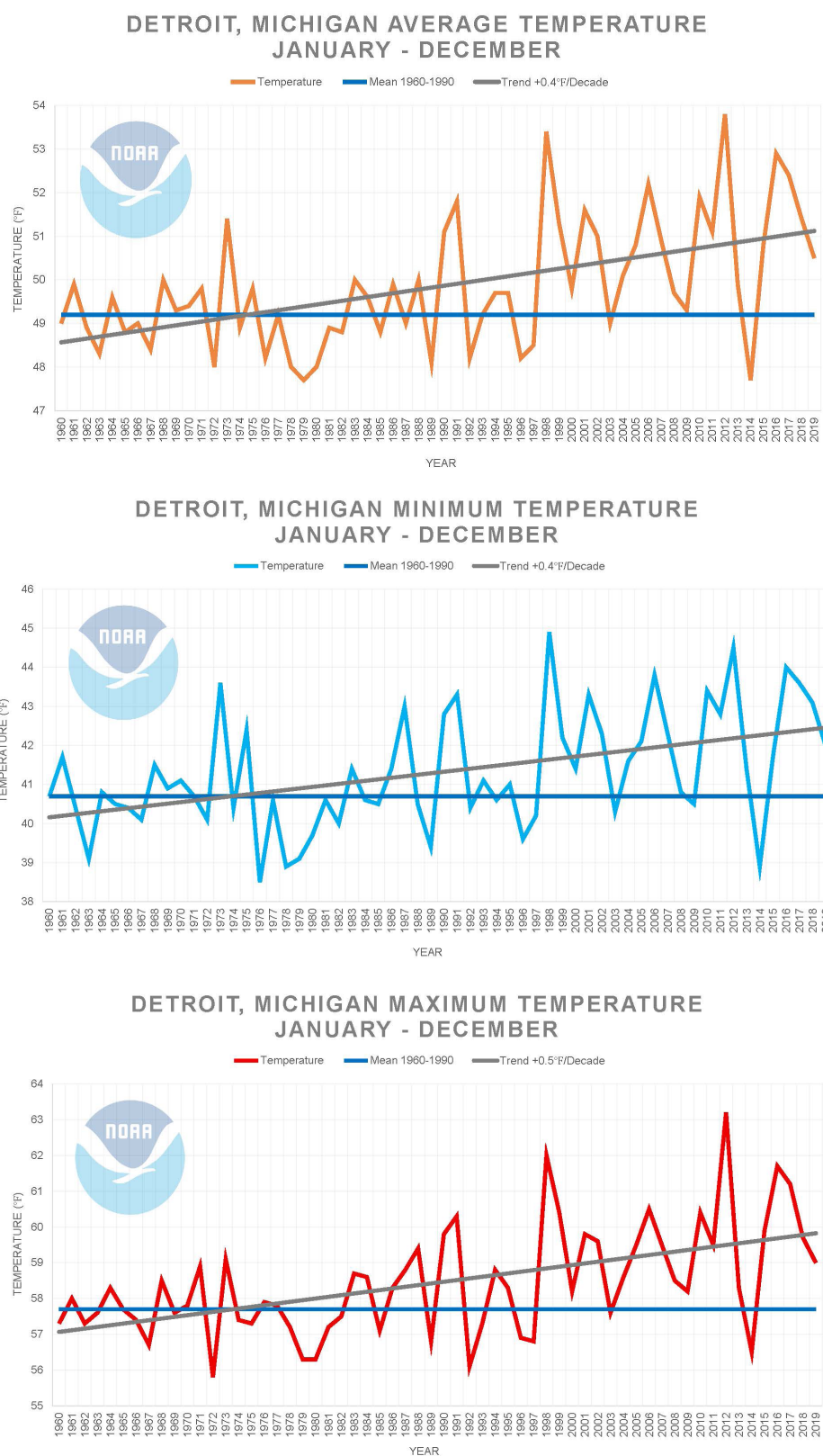


Figure 14.—Annual average, minimum, and maximum temperature for Detroit, MI, 1960 through 2019. The blue line indicates the average for 1960 through 1990 and the gray line shows the trend over the observational record (NOAA National Centers for Environmental Information 2020).

Precipitation Observations

The climate in Michigan is classified as humid continental, characterized by distinct summer and winter seasons and a relatively equal precipitation distribution throughout the year. June is the wettest month in Detroit (average 3.6 inches), and January and February are the driest months, with less than 2 inches of precipitation (1.95 and 1.78 inches, respectively; NOAA National Centers for Environmental Information 2020). Multiple sources have demonstrated that precipitation has increased in the SEMCOG region. In a comparison of the averages for 1961 through 1990 and 1981 through 2010, the total annual precipitation in southeast Michigan increased by 11 percent and extreme precipitation events have become more frequent and intense (GLISA 2023). Annual precipitation in Detroit has increased from 1960 through 2019 by 0.95 inch per decade (Fig. 15) (NOAA National Centers for Environmental Information 2020). Across the SEMCOG region, precipitation has increased in each season from 1960 through 2019 (see Appendix 2). The increasing trend is the greatest in March to May (0.42 inch per decade) and September to November (0.43 inch per decade), and the least in June to August (0.15 inch per decade). See Appendix 3 for more information on the observation datasets.

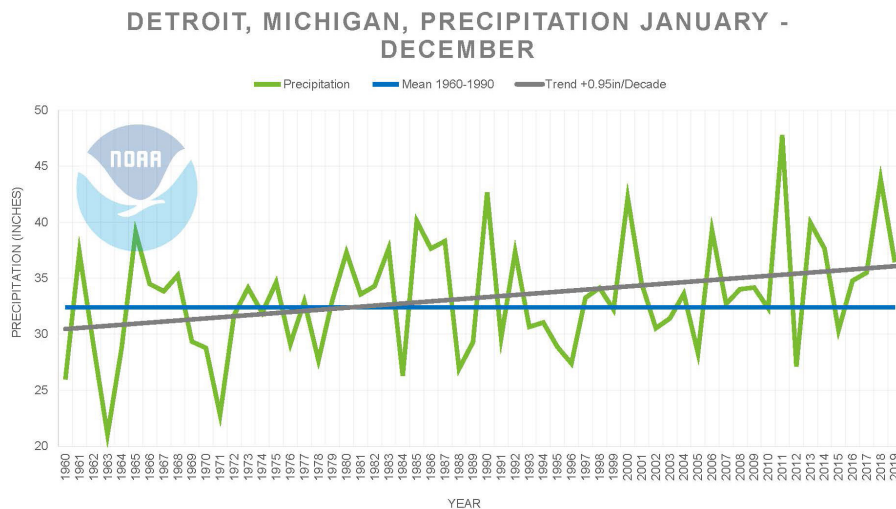


Figure 15.—Average annual precipitation for Detroit, MI, 1960 through 2019. The blue line indicates the average precipitation for 1960 through 1990 and the blue line shows the trend over the observational record (NOAA National Centers for Environmental Information 2020).

Climate Projections

Temperature Projections

All climate models project continued warming, with the degree of warming dependent on the amount of future greenhouse gas emissions. Temperatures are projected to increase across all seasons, greenhouse gas scenarios, and climate models over the rest of the century in the SEMCOG region compared to the mean for 1980 through 2009 (Table 14 in Appendix 4). Projected increases in mean annual temperature range from 5 to 13 °F for the last 30 years of the century compared to the mean for 1980 through 2009, depending on the climate change scenario and climate model. All seasons are projected to warm by at least 4 °F, and by as much as 9 °F in the spring, more than 14 °F in the summer and winter, and nearly 14 °F in the fall (Table 14).

Precipitation Projections

Mean annual precipitation is projected to increase across Michigan, especially in the winter. However, changes are expected to vary by scenario and region of the state. Annual precipitation in the Detroit and SEMCOG region is expected to increase 1.35 inches on average.

In the SEMCOG region, precipitation projections vary by season and climate scenario (Table 15 in Appendix 4). Generally, precipitation is expected to increase in the winter and spring, decrease in the summer, and remain relatively steady in the fall (Fig. 16).

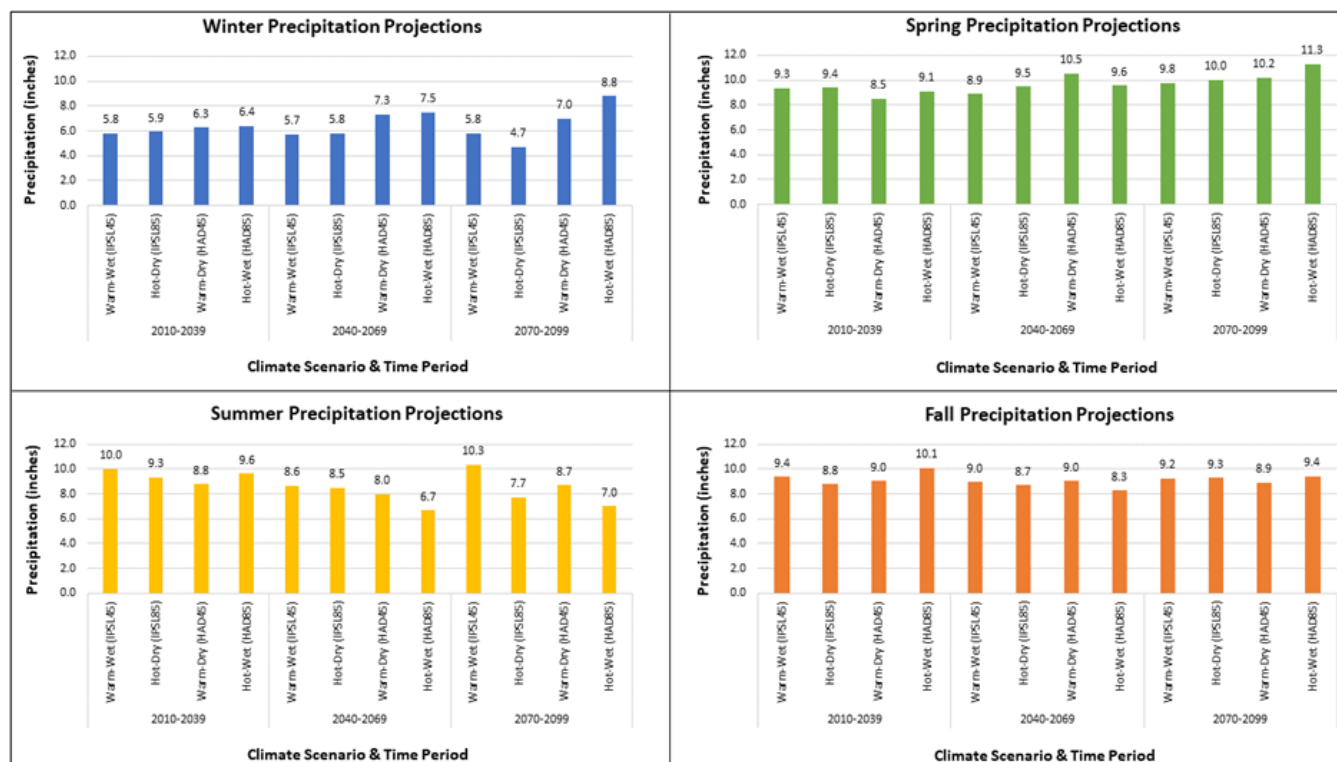


Figure 16.—Precipitation projections by season under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties). See Appendix 3 for more information.

Trends and Projections in Extreme Weather

Extreme weather, such as heat and cold waves, heavy precipitation events, tornadoes, thunderstorms, windstorms, and winter storms can cause disturbance in urban and natural areas. Some of these extreme weather events have been increasing across the United States and globally in recent decades, consistent with a changing climate. The following subsections provide a summary of these extreme events and how they are projected to shift over the next century.

Temperature Extremes

The average number of days less than or equal to 0 °F is projected to decrease compared to the mean from 1980 through 2009 under each climate scenario. The Detroit region could experience no days below zero in a typical year by the end of the century under some scenarios (Fig. 17). The average number of days greater than or equal to 90 °F is projected to increase under each climate scenario to nearly 87 days under the hot-wet (HAD85) scenario compared to the 1980 through 2009 mean of fewer than 8 days.

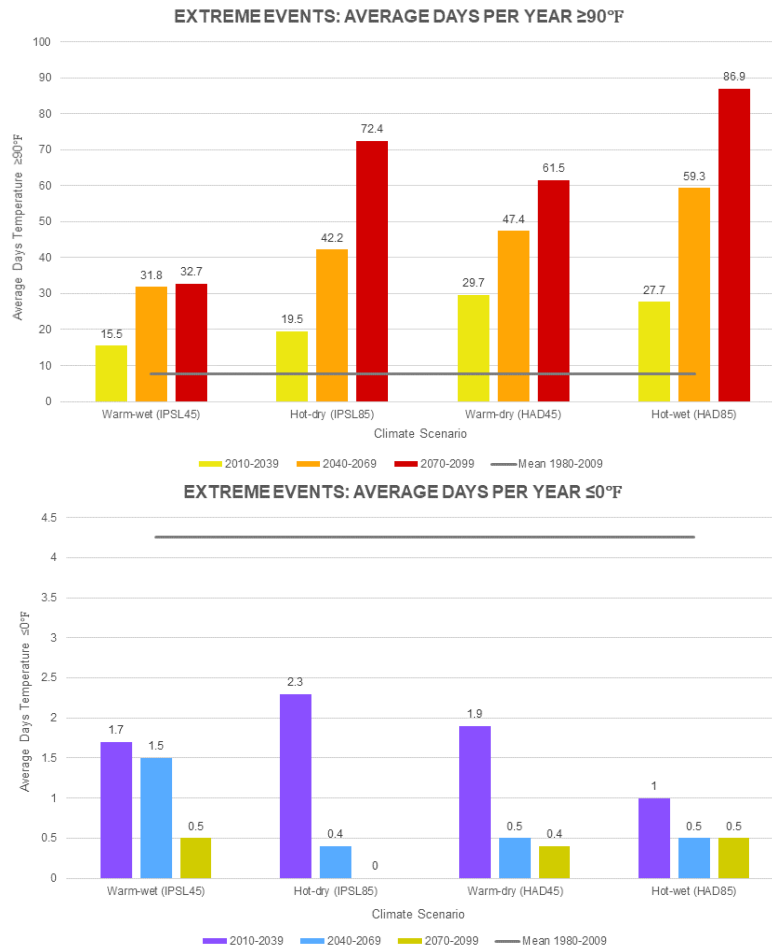


Figure 17.—Extreme temperature projections under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties). See Appendix 3 for more information.

Heavy Precipitation Events

The scenarios projecting the greatest atmospheric greenhouse gas concentrations show an increase in the 100-year storm event of as much as 3 inches by 2100, almost double the current state average of 4 inches (Michigan Department of Transportation 2015). Inland flooding is projected to occur more frequently in the Detroit region because of increases in extreme storm and precipitation events (GLISA 2023). Detroit has an estimated 41,691 properties (10 percent of total properties) that will be at risk of flooding in 30 years, an increase of 4.8 percent from 2020 (First Street Foundation 2020). The average number of days with precipitation greater than or equal to 1 inch is projected to increase in each time period and climate scenario, with the exception of warm-wet (IPSL45) in 2040 through 2069 (Table 16 in Appendix 4, Fig. 18). The average number of days with precipitation greater than or equal to 2 inches is projected to increase in each time period and climate scenario, increasing the most in 2070 through 2099 and under the hot-wet climate scenario (HAD85).

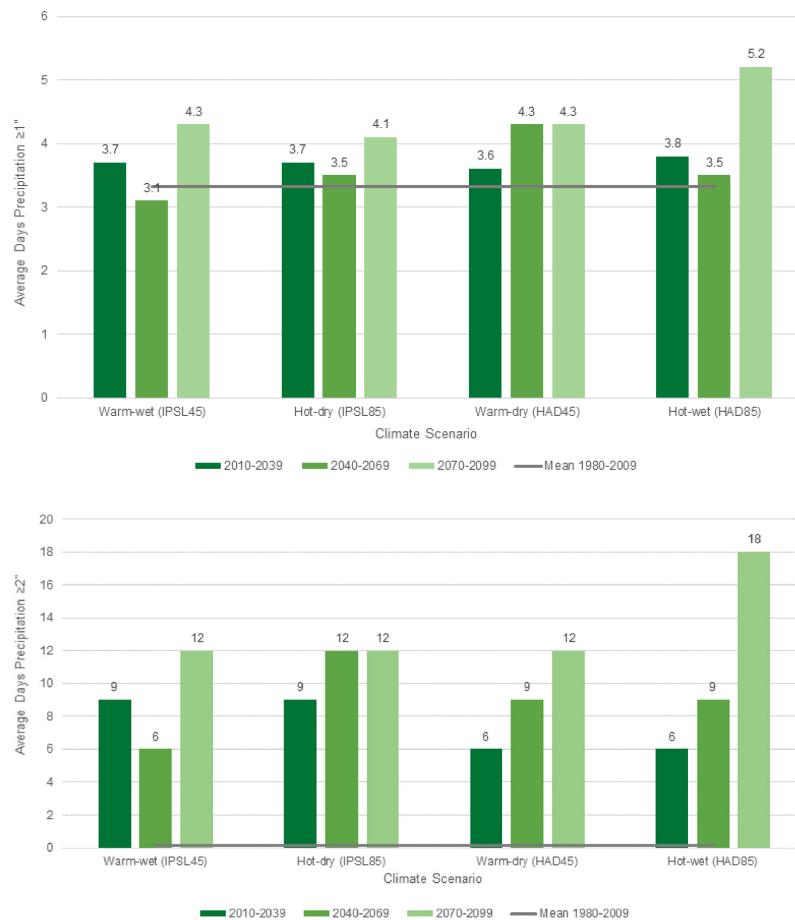


Figure 18.—Extreme precipitation projections under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties). The top graph displays the average number of days per year with precipitation of 1 inch or more; the bottom graph displays the average number of days per year with precipitation of 2 inches or more. See Appendix 3 for more information.

Tornadoes, Thunderstorms, and Windstorms

Tornadoes, thunderstorms, and windstorms can lead to local tree damage from strong winds and lightning strikes. Michigan is located on the northeast edge of the midwestern tornado belt and in the past 30 years, Tornado Alley has shifted 500 miles east (Jones 2018). However, future tornado activity is difficult to project because the formation of tornadoes is not fully understood. Although some studies project an increase in severe thunderstorms, only about 20 percent of supercell thunderstorms create tornadoes (National Geographic 2019). Additionally, historical records appear to show an increase in the number of tornadoes in the United States throughout the previous century, but this trend is primarily due to the increase in tornado detection via enhanced technology and monitoring networks. Tornado records date back to just the 1950s and there are challenges with collecting reliable wind data to determine trends (Diffenbaugh et al. 2008, Kunkel et al. 2008). Further, the number of severe tornadoes has decreased in the past century, but severity is determined by the level of structural damage as opposed to windspeed (Diffenbaugh et al. 2008). Scientists may not be able to determine whether storms are weaker overall, or whether there is less damage due to improved building construction.

Over the past century, it has been difficult to measure changes in the severity and frequency of thunderstorms in the United States (Kunkel et al. 2008). Researchers have taken a variety of approaches because of limitations in observational records for past trends, which makes it challenging to establish a baseline for interpreting future projections (Allen 2018). Despite the lack of clear past trends, severe storms may become more frequent, as increased temperatures could result in longer storm and tornado seasons.

Thunderstorms in a changing climate have become a rapidly growing research area. One study found that severe thunderstorms will increase under both RCP 4.5 (30 to 150 percent) and RCP 8.5 (50 to 180 percent) climate change scenarios (Seeley and Romps 2015). Although this study contributed to a growing understanding that there may be an increase in severe thunderstorms in a changing climate, sources of uncertainty remain in these models due to assumptions that researchers had to make. For example, there is a lack of long-term datasets of near-surface wind speeds due to irregular spatial coverage as well as local land cover changes, and projected changes in windspeed remain uncertain for the Midwest (Kunkel et al. 2013). In addition, there are remaining questions and areas to explore such as storm structure in a warming climate and what changes to storms, including frequency and intensity, will look like in the face of threats such as hail, tornadoes, and damaging winds (Allen 2018).

Winter Storms and Extreme Cold Events

Increased temperatures can result in a decrease in the frequency of snowstorms and ice storms due to the reduction in the number of days with low enough temperatures for these events to occur. Historically (1961 through 2000), the occurrence of extreme cold has been heavily influenced by the Great Lakes and has exhibited maximum frequencies along the northernmost fringe of the assessment area, resulting in approximately 10 days of extreme cold per year in the SEMCOG region (Vavrus et al. 2015). Detroit has already been experiencing shorter winters and more precipitation in the form of rain instead of snow, and this trend is projected to continue.

Winter storms and cold snaps are a major concern among local practitioners. Plants that have not become acclimated to the cold may suffer injury and stress when subjected to abrupt or extensive drops in temperature after mild fall weather (The Morton Arboretum 2020). In 2019, the sudden onset of freezing temperatures in Detroit led to an increase in winter injury to trees in recently implemented planting projects. Winter injury can include limb-breaking ice buildup,

frost cracks, sunscald, and the freezing of buds, all of which cause stress to newly established trees. Furthermore, long periods of mild winter temperatures can deacclimate trees, increasing risk of injury from sudden drops in temperature (The Morton Arboretum 2020).

There is a range of evidence connecting climate change to winter severity. While there is a connection between polar vortexes and climate change, there is a lack of consensus across scientific evidence (Blackport et al. 2019; University of California, Davis 2021). Research points to an overall decline in winter severity in the Great Lakes region through the end of the century. A 2018 study of the Great Lakes and Midwest regions projects significant declines in winter weather, including reductions in cold days, snow depth, and length of winter (Chin et al. 2018). Michigan is projected to undergo significant, warming-induced losses in snow cover, and daily snowfall events are also projected to become less common but more intense in the Upper Midwest and Great Lakes region (Chin et al. 2018, Notaro et al. 2014). This finding is similar to existing research, though the amount of decline in winter weather varies (Scott et al. 2008, Wobus et al. 2017). Making accurate predictions about winter severity based on climate model projections can be a challenge, as many can demonstrate scattered results or even differ in their direction of change (Vavrus et al. 2015). More research will elucidate whether we can expect fewer extreme cold events in the future.

Effects on Soils and Hydrology

The hydrologic behavior of urban areas is complex. Due to the increasing frequency of heavy rain events, the region is expected to experience more soil erosion and nutrient runoff (Angel et al. 2018). A combination of increased precipitation and soil moisture can lead to loss of soil carbon and surface water quality, and waterlogged soils can also lead to a reduction in planting season work days. Many trees have already met their hydraulic limits; thus, a small increase in moisture stress can lead to ecological shifts and species decline (Choat et al. 2012, Pederson et al. 2014). In addition, soils typically insulated by snowpack can freeze due to the lack of cover, which can kill thin roots, decrease plant productivity, and alter nutrient and water cycling (Notaro et al. 2014, Reinmann et al. 2019).

Urban environments are more vulnerable to stormwater runoff because of the increased concentrations of impervious surfaces. Green infrastructure, such as rain gardens and green street corridors, are increasingly being considered as strategies to decrease stormwater runoff by increasing water storage in soil and groundwater (Carlson and White 2017, Hopton et al. 2015). Climate change can also impact groundwater quality and quantity. Although annual precipitation is projected to increase, the seasonal distribution of precipitation is projected to change, leading to changes in water availability, winter rain, and earlier peak streamflows (GLISA 2023). Land surfaces in the region can become drier due to increased temperatures and evaporation, impacting groundwater supply in addition to soil moisture and surface waters. Drying of land surfaces will be strongest in summer, when temperatures are high; groundwater recharge will decrease, leading to an increase in low-flow periods (Wu et al. 2020).

Shifts in Plant Hardiness Zones and Heat Zones

Hardiness zones and heat zones are geographic areas that define which species or cultivars are considered suitable for planting and survival. These zones are critical for understanding tree species selection under a changing climate. Defined by the U.S. Department of Agriculture (USDA), plant hardiness zones help arborists, gardeners, farmers, and others interested in tree and plant growth compare their local climate to the climate where a specific tree or other plant is known to grow well. The modern USDA hardiness zone system delineates geographical areas based on their average annual minimum temperatures, which helps growers determine whether plants may be adapted to withstand winter cold temperatures. The system and corresponding maps were originally developed in the mid-20th century but have undergone several revisions over the decades. Each hardiness zone is 10 °F warmer (or colder) than the adjacent zone to its north (or south, respectively). The 2012 USDA Plant Hardiness Zone Map (Agricultural Research Service, n.d.) generally shows areas as being one-half zone warmer than the earlier maps (Cathey 1990) due to the inclusion of more recent climate data and improvements in data analysis (Daly et al. 2012). Southeast Michigan was in zone 5 in 1990; in 2012 it was determined to be in zone 6. Since 1990, hardiness zones have been moving north 13 miles per decade nationally as temperatures increase and habitats shift due to a changing climate (Jones 2018).

The Detroit region is in plant hardiness zone 6 (average annual extreme minimum temperature of -10 to 0 °F; Agricultural Research Service, n.d.). Future projections of hardiness zones and heat zones were obtained from Matthews et al. (2018). Under the RCP 4.5 scenario, the hardiness zone is projected to begin shifting to zone 7 (average annual extreme minimum temperature of 0 to 10 °F) in parts of the SEMCOG region by 2039 and the entire region by 2040 to 2069. Under RCP 8.5, the hardiness zone is projected to shift to zone 7 by 2039, to zone 8 (average annual extreme minimum temperature of 10 to 20 °F) in parts of the region by 2040 to 2069, and entirely to zone 8 across the region by 2070 to 2099 (see Appendix 5).

The American Horticultural Society produced a map of heat zones based on the average number of days exceeding 86 °F for use in determining the upper temperature limits that trees are able to tolerate (Cathey 1997). Detroit and the SEMCOG region are in heat zones 4 and 5 (between 14.1 and 30 and between 30.1 and 45 days exceeding 86 °F, respectively). Under the RCP 4.5 scenario, the heat zone is projected to shift to zone 6 (more than 45 to 60 days exceeding 86 °F) by 2039 and zone 7 (more than 60 to 90 days exceeding 86 °F) by 2040 to 2069 (Table 2). Under RCP 8.5, the heat zone is projected to shift to zone 7 by 2039, zone 8 (more than 90 to 120 days exceeding 86 °F) by 2040 to 2069, and zone 9 (more than 120 to 150 days exceeding 86 °F) by 2070 to 2099 (see Appendix 5).

Table 2.—Projected shifts in hardiness zones and heat zones by time period and climate change scenario (RCP 4.5 and RCP 8.5) compared to the zones for 1980 through 2009

Time period	Hardiness zone 6 (1980–2010) under RCP 4.5	Hardiness zone 6 (1980–2010) under RCP 8.5	Heat zone 5 (1980–2010) under RCP 4.5	Heat zone 5 (1980–2010) under RCP 8.5
2010 through 2039	Zone 7	Zone 7	Zone 6	Zone 7
2040 through 2069	Zone 7	Zone 8	Zone 7	Zone 8
2070 through 2099	Zone 7	Zone 8	Zone 7	Zone 9

Summary

Temperatures in Detroit have been increasing and are projected to continue to increase throughout the rest of the 21st century, leading to more extremely hot days. Precipitation has also been increasing, but there is more uncertainty in the timing and direction of future precipitation. Spring precipitation is projected to increase across all models, however. Detroit is projected to experience more extreme events, including days above 90 °F and days with precipitation over 1 inch. Trees can be subject to more stress due to effects on soils and hydrology, such as loss of soil carbon and waterlogged soils. The hardiness zone and heat zones are projected to shift, which could create both new opportunities and challenges for species selection.

Key Points

- The average temperature in Detroit has warmed by 0.4 °F per decade since 1960 and the average temperature is projected to increase in each season under a range of climate scenarios compared to the mean for 1980 through 2009.
- The average precipitation in Detroit increased by 0.95 inch per decade since 1960. Although precipitation projections vary by season and climate scenario, spring precipitation is generally expected to increase under all climate scenarios.
- Extreme heat and heavy precipitation events are expected to increase in intensity and become more frequent.
- The USDA hardiness zone for the region is projected to shift by one to two zones and the heat zones are projected to shift by three to five zones by end of century, depending on the climate scenario.

CHAPTER 3: BIOLOGICAL CLIMATE IMPACTS

A changing climate has the potential to affect the Detroit region urban forest directly and indirectly. Climate change can disrupt the relationship between trees and their local environment through altered physiological effects and nutrient cycling. In addition, climate change can have indirect effects on urban forests because of its influence on invasive pests and pathogens. Planted and naturally occurring tree species will have different capacities for adapting to these stressors. This chapter synthesizes the following potential climate impacts on urban forests in the Detroit region: carbon sequestration and productivity, phenological shifts, nutrient cycling, pests and pathogens, invasive plant species, wildfire risk, and flooding.

Carbon Sequestration and Productivity

Urban forests play an important role in climate mitigation and the regulation of ecosystem services by offsetting sources of carbon dioxide to the atmosphere and providing carbon benefits to communities. Carbon sequestration is the process by which carbon dioxide is removed from the atmosphere by trees and other plants and stored as carbon in biomass such as wood, roots, and leaves. Tree species vary in terms of their carbon benefit. Carbon benefits can be determined by looking at carbon storage (total of all carbon stored during the average lifespan of the species), carbon sequestration rate (carbon absorption per year), and carbon savings from energy use (total amount of carbon saved from reduced heating and cooling energy use) (Janowiak et al. 2021). Larger trees tend to store more carbon and species that gain substantial volume per year have higher carbon sequestration rates. The estimated carbon benefits of some common trees in the Detroit region are summarized in Table 3.

Carbon dioxide can affect plant productivity and species composition, although there is uncertainty about the effects of increased atmospheric carbon dioxide, known as carbon dioxide fertilization, on plant physiology. There are several challenges with modeling carbon dioxide fertilization and few observational studies have evaluated the impact of fertilization above 600 ppm, which makes it difficult to project how forests may respond under even higher carbon dioxide levels (Janowiak et al. 2014). If global energy demand continues to increase and is met with fossil fuels, carbon dioxide levels are projected to exceed 900 ppm by 2100 (Lindsey 2022). Furthermore, the carbon dioxide fertilization effect may be limited by ozone pollution and nutrient and water availability, as well as tree age and size (Ainsworth and Long 2005). Factors such as fire, disease, insects, and forest management could also reduce productivity, as could long-term ecosystem transitions that influence the ability of a forest to utilize atmospheric carbon dioxide.

Increased carbon dioxide can reduce the rate of water loss from trees, enhancing growth in some tree species with the potential of offsetting some effects of drier growing seasons (Ainsworth and Rogers 2007, Franks et al. 2013, Norby and Zak 2011, Wang et al. 2006). However, increases in productivity under increased carbon dioxide levels could be partly offset by reduced productivity from climate-induced drought stress and by the effects of future disturbances (Dieleman et al. 2012, Franks et al. 2013). Overall, it is still unclear how influential carbon dioxide fertilization will be in the long term.

Higher temperatures may be likely to stimulate soil organic matter decomposition rates, allowing nutrients to be more readily mineralized and available (Kirschbaum 2004). Acceleration of this process can increase the photosynthetic carbon gain in systems that are nutrient limited.

Species may be able to acclimate or adapt to increased temperatures through mechanisms such as increasing the number of stomata, which are small pores located under the leaves that assist with regulating plant temperature and allow for a critical part of photosynthesis—the exchange of carbon dioxide and oxygen (Rudolph 2017). Examining long-term growth in Lafayette Park and in the St. Aubin Avenue median in Detroit, researchers found elm trees and some oaks had a favorable growth response to increased temperatures (Rudolph 2017).

Table 3.—Estimated carbon benefits of common trees in the Detroit region (Janowiak et al. 2021)

Common name	Estimated number of trees in Detroit	Carbon benefit
honeylocust (thornless)	22,971	moderate-high
silver maple	20,476	moderate
red maple	7,287	high
London planetree	6,971	moderate-high
American sycamore	5,771	high
littleleaf linden	5,396	low-moderate
sugar maple	5,240	moderate-high
American elm	2,509	high
American linden (basswood)	2,482	low-moderate
common hackberry	2,270	moderate
northern red oak	2,234	high
pin oak	2,033	moderate-high
ginkgo	1,220	low-moderate
common horse chestnut	1,180	moderate-high
boxelder	1,002	moderate
eastern cottonwood	885	moderate
swamp white oak	858	high
sweetgum	632	high
bur oak	595	low-moderate
English oak	530	moderate-high
Japanese zelkova	528	low
tulip tree	509	high
eastern redbud	416	low
hedge maple	304	low
white oak	232	moderate-high

Phenological Effects

The timing of leaf-out, flowering, fruit production, and senescence in urban trees may shift under a changing climate, as seasonal changes in temperature often act as cues to these biological processes. If other species in the ecological system fail to shift in a similar direction at a similar rate (i.e., a mismatch), these species can have a decreased ability to survive and reproduce (Hall 2012). For example, a shift in the timing of spring warming could change the dates when plants start to grow or flower. This shift could lead to a dramatic change in the foundation of the food web, affecting food sources to pollinators and other wildlife that depend on trees. Projecting the changes in timing and possible mismatches of phenological shifts is very uncertain, as patterns in phenology vary in time and space.

Freeze damage depends on the developmental stage of the fruit. For example, tissues that are young and actively growing can be harmed or killed by warming temperatures, whereas swollen fruit buds in earlier stages of development can often survive low temperatures in the teens without harm (Wallis 2021). When the buds open, they can be harmed by temperatures in the low 20s. Fruit tree species that flower early in response to warmer temperatures are the most susceptible to damage, including some apple varieties (Fruit Growers News 2017). Grapes and blueberries, on the other hand, are less susceptible to damage. Warming temperatures can allow plant development to proceed faster, which can create additional opportunities for pests, such as plum curculio, to feed on and lay eggs in exposed fruit. As temperatures increase, fruit trees will grow more rapidly and temperatures may be just below freezing at the time of flowering (Wallis 2021), making the trees more vulnerable to freeze injury. A variety of trees and shrubs are susceptible to late spring frost, such as baldcypress, sycamores, and planetrees (Cregg 2017). Though this damage often looks severe, it is mostly aesthetic and plants are able to quickly recover and resume growth.

Nutrient Cycling and Mycorrhizae

Climate change is altering primary production and nutrient cycling in forests (Lipton et al. 2018). The combination of increased carbon dioxide and temperature levels may increase nutrient cycling rates by affecting soil enzyme activity (Lukac et al. 2010). Warming temperatures and shifts in precipitation patterns, soil frost, soil pH, soil moisture, and the growing season can alter the way nutrients are cycled between soils, plants, and the atmosphere (Campbell et al. 2009). Changes in nutrient cycling can impact forest productivity, which can be limited by nutrients such as nitrogen, phosphorus, and calcium (Handler et al. 2014). Changes in tree species composition could also shift the rate of nitrogen cycling, leading to additional alterations in productivity and vegetation.

Nutrient cycling in trees is influenced by abiotic and biotic factors that may be affected by changes in climate. A previous review found that sugar maple nutrient imbalances can be induced or amplified by herbivory, pathogen attacks, and extremes in light environment, temperature, and precipitation (St. Claire et al. 2008). In addition, nutrient acquisition by tree roots can be limited by excessive or inadequate soil moisture. Extended dry periods followed by moisture pulses can lead to a flush of mineral nitrogen, but it is not enough to compensate for the insufficient microbial activity that occurs during dry periods (Borken and Matzner 2009). As a result, episodic precipitation (which is projected to occur in the Detroit region) may lead to a reduction in tree nutrient availability.

Drought has been found to consistently reduce plant growth. Arbuscular mycorrhizal fungi are symbiotic soil microorganisms that can play a key role in long-term maintenance of soil health and fertility by helping host plants, including trees, grow under stressful conditions. When

sufficient water is available, these fungi can help mitigate the impact of temperature stress on trees and other plants by increasing the amount of plant-available nutrients; plant growth and flower production are thus increased compared to plants without mycorrhizal fungi (Pischl and Barber 2016).

Pests and Pathogens

Insect pests and forest pathogens are generally expected to increase in a changing climate and can greatly alter habitat and ecosystem function (Weed et al. 2013). In response to climatic conditions and in combination with anticipated increases in tree stress and disturbance, pests and pathogens may increase in abundance and distribution. However, it is difficult to project pathogen response under increased temperatures due to complex modes of survival, infection, and transmission, along with tree response (Dukes et al. 2009).

Climate change can cause direct effects on forest pathogens such as increased growth and reproduction, altered transmission rates and infection phenology, and changes in overwinter survival (Dukes et al. 2009). In addition, it can allow pests and pathogens to expand their range into cooler climates as winter temperatures rise, and allow pests to have more life cycles per year. Climate change can also have indirect effects by increasing other stressors that exacerbate tree vulnerability, which is expected to make some already existing pests more problematic.

Emerging infectious diseases (EIDs) are another concern. These diseases are caused by pathogens that have newly evolved, have been discovered or newly recognized, have changed pathogenesis, or have increased in their abundance or in their geographical or host range (Anderson et al. 2004). Plant EIDs can have a negative impact on biodiversity as well as human well-being via economic and agricultural loss (Anderson et al. 2004). Extreme weather events and gradual changes in climate can lead to disease emergence by providing the conditions needed for introduced pathogens. In addition, milder winters and higher temperatures can allow for increased survival of plant pathogens, enabling plants and pathogens to survive outside their typical ranges (Harvell et al. 2002).

The emerald ash borer (EAB) was first discovered in Michigan near Detroit in 2002 and has killed tens of millions of ash trees in forests and neighborhoods (State of Michigan 2019b). Milder winters can be beneficial for the species, raising the costs of EAB damage in addition to causing increased tree mortality and human health impacts such as cardiovascular and lower respiratory tract illnesses from a loss of tree canopy (Donovan et al. 2013, Kovacs et al. 2010). The European oak borer, a beetle species first found in Michigan in 2003, has been reported to attack weakened or recently dead oaks and may pose a risk to trees under climate stress (Petrice and Haack 2014).

Oak wilt, caused by a fungal pathogen, leads to high mortality in oaks and is of particular concern to Detroit land managers and citizens. The disease benefits from cool, moist conditions for transmission, and from hot, dry conditions for progression. Because models project higher precipitation in the spring and increased temperatures and drought in the summer, oak wilt could thrive in the Detroit region. Oak wilt is currently found throughout Michigan, including the southwest region, and has been reported from Belle Isle, an island in the Detroit River (Pedlar et al. 2020). Climate suitability for oak wilt remains relatively high and suitability is projected to move northward, eventually covering much of the oak range in eastern Canada (Pedlar et al. 2020).

Climate change may make the Detroit region urban forest more vulnerable to new pests, especially as drought stress can increase the vulnerability of tree species to potential attacks. The preferred host of the Asian longhorned beetle (ALB) is the maple tree, which is abundant in Detroit; the

beetle can also cause tree mortality in other species such as willow, poplar, sycamore, and horse chestnut (State of Michigan 2019a). While not currently detected in Michigan, ALB poses a considerable risk to the Detroit region urban forest. A study modeling ALB phenology found that the species adapts well to ambient environmental conditions and the possibility of ALB outbreaks is much higher in the Northern Hemisphere due to the rich abundance of hosts (Keena 2009, Zhou et al. 2021). The spotted lanternfly is another insect that poses a risk of infestation; it feeds on fruit and prefers tree hosts such as oak, maple, willow, and sycamore (State of Michigan 2019c). Populations have been detected in other states such as Pennsylvania and are rapidly growing.

Invasive Plant Species

Invasive plant species can outcompete native trees in urban natural areas. Many invasive species have spread from horticultural plantings, including trees planted as street trees (Reichard and White 2001). Similar to pests and pathogens, invasive species also have direct and indirect climate impacts. Climate change allows nonnative invasive plants to shift their range. As invasive species shift under a changing climate, hotspots are projected to develop, allowing for species to establish and spread. Researchers have found strong support for the biotic resistance hypothesis, which predicts that native, diverse plant communities are more resistant to invasive species (Beaury et al. 2020a). According to this hypothesis, there are mutual benefits between management of invasive species and conservation of native biodiversity. However, plant stress associated with climate change (e.g., drought and increased temperatures) can reduce the ability of native species to compete with invasive species, while disturbances allow for increased introductions of invasive species.

Researchers have mapped the future distribution of invasive species common in the United States at the county level in the Early Detection and Distribution Mapping System (EDDMapS 2020). The maps indicate projected range dynamics by 2040 to 2060 based on the latest available information and aggregate data from other databases, organizations, and volunteer observations. By mapping the distribution of invasive species, EDDMapS can identify leading edges of new infestations, which allows for the implementation of Early Detection and Rapid Response programs. Under a range of future climate scenarios, the following are projections for common invasive plants in the SEMCOG region.

- Garlic mustard, multiflora rose, common burdock, tree of heaven, Japanese knotweed, purple loosestrife, spotted knapweed, and wild parsnip are projected to remain stable across the region.
- Japanese chaff flower is projected to expand across the region.
- European buckthorn is projected to expand in all counties with the exception of St. Clair County, where conditions are projected to be unsuitable for this species. There is some discrepancy in modeled results regarding future suitable habitat for European buckthorn in the region under a changing climate.
- Japanese honeysuckle is projected to remain stable in all counties with the exception of St. Clair County, where it is projected to expand.
- Giant hogweed is projected to retract in Oakland County and expand in Livingston and Washtenaw Counties. Conditions are projected to be unsuitable for this species in Macomb, Monroe, St. Clair, and Wayne Counties.

Fire

Wildfire risk depends on many factors including soil moisture, temperature, and trees and other plants that create potential fuel (Center for Climate and Energy Solutions 2021). These factors have direct or indirect connections to climate variability. Secondary factors, such as blowdown events or tree mortality due to pests, pathogens, heat, or drought, could create additional fuels and increase fire risk, but the interactions between these factors can be complex (Hicke et al. 2012). Ultimately, fires can decrease forest productivity and be a catalyst for change in vegetation (Sommers et al. 2011). Low-severity fires can help maintain the health and vigor of native ecosystems such as prairies and savannas.

Climate change is expected to affect weather conditions suitable for fire. Wildfire risk is expected to increase in the Midwest, but fire behavior will be dependent on climatic shifts over the 21st century (Sommers et al. 2011). Fire is driven in part by hot, dry conditions, which are expected to become more prevalent during the summer in the Detroit region. A study examining the potential effects of climate change on the occurrence of fire-weather patterns that are frequently associated with extreme and unpredictable wildfire behavior found that some of the largest projected increases in August are in areas of the Midwest (Heilman et al. 2015). Though the center of increase is projected to be in areas of Ohio, Pennsylvania, West Virginia, Kentucky, and Tennessee, southwest Michigan is also projected to experience an increase in fire-weather patterns.

Many factors influence whether a fire actually occurs in an area, regardless of whether conditions are conducive to fire. Occurrence will vary over time and space, and is determined by climate in addition to topography, efforts to suppress and prevent fires, and fuel accumulation affected by plant growth and disturbance frequency (Vose et al. 2018). The wildland-urban interface (WUI), areas where houses are built near or on lands vulnerable to wildland fires, is an important consideration, as wildfires in the WUI disrupt natural systems and harm humans and property. In the Detroit region, WUI growth exists in suburbs and beyond, expanding into the countryside. Land use and management are primary factors in determining whether an increase in fire risk is associated with an increase in wildfire activity (Miranda et al. 2012). Detroit is a fragmented and highly developed landscape, which may limit the spread of a potential fire. However, wildfires have occurred in remote areas just outside of city boundaries. Due to the complexity of interacting factors, there are many unknowns. Future policy regarding wildfire suppression and prescribed burns are key sources of uncertainty.

Flooding

Flooding is a major concern in the Detroit region as precipitation and extreme precipitation events are projected to increase. Urban floods tend to be short-lived, but increased flooding can induce stress in trees, causing defoliation, leaf yellowing, crown dieback, and potential mortality. Flooding can also lead to secondary attacks by other stressors such as pests and diseases (Bratkovich et al. 1993). Tree species vary in terms of flood tolerance, in addition to age class and vigor. Upland species, such as white oak, Kentucky coffeetree, bitternut hickory, and shagbark hickory, tend to be flood-intolerant (Bratkovich et al. 1993). Species that are generally more flood-tolerant include those native to wetlands and riparian zones, such as red maple, silver maple, and American sycamore (Bratkovich et al. 1993). The mesic forest on Belle Isle and other areas have already been subjected to flooding and its aftermath; rising water levels on the Detroit River, Lake St. Clair, and western Lake Erie have resulted in property damage and shoreline erosion (Hartig et al. 2020).

Summary

Climate change is projected to impact several major biological stressors in the Detroit region including phenology shifts, physiological effects, nutrient cycling, pests and pathogens, and invasive plant species, and to increase the risk of extreme events such as flooding and wildfire. Changes in climate conditions have the potential to shift many biological processes such as the timing of leaf-out, flowering, fruit production, and senescence, as well as growth, nutrient cycling, photosynthesis rates, and transpiration rates. The range of pests, pathogens, and invasive species may also increase under a changing climate, posing a risk to trees already under stress. Many of these risks and processes are uncertain due to limiting factors such as nutrient and water availability.

Key Points

- Changes in carbon dioxide levels can affect plant productivity and species composition, but there are challenges and limitations with carbon dioxide fertilization.
- A changing climate may shift the timing of leaf-out, flowering, fruit production, and senescence in Michigan trees; urban trees in Detroit may be subject to frost and freeze damage.
- Climate change can alter nutrient cycling and rates of tree growth, photosynthesis, and transpiration (loss of water vapor). Trees may benefit from longer growing seasons and higher carbon dioxide concentrations, but can be limited by available moisture and nutrients.
- The abundance and range of pests and pathogens, such as emerald ash borer, oak borers, Asian longhorned beetle, spotted lanternfly, and oak wilt, are projected to increase under a changing climate due to increased temperatures and greater tree stress. Nonnative invasive species are projected to spread and become established as plants shift their range.
- Wildfire risk is projected to increase, but fire behavior is uncertain due to its connection with climatic shifts as well as various occurrence factors.
- Urban flooding is a major concern in the Detroit region. Flooding can lead to tree stress and secondary attacks, property damage, and shoreline erosion.

CHAPTER 4: TREE SPECIES VULNERABILITY

Changes in climate have the potential to profoundly affect trees in the Detroit region in both developed and natural areas. Suitable habitat for some tree species that are currently present may decline under warmer temperatures and altered precipitation patterns. Other tree species may be less vulnerable to these conditions. Some species not currently present could potentially be planted in the area as hardiness zones shift with milder winters. Climate change can have indirect effects on the urban forests in the region by influencing the distribution and severity of insect pest, pathogen, and nonnative invasive species, in addition to its direct effects on the probability, severity, and extent of severe storms, as mentioned in the preceding chapters. Tree species in the area will differ in their capacity to adapt to such stressors. This chapter summarizes expected changes in habitat suitability and the adaptive capacity of different species in developed and natural areas of the Detroit region.

Modeled Projections of Habitat Suitability

Climate change has the potential to alter 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 larger area. Users should be aware of some caveats, however (Wiens et al. 2009). SDMs use the realized niche for a species instead of its fundamental niche. The realized niche is the actual habitat that a species occupies given predation, disease, and competition with other species. The fundamental niche, in contrast, is the habitat that a species could potentially occupy in the absence of competitors, diseases, or predators. Given that the fundamental niche can 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 could 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 can create obstacles for species otherwise poised to occupy new habitat. With these caveats in mind, SDMs can still be a useful tool for projecting changes in habitat suitability across species.

Modeling Native Trees

Suitable habitats for tree species native to the eastern United States were modeled in the Detroit region using the DISTRIB-II model, an SDM that is an updated component of the Climate Change Tree Atlas toolset (Iverson et al. 2008, 2019; Peters et al. 2019, 2020). DISTRIB-II measures relative size and abundance, referred to as “importance values,” for 125 eastern tree species. Of these species, only 61 were of interest to the Detroit region because they are currently present or expected to gain habitat in the area. Inputs to DISTRIB-II include tree species distribution data from the Forest Service’s 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 current species abundance with respect to current habitat distributions.

DISTRIB-II then projects future importance values and suitable habitat for individual tree species using projections of future climate conditions on a 12-mile by 12-mile grid (Peters et al. 2019). For this assessment, the DISTRIB-II model uses an average of three downscaled climate models (CCSM4, Hadley, and GFDL) and two representative concentration pathways (RCPs; RCP 4.5 and RCP 8.5). Note that this model does not account for projected changes in human population, land use, or the urban heat island effect.

Change in potential suitable habitat for the 61 tree species was projected within an approximately 3,500 square mile buffer zone around the Detroit Metropolitan Statistical Area (Table 4). The tree species modeled are either currently present in the region or expected to gain suitable habitat in the region for the years 2070 to 2099 compared to present values. Species were categorized based on whether the results from the two climate scenarios (RCP 4.5 and RCP 8.5) projected an increase, decrease, or no change in suitable habitat compared to current conditions; model results were mixed; or species were identified as having potential new, suitable habitat in the future under one or both scenarios. 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 (see Appendix 6).

Of the 61 species examined for the Detroit region, suitable habitat for 19 species (31 percent) was projected to decline under both low (RCP 4.5) and high (RCP 8.5) scenarios. The native species expected to decline in suitable habitat are boxelder, black maple, red maple, yellow birch, paper birch, musclewood, shagbark hickory, flowering dogwood, black ash, tamarack, eastern hophornbeam, white spruce, red pine, bigtooth aspen, quaking aspen, scarlet oak, northern pin oak, Shumard oak, and northern white-cedar.

For 10 of the species examined (17 percent), model results were mixed regarding the direction of change. Except for swamp white oak, the alternate scenario suggested no change in habitat suitability for each of the species. There were several species that had no projected change under one climate change scenario, and a decrease or increase under the other scenario. A small increase was projected for sugar maple, white oak, and swamp white oak and a small decrease was projected for black willow under a low climate change scenario. There was a small projected increase for slippery elm under a high climate change scenario. Under a high climate change scenario, there was a small decrease for American beech, black cherry, swamp white oak, and American linden, and a large decrease for eastern white pine and sassafras.

Suitable habitat for eight species (13 percent) was projected to remain relatively stable under both scenarios. Species in Detroit that fell under this category are silver maple, bitternut hickory, pignut hickory, green ash, black walnut, bur oak, northern red oak, and black oak. Eight species were projected to gain suitable habitat: common hackberry, white ash, eastern redcedar, tulip tree, blackgum, eastern cottonwood, black locust, and American elm. Sixteen species (26 percent) were projected to be able to colonize new, suitable habitats under low and high climate change scenarios: hardy pecan, black hickory, mockernut hickory, southern hackberry, eastern redbud, common persimmon, honeylocust, sweetgum, Osage-orange, red mulberry, American sycamore, blackjack oak, pin oak, post oak, winged elm, and cedar elm.

Note that these projections are available only for native species and are based on data collected from Phase 2 plots with a sampling intensity of 1 plot every 6,000 acres in natural areas through the FIA program. Thus, these projections are not directly applicable to native species planted in highly developed cultivated settings that may have very different soils, microclimates, and management. For more discussion on modeling methods, see Iverson et al. (2019) and Peters et al. (2019).

Projected Suitability from Shifts in Hardiness Zones and Heat Zones

Model information is not available for all species and cultivars that are found in the Detroit region or for some of the species being considered for future planting. Usually these species either are too rare in the region to be modeled reliably, have a range that extends outside of the United States, are not native to North America, or are cultivars. To understand how climate change 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.

Based on the climate of Detroit and current hardiness zones and heat zones, species that have a minimum hardiness of zone 6 or higher may benefit from milder winters. Species that can tolerate only a heat zone of 10 or lower may experience negative effects from hotter summers. See Chapter 2 for projections of hardiness zones and heat zones in the region. Note that using hardiness and heat zones to estimate which species may benefit or fare worse in a changing climate is not as informative as the SDMs described earlier (Table 4) because SDMs take into account changes in precipitation, seasonal changes in climate, and other habitat requirements such as soil texture. This analysis provides only a coarse estimate of potential changes in habitat suitability based on temperature extremes.

Table 4.—Projected changes in habitat suitability for trees native to the 1-degree by 1-degree latitude/longitude area around the Detroit region based on the DISTRIB-II model

Projected change in habitat suitability	Common name	Model reliability	Change class under low climate change scenario (RCP 4.5)	Change class under high climate change scenario (RCP 8.5)
decrease under both scenarios	bigtooth aspen	medium	large decrease	large decrease
decrease under both scenarios	black ash	medium	very large decrease	very large decrease
decrease under both scenarios	black maple	low	large decrease	large decrease
decrease under both scenarios	boxelder	low	small decrease	small decrease
decrease under both scenarios	eastern hophornbeam (ironwood)	low	large decrease	large decrease
decrease under both scenarios	flowering dogwood	medium	small decrease	very large decrease
decrease under both scenarios	musclewood (American hornbeam)	low	small decrease	small decrease
decrease under both scenarios	northern pin oak	medium	small decrease	small decrease
decrease under both scenarios	northern white-cedar	high	small decrease	small decrease
decrease under both scenarios	paper birch	high	large decrease	large decrease
decrease under both scenarios	quaking aspen	high	large decrease	large decrease
decrease under both scenarios	red maple	high	small decrease	small decrease
decrease under both scenarios	red pine	medium	large decrease	large decrease
decrease under both scenarios	scarlet oak	medium	very large decrease	very large decrease

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Table 4 (continued).—Projected changes in habitat suitability for trees native to the 1-degree by 1-degree latitude/longitude area around the Detroit region based on the DISTRIB-II model

Projected change in habitat suitability	Common name	Model reliability	Change class under low climate change scenario (RCP 4.5)	Change class under high climate change scenario (RCP 8.5)
decrease under both scenarios	shagbark hickory	medium	small decrease	large decrease
decrease under both scenarios	Shumard oak	low	small decrease	small decrease
decrease under both scenarios	tamarack	high	small decrease	small decrease
decrease under both scenarios	white spruce	medium	large decrease	large decrease
decrease under both scenarios	yellow birch	high	large decrease	large decrease
mixed results	American beech	high	no change	small decrease
mixed results	American linden (basswood)	medium	no change	small decrease
mixed results	black cherry	medium	no change	small decrease
mixed results	black willow	low	small decrease	no change
mixed results	eastern white pine	high	no change	large decrease
mixed results	sassafras	low	no change	large decrease
mixed results	slippery elm	low	no change	small increase
mixed results	sugar maple	high	small increase	no change
mixed results	swamp white oak	low	small increase	small decrease
mixed results	white oak	medium	small increase	no change
no change under both scenarios	bitternut hickory	low	no change	no change
no change under both scenarios	black oak	high	no change	no change
no change under both scenarios	black walnut	low	no change	no change
no change under both scenarios	bur oak	medium	no change	no change
no change under both scenarios	green ash	low	no change	no change
no change under both scenarios	northern red oak	medium	no change	no change
no change under both scenarios	pignut hickory	medium	no change	no change
no change under both scenarios	silver maple	low	no change	no change
increase under both scenarios	American elm	medium	small increase	small increase
increase under both scenarios	black locust	low	small increase	large increase

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Table 4 (continued).—Projected changes in habitat suitability for trees native to the 1-degree by 1-degree latitude/longitude area around the Detroit region based on the DISTRIB-II model

Projected change in habitat suitability	Common name	Model reliability	Change class under low climate change scenario (RCP 4.5)	Change class under high climate change scenario (RCP 8.5)
increase under both scenarios	blackgum	medium	small increase	large increase
increase under both scenarios	common hackberry	medium	small increase	small increase
increase under both scenarios	eastern cottonwood	low	large increase	large increase
increase under both scenarios	eastern red cedar	medium	large increase	large increase
increase under both scenarios	tulip tree	high	large increase	large increase
increase under both scenarios	white ash	medium	large increase	large increase
new habitat under both scenarios	American sycamore	low	new habitat	new habitat
new habitat under both scenarios	black hickory	high	new habitat	new habitat
new habitat under both scenarios	blackjack oak	medium	new habitat	new habitat
new habitat under both scenarios	cedar elm	medium	new habitat	new habitat
new habitat under both scenarios	common persimmon	low	new habitat	new habitat
new habitat under both scenarios	eastern redbud	low	new habitat	new habitat
new habitat under both scenarios	hardy pecan	low	new habitat	new habitat
new habitat under both scenarios	honeylocust	low	new habitat	new habitat
new habitat under both scenarios	mockernut hickory	medium	new habitat	new habitat
new habitat under both scenarios	Osage-orange	medium	new habitat	new habitat
new habitat under both scenarios	pin oak	low	new habitat	new habitat
new habitat under both scenarios	post oak	high	new habitat	new habitat
new habitat under both scenarios	red mulberry	low	new habitat	new habitat
new habitat under both scenarios	southern hackberry (sugarberry)	medium	new habitat	new habitat
new habitat under both scenarios	sweetgum	high	new habitat	new habitat
new habitat under both scenarios	winged elm	medium	new habitat	new habitat

The hardiness zone and heat zone ranges for a species are the areas in which the species is considered suitable for planting. For Detroit, a species was considered to be suitable under the low climate change scenario if the minimum hardiness zone for the species was 6 or lower and the maximum hardiness and heat zone was 7 or greater (Table 5). The species was considered suitable under the high climate change scenario if it had a minimum hardiness zone of 6 and a maximum hardiness zone of 8 or greater, and a maximum heat zone of 9 or greater. These minimums and maximums were determined by the current and projected hardiness and heat zones for the Detroit region through the end of the century (see Chapter 2). For some species, only the hardiness zone ranges were available, and minimums and maximums were determined by hardiness alone. Nearly all (176) of the 187 evaluated species, or 94 percent, were projected to be in a suitable hardiness or heat zone (or both, depending on availability of heat zone information) for planting under the low climate change scenario. Under the high climate change scenario, however, only 42 percent, or 79 species, were projected to be suitable for planting based on hardiness and heat zone ranges. Among the 58 percent (108 species) projected to be not suitable for planting under the high climate change scenario were many species that are currently common in the Detroit region, such as American linden, boxelder, bur oak, eastern cottonwood, shagbark hickory, silver maple, and sugar maple. Common species projected to remain in suitable zone ranges include black cherry, bur oak, eastern cottonwood, green ash, northern red oak, and red maple.

Table 5.—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
Accolade™ elm	4 to 9	8 to 1	suitable	not suitable
American beech	4 to 9	9 to 1	suitable	suitable
American chestnut	5 to 8	8 to 1	suitable	not suitable
American elm	3 to 9	9 to 1	suitable	suitable
American linden (basswood)	3 to 8	8 to 1	suitable	not suitable
American mountain ash	2 to 6	6 to 1	not suitable	not suitable
American sycamore	4 to 9	9 to 3	suitable	suitable
Amur corktree	3 to 7	8 to 1	suitable	not suitable
Amur maackia	3 to 7	7 to 4	suitable	not suitable
Amur maple	3 to 8	7 to 1	suitable	not suitable
apple	3 to 8	10 to 1	suitable	suitable
apple serviceberry	4 to 9	7 to 1	suitable	not suitable
Austrian pine	4 to 7	8 to 1	suitable	not suitable
bald cypress	4 to 11	12 to 2	suitable	suitable
balsam fir	3 to 6	6 to 1	not suitable	not suitable
balsam poplar	5 to 9	N/A	suitable	suitable
bigtooth aspen	2 to 5	N/A	not suitable	not suitable
bitternut hickory	4 to 9	9 to 1	suitable	suitable

¹ N/A: not available.

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Table 5 (continued).—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
black alder	4 to 7	7 to 1	suitable	not suitable
black ash	2 to 5	7 to 1	suitable	not suitable
black cherry	3 to 9	9 to 1	suitable	suitable
black gum	6 to 9	9 to 7	suitable	suitable
black hickory	5 to 9	N/A	suitable	suitable
black locust	4 to 8	9 to 3	suitable	suitable
black maple	4 to 8	8 to 3	suitable	not suitable
black oak	3 to 9	8 to 1	suitable	not suitable
black poplar	3 to 9	9 to 1	suitable	suitable
black walnut	4 to 9	9 to 3	suitable	suitable
black willow	4 to 9	N/A	suitable	suitable
blackjack oak	5 to 9	9 to 3	suitable	suitable
boxelder	2 to 10	8 to 3	suitable	not suitable
bur oak	3 to 8	9 to 1	suitable	suitable
Callery pear	5 to 9	8 to 3	suitable	not suitable
cedar elm	7 to 9	9 to 6	not suitable	not suitable
cherry plum	4 to 9	9 to 1	suitable	suitable
chestnut oak	4 to 8	8 to 1	suitable	not suitable
Chinese chestnut	4 to 8	8 to 1	suitable	not suitable
Chinese juniper	4 to 9	9 to 1	suitable	suitable
Chinese willow	5 to 9	N/A	suitable	suitable
chinkapin oak	4 to 7	8 to 2	suitable	not suitable
chokecherry	2 to 7	8 to 1	suitable	not suitable
cockspur thorn	3 to 7	7 to 1	suitable	not suitable
Colorado spruce	2 to 7	8 to 1	suitable	not suitable
common hackberry	2 to 9	9 to 1	suitable	suitable
common horse chestnut	3 to 8	8 to 1	suitable	not suitable
common lilac	4 to 8	8 to 1	suitable	not suitable
common lime	3 to 7	8 to 1	suitable	not suitable
common oak	3 to 8	8 to 3	suitable	not suitable
common persimmon	4 to 9	9 to 1	suitable	suitable
cornelian cherry dogwood	4 to 8	8 to 5	suitable	not suitable

¹ N/A: not available.

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Table 5 (continued).—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
Crimean linden	3 to 7	7 to 1	suitable	not suitable
dawn redwood	4 to 8	10 to 5	suitable	suitable
Douglas-fir	4 to 6	7 to 1	suitable	not suitable
downy serviceberry	4 to 9	9 to 1	suitable	suitable
eastern cottonwood	3 to 9	9 to 1	suitable	suitable
eastern hemlock	3 to 7	8 to 1	suitable	not suitable
eastern hophornbeam (ironwood)	3 to 9	9 to 5	suitable	suitable
eastern redbud	4 to 8	9 to 6	suitable	suitable
eastern redcedar	3 to 9	9 to 1	suitable	suitable
eastern white pine	3 to 8	7 to 1	suitable	not suitable
English walnut	4 to 8	7 to 1	suitable	not suitable
European ash	5 to 7	8 to 3	suitable	not suitable
European beech	5 to 8	8 to 1	suitable	not suitable
European buckthorn	3 to 8	N/A	suitable	suitable
European hornbeam	4 to 9	8 to 1	suitable	not suitable
European larch	3 to 6	6 to 1	not suitable	not suitable
European mountain ash	3 to 6	7 to 1	suitable	not suitable
European pear	5 to 9	9 to 5	suitable	suitable
flowering dogwood	5 to 9	9 to 3	suitable	suitable
Freeman maple	3 to 8	8 to 1	suitable	not suitable
fringetree	4 to 9	9 to 1	suitable	suitable
ginkgo	4 to 8	9 to 3	suitable	suitable
glossy buckthorn	3 to 7	N/A	suitable	not suitable
goldenrain tree	5 to 9	9 to 1	suitable	suitable
gray alder	2 to 6	7 to 1	suitable	not suitable
gray birch	3 to 6	6 to 1	not suitable	not suitable
gray dogwood	3 to 8	8 to 3	suitable	not suitable
green ash	3 to 9	9 to 1	suitable	suitable
green hawthorn 'Winter King'	4 to 8	7 to 5	suitable	not suitable
hardy pecan	5 to 9	9 to 1	suitable	suitable
hardy rubber tree	4 to 7	7 to 1	suitable	not suitable
hedge maple	5 to 8	8 to 4	suitable	not suitable

¹ N/A: not available.

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Table 5 (continued).—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
Heritage® oak	4 to 9	N/A	suitable	suitable
Higan cherry	5 to 8	8 to 6	suitable	not suitable
honeylocust	4 to 8	9 to 1	suitable	suitable
honeylocust (thornless)	4 to 8	9 to 1	suitable	suitable
jack pine	2 to 6	6 to 1	not suitable	not suitable
Japanese cherry	5 to 6	9 to 4	not suitable	not suitable
Japanese maple	5 to 8	8 to 2	suitable	not suitable
Japanese pagoda tree	5 to 8	9 to 5	suitable	suitable
Japanese tree lilac	3 to 7	7 to 1	suitable	not suitable
Japanese white birch	5 to 7	7 to 5	suitable	not suitable
Japanese white pine	6 to 9	9 to 1	suitable	suitable
Japanese zelkova	5 to 8	9 to 5	suitable	suitable
katsura tree	4 to 8	8 to 1	suitable	not suitable
Kentucky coffeetree	4 to 8	9 to 2	suitable	suitable
kousa dogwood	5 to 8	8 to 5	suitable	not suitable
lacebark elm	5 to 9	9 to 1	suitable	suitable
lacebark pine	4 to 7	7 to 1	suitable	not suitable
littleleaf linden	3 to 7	8 to 1	suitable	not suitable
London planetree	5 to 8	9 to 5	suitable	suitable
Miyabe maple	4 to 8	8 to 1	suitable	not suitable
mockernut hickory	4 to 9	9 to 1	suitable	suitable
mountain silverbell	5 to 8	8 to 4	suitable	not suitable
mugo pine	3 to 7	7 to 1	suitable	not suitable
musclewood (American hornbeam)	3 to 9	9 to 1	suitable	suitable
nannyberry	2 to 8	8 to 1	suitable	not suitable
northern catalpa	4 to 8	8 to 1	suitable	not suitable
northern pin oak	4 to 7	7 to 1	suitable	not suitable
northern red oak	4 to 8	9 to 5	suitable	suitable
northern white-cedar	2 to 7	7 to 1	suitable	not suitable
Norway maple	4 to 7	7 to 1	suitable	not suitable
Norway spruce	3 to 7	8 to 1	suitable	not suitable
Ohio buckeye	3 to 7	7 to 1	suitable	not suitable
Osage-orange	4 to 9	10 to 1	suitable	suitable

¹ N/A: not available.

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Table 5 (continued).—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
overcup oak	6 to 9	8 to 4	suitable	not suitable
pagoda dogwood	4 to 8	8 to 1	suitable	not suitable
paper birch	2 to 6	7 to 1	suitable	not suitable
paperbark maple	5 to 8	8 to 1	suitable	not suitable
paradise apple	4 to 7	10 to 1	suitable	suitable
pawpaw	6 to 9	8 to 6	suitable	not suitable
peach	5 to 9	9 to 1	suitable	suitable
Persian parrotia	5 to 8	8 to 1	suitable	not suitable
Persian silk tree	6 to 9	9 to 6	suitable	suitable
pignut hickory	4 to 9	8 to 1	suitable	not suitable
pin oak	4 to 8	7 to 3	suitable	not suitable
post oak	5 to 9	9 to 4	suitable	suitable
princess tree	5 to 9	8 to 4	suitable	not suitable
pussy willow	2 to 7	8 to 2	suitable	not suitable
quaking aspen	2 to 6	8 to 1	suitable	not suitable
red horse chestnut	5 to 9	8 to 6	suitable	not suitable
red maple	3 to 9	9 to 1	suitable	suitable
red mulberry	4 to 9	N/A	suitable	suitable
red pine	2 to 5	7 to 1	suitable	not suitable
red spruce	2 to 5	N/A	not suitable	not suitable
river birch	4 to 9	9 to 1	suitable	suitable
rose of Sharon	5 to 8	9 to 1	suitable	suitable
Russian olive	3 to 7	8 to 1	suitable	not suitable
Sargent cherry	5 to 8	9 to 4	suitable	suitable
sassafras	3 to 9	10 to 1	suitable	suitable
saucer magnolia	4 to 9	9 to 5	suitable	suitable
sawtooth oak	5 to 9	8 to 3	suitable	not suitable
scarlet oak	4 to 9	9 to 4	suitable	suitable
Scots pine	3 to 7	7 to 1	suitable	not suitable
shagbark hickory	4 to 8	8 to 1	suitable	not suitable
shellbark hickory	4 to 9	8 to 1	suitable	not suitable
shingle oak	4 to 8	8 to 4	suitable	not suitable
Shumard oak	5 to 9	9 to 1	suitable	suitable

¹ N/A: not available.

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Table 5 (continued).—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
Siberian elm	4 to 9	9 to 1	suitable	suitable
silver birch	2 to 7	7 to 1	suitable	not suitable
silver linden	4 to 7	9 to 1	suitable	suitable
silver maple	3 to 9	8 to 1	suitable	not suitable
slippery elm	3 to 9	10 to 3	suitable	suitable
smoketree	4 to 8	9 to 3	suitable	suitable
sourwood	5 to 9	9 to 3	suitable	suitable
southern hackberry (sugarberry)	5 to 9	N/A	suitable	suitable
southern magnolia	7 to 10	11 to 1	not suitable	not suitable
staghorn sumac	4 to 8	8 to 1	suitable	not suitable
star magnolia	4 to 9	9 to 5	suitable	suitable
sugar maple	3 to 8	8 to 1	suitable	not suitable
swamp white oak	4 to 8	8 to 1	suitable	not suitable
sweet cherry	3 to 8	8 to 1	suitable	not suitable
sweetbay magnolia	5 to 9	9 to 6	suitable	suitable
sweetgum	5 to 9	10 to 1	suitable	suitable
sycamore maple	4 to 7	8 to 1	suitable	not suitable
tamarack	2 to 5	5 to 1	not suitable	not suitable
Tatarian maple	3 to 8	7 to 1	suitable	not suitable
tree of heaven	4 to 8	8 to 1	suitable	not suitable
trident maple	5 to 9	9 to 5	suitable	suitable
tulip tree	5 to 7	9 to 2	suitable	suitable
turkey oak	7 to 9	8 to 1	suitable	not suitable
Turkish hazel (Turkish filbert)	4 to 7	7 to 4	suitable	not suitable
umbrella magnolia	5 to 8	N/A	suitable	suitable
Virginia pine	5 to 8	8 to 1	suitable	not suitable
water locust	5 to 9	9 to 1	suitable	suitable
weeping willow	6 to 9	9 to 1	suitable	suitable
white ash	4 to 9	10 to 1	suitable	suitable
white fir	3 to 7	7 to 1	suitable	not suitable
white mulberry	4 to 8	8 to 1	suitable	not suitable
white oak	3 to 9	8 to 1	suitable	not suitable

¹ N/A: not available.

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Table 5 (continued).—Suitability by hardiness zone and heat zone (where available) under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Hardiness zone	Heat zone ¹	Zone suitability - low	Zone suitability - high
white poplar	4 to 9	9 to 1	suitable	suitable
white spruce	2 to 6	7 to 1	suitable	not suitable
willow oak	6 to 9	9 to 3	suitable	suitable
winged elm	6 to 7	N/A	suitable	not suitable
yellow birch	3 to 7	7 to 1	suitable	not suitable
yellowwood	4 to 8	9 to 1	suitable	suitable
Yoshino cherry	5 to 6	8 to 3	suitable	not suitable

¹ N/A: not available.

Adaptive Capacity of Urban Trees

The results presented earlier provide information on potential changes in tree species habitat suitability across a range of projected future temperature and precipitation regimes (in the case of DISTRIB-II) or extreme high and low temperatures (in the case of hardiness and heat zones), but do not account for factors such as changes in flood regime, extreme weather events, insects and disease, and nonnative 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 Modification Factors. Other scoring systems have been developed (Roloff et al. 2009), but we found the system developed by Matthews and coauthors to be the most comprehensive for all potential climate change-related stressors.

Modification 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 Modification Factors are tolerance to fire or drought, dispersal ability, shade tolerance, site specificity, and susceptibility to insect pests and diseases (Table 6). These factors can then be weighted by their intensity, the level of uncertainty about their impacts, and relative importance to future changes to tree mortality and survival to arrive at a numerical score (see Appendix 7). Modification Factors are highly related to the adaptive capacity of a species: the ability to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2014). A species with many positive Modification Factors would have a high adaptive capacity, and a species with many negative Modification Factors would have a low adaptive capacity.

We used the Modification Factors developed for the Chicago Wilderness region vulnerability assessment to better capture the unique environment of urban areas (Brandt et al. 2017). As in the Chicago, IL and Austin, TX (Brandt et al. 2020) assessments, we created separate scores for developed and natural areas. We developed Modification Factor scores for 187 tree species and varieties. Scores were then converted to categories of high, medium, and low adaptability. It is important to note that Modification Factors are meant to be used as a general summary of the adaptive capacity of a species across its entire range, and not meant to capture site-specific factors that may enhance or reduce the ability of the species to withstand stressors.

Table 6.—Codes and descriptions for Modification Factors¹

Code	Factor	Type ²	Description (if positive) ³	Description (if negative)
AIP	Air pollution	N, P	Tolerant of air pollution	Intolerant of air pollution
BRO	Browse	N, P	Resistant to browsing	Susceptible to browsing
COL	Competition-light	N, P	Tolerant of shade or limited light conditions	Intolerant of shade or limited light conditions
DISE	Disease	N, P	Disease-resistant	Has a high number or severity (or both) of known pathogens that attack the species
DISP	Dispersal	N	High ability to effectively produce and distribute seeds	Low ability to effectively produce and distribute seeds
DRO	Drought	N, P	Drought-tolerant	Susceptible to drought
ESP	Edaphic specificity	N, P	Wide range of soil tolerance	Narrow range of soil requirements
EHS	Environmental habitat specificity	N	Wide range of slopes/aspects/topographic positions	Small range of slopes/aspects/topographic positions
FLO	Flood	N, P	Flood-tolerant	Flood-intolerant
FRG	Fire regeneration	N	Regenerates well after fire	N/A
FTK	Fire topkill	N	Resistant to fire topkill	Susceptible to fire topkill
ICE	Ice	N, P	N/A	Susceptible to breakage from ice storms
INS	Insect pests	N, P	Pest-resistant	Has a high number or severity (or both) of insects that may attack the species
INPL	Invasive plants	N, P	N/A	Strong negative effects of invasive plants on the species, either through competition for nutrients or as a pathogen
INPO	Invasive potential	P	N/A	Has the potential to become invasive and thus disfavored for planting
LPS	Land-use and planting site specificity	P	Can be planted on a wide variety of sites	Can be planted in only a narrow range of sites or as a specimen
MAR	Maintenance required	P	Requires little pruning, watering, or cleanup	Requires considerable pruning, watering, or cleanup of debris
NUP	Nursery propagation	P	Easily propagated in nursery and widely available	Not easily propagated or not usually available
PLE	Planting establishment	P	Easily transplanted and requires little care to establish	Difficult to transplant or requires considerable care to establish
RRC	Restricted rooting conditions	P	Can tolerate restricted rooting conditions	Intolerant of restricted rooting conditions
SAL	Salt tolerance	N, P	Tolerant of road salt/salt spray	Intolerant of road salt/salt spray
SES	Seedling establishment	N	High ability to regenerate with seeds to maintain future populations	Low ability to regenerate with seeds to maintain future populations
SWP	Soil and water pollution	N, P	Tolerant of soil or water pollution	Intolerant of soil or water pollution
TEM	Temperature gradients	N, P	Tolerant of a wide range of temperatures	Narrow range of temperature requirements
VRE	Vegetative reproduction	N	Capable of vegetative reproduction through stump sprouts or cloning	Not capable of vegetative reproduction
WIN	Wind	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 7 for more information.

² N: applies to naturally occurring trees; P: applies to planted trees.

³ N/A: not applicable.

For natural areas (both native and naturalized), 41 species received a high adaptability score, 8 received a low adaptability score, and 43 received a medium adaptability score (Table 7). Not surprisingly, many of the most adaptable species are nonnative invasive species, such as tree of heaven, goldenrain tree, European buckthorn, glossy buckthorn, Persian silk tree, honeylocust, Amur corktree, Siberian elm, and white mulberry. Common species in Detroit with high adaptability scores (5 or greater) include boxelder, Norway maple, red maple, silver maple, and tulip tree.

Table 7.—Adaptability scores for trees in natural areas¹

Common name	Native? ²	Natural Adapt score	Natural Adapt class	Natural positive factors	Natural negative factors
American beech	yes	4.3	medium	COL	INPL FLO
American chestnut	yes	3.1	low	--	RRC NUP
American elm	yes	4.6	high	EHS	DISE INS DRO
American linden (basswood)	yes	4.2	medium	FLO COL	INPL PLE
American sycamore	yes	3.5	low	FLO	INPL DRO
Amur corktree	no	5.1	high	PLE	-
bald cypress	yes	3.8	medium	FLO	INPL DRO
balsam poplar	yes	4.2	medium	FLO VEGR FIRE	INPL DRO COL
bigtooth aspen	yes	4.7	high	VEGR FIR	INPL DRO AIP COL
bitternut hickory	yes	4.1	medium	DRO	INPL
black ash	yes	2.9	low	FLO	INS DRO COL PLE
black cherry	yes	3.6	medium	DISP PLE	INPL EHS
blackgum	yes	5.3	high	COL	INPL
black hickory	no	3.5	medium	DRO EHS PLE	INPL FLO
black locust	yes	4.7	medium	DRO	INPL
black maple	yes	4.8	high	COL	INS INPL
black oak	yes	4.6	high	DRO	INPL
black walnut	yes	3.9	medium	PLE	INPL COL
black willow	yes	3.3	low	FLO	INPL DRO COL
blackjack oak	no	4.7	high	DRO PLE VEGR FIR	INPL FLO COL
boxelder	yes	5.6	high	DRO FLO TEM COL DIS PLE	--
bur oak	yes	4.8	high	DRO AIP	INPL
cedar elm	no	5.6	high	DRO FLO AIP ESP DISP PLE FIR	INPL

¹ See Appendix 7 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 7 (continued).—Adaptability scores for trees in natural areas¹

Common name	Native? ²	Natural Adapt score	Natural Adapt class	Natural positive factors	Natural negative factors
cherry plum	no	3.8	medium	TEM NUP	INS AIP
chestnut oak	no	5.5	high	DRO EHS PLE VEGR	INPL
chinkapin oak	yes	5	high	DRO TEM	INPL
chokecherry	yes	3.9	medium	--	INPL COL
common hackberry	yes	4.9	medium	DRO	INPL
common lilac	no	3.9	medium	RRC NUP	AIP
downy serviceberry	yes	5.8	high	TEM COL EHS PLE FIRE	INPL
eastern cottonwood	yes	3.2	low	TEM NUP	INS AIP
eastern hophornbeam (ironwood)	yes	4.9	high	FLO COL PLE	INPL DRO
eastern red cedar	yes	4	medium	DRO	INPL
eastern redbud	yes	5	medium	FLO	INPL
eastern white pine	yes	3.8	medium	--	INS INPL DRO
European buckthorn	no	6.7	high	INPL DRO TEM AIP COL ESP DISP PLE VEGR	--
European pear	no	3.5	medium	TEM NUP	AIP
flowering dogwood	yes	4.9	high	COL	INPL DRO
glossy buckthorn	no	6.7	high	INPL FLO TEM AIP COL ESP EHS DISP PLE VEGR	--
goldenrain tree	no	4.7	high	DRO DISP PLE	INPL COL
gray alder	yes	4.2	medium	FLO	INPL DRO
gray birch	yes	4.2	medium	--	INS INPL COL
gray dogwood	yes	5	high	COL PLE	INPL
green ash	yes	4.5	medium	FLO	INS INPL
hardy pecan	no	3.1	low	--	INPL
honeylocust	yes	4.7	high	DRO EHS	INPL
Kentucky coffeetree	yes	4.3	medium	DRO	INPL
lacebark elm	no	5.4	high	DRO ESP EHS PLE	INPL
mockernut hickory	yes	3.7	medium	TEM	AIP
nannyberry	yes	4.7	high	COL	INPL

¹ See Appendix 7 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 7 (continued).—Adaptability scores for trees in natural areas¹

Common name	Native? ²	Natural Adapt score	Natural Adapt class	Natural positive factors	Natural negative factors
northern catalpa	yes	3.4	low	--	INPL COL
northern pin oak	yes	4.2	medium	DRO FIRT	INPL COL
northern red oak	yes	4.9	high	--	INPL
northern white cedar	yes	4.4	medium	COL	INPL DRO
Norway maple	yes	6	high	DRO FLO COL ESP PLE	INS
Ohio buckeye	yes	3.1	low	COL	INPL PLE
Osage-orange	yes	4.9	high	DRO ESP EHS	INPL
pagoda dogwood	yes	4.5	medium	--	INPL
Persian silk tree	no	5	high	DRO FLO ESP EHS PLE	INPL
pignut hickory	yes	4.7	high	EHS	INPL
pin oak	yes	3.7	medium	FLO	INPL COL
post oak	no	4.2	medium	DRO TEM	INPL FLO COL
pussy willow	yes	4.2	medium	INS DISP PLE FIRE	DRO COL
quaking aspen	yes	4.4	medium	TEM EHS VEGR	INS INPL DRO COL
red maple	yes	5.5	high	FLO COL EHS PLE VEGR	INS INPL DRO
red mulberry	yes	4.4	medium	COL	INPL
red spruce	yes	3.5	medium	EHS	DRO PLE INPL
river birch	yes	4.1	medium	--	INPL DRO COL
scarlet oak	yes	5	high	ESP EHS VEGR	INPL
shagbark hickory	yes	4.7	medium	--	INPL
shellbark hickory	yes	4	medium	COL	INPL DRO
shingle oak	yes	4.3	medium	DRO EHS	INPL COL
Shumard oak	yes	4	medium	DRO FLO TEM	INPL COL
Siberian elm	no	4.8	high	INS DRO EHS PLE	--
silver birch	no	4.2	medium	EHS	INS INPL COL
silver maple	yes	5.2	high	FLO DISP PLE COL	INS INPL
slippery elm	yes	4.5	high	DRO COL	INPL
sourwood	no	5.3	high	COL EHS	INPL

¹ See Appendix 7 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 7 (continued).—Adaptability scores for trees in natural areas¹

Common name	Native? ²	Natural Adapt score	Natural Adapt class	Natural positive factors	Natural negative factors
southern hackberry/sugarberry	no	5.7	high	DRO COL ESP EHS DISP PLE	INPL
southern magnolia	no	4.3	medium	COL PLE	INPL DRO
staghorn sumac	yes	4.8	high	DRO PLE VEGR FIRE	INPL COL
sugar maple	yes	4.8	high	COL EHS	INS INPL
swamp white oak	yes	4.4	medium	--	INPL
sweetbay magnolia	no	4.3	medium	--	--
sweetgum	no	4.6	high	FLO EHS VEGR	INS INPL DRO COL
tree of heaven	no	6.6	high	INS INPL DRO AIP EHS ESP DISP PLE VEGR FIRE	--
tulip tree	yes	5.4	high	EHS PLE FIRE	INPL DRO
umbrella magnolia	no	4.3	medium	--	--
Virginia pine	no	3.8	medium	--	INPL AIP COL
white ash	yes	4.1	medium	--	INS INPL
white mulberry	no	5	high	DISP PLE	--
yellow birch	yes	5.2	high	COL PLE VEGR	INPL

¹ See Appendix 7 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

For planted or developed conditions, 50 species received a high adaptability score, 30 received a low adaptability score, and the remaining 107 received a medium adaptability score (Table 8). Common species in Detroit with high adaptability scores (5 or greater) include Norway maple, ginkgo, swamp white oak, and littleleaf linden. Factors that tended to enhance adaptive capacity include the ability to be planted on a wide range of sites, ease of propagation in a nursery, and tolerance to a range of disturbances and conditions (e.g., floods, droughts, soils, shade, air pollution, restricted rooting conditions, and road salt or salt spray).

Species that received low adaptability ratings are American chestnut, balsam poplar, black ash, black cherry, black hickory, black oak, black walnut, black willow, blackjack oak, Douglas-fir, eastern hemlock, eastern white pine, gray birch, hardy pecan, jack pine, katsura tree, northern pin oak, paperbark maple, Persian silk tree, post oak, red pine, shagbark hickory, shellbark hickory, silver birch, sweetgum, tulip tree, Virginia pine, white ash, white oak, and Yoshino cherry. These species tended to receive low adaptability ratings because they are susceptible to pests or diseases, were intolerant of a variety of disturbances and conditions (e.g., floods, droughts, air pollution, restricted rooting conditions), and had a narrow range in terms of urban sites and soil and temperature requirements.

Table 8.—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
Accolade™ elm	no	4.8	high	NUP	INS
American beech	yes	3.6	medium	TEM NUP	FLO AIP LPS RRC
American chestnut	yes	3.1	low	--	RRC NUP
American elm	yes	4.5	medium	TEM NUP DRO FLO LPS SAL	DISE INS MAR
American linden (basswood)	yes	4.4	medium	TEM NUP LPS PLE	AIP RRC INS DRO WIN SAL
American mountain ash	yes	4.2	medium	NUP	DRO AIP
American sycamore	yes	4.1	medium	TEM NUP FLO SAL	DRO
Amur corktree	no	4.5	medium	TEM NUP	RRC INPO
Amur maackia	no	4.9	high	DRO TEM RRC NUP	FLO
Amur maple	no	4.5	medium	TEM LPS DRO	INPO
apple	yes (not all species)	4	medium	TEM LPS RRC NUP	INS
apple serviceberry	no	4	medium	LPS RRC NUP	DRO FLO AIP
Austrian pine	no	3.9	medium	DRO TEM RRC	DISE INS
bald cypress	yes	4.9	high	FLO RRC NUP	AIP
balsam fir	yes	4.2	medium	NUP	DRO TEM AIP
balsam poplar	yes	3.3	low	FLO	DRO TEM
bigtooth aspen	yes	3.5	medium	--	DRO AIP LPS NUP
bitternut hickory	yes	3.8	medium	DRO	AIP
black alder	no	4.3	medium	FLO	INS AIP INPO
black ash	yes	2.6	low	FLO	INS DRO AIP ESP LPS RRC NUP
black cherry	yes	2.1	low	CRO TEM	FLO AIP LPS RRC DRO
black gum	yes	4.7	high	RRC	AIP
black hickory	no	2.9	low	--	FLO NUP
black locust	yes	3.9	medium	DRO TEM ESP SAL PLE	INS FLO AIP LPS RRC INPO WIN
black maple	yes	3.7	medium	TEM	INS AIP SAL NUP

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
black oak	yes	3	low	DRO TEM	FLO NUP PLE RRC DISE
black poplar	no	3.6	medium	TEM	--
black walnut	yes	2.7	low	DRO	AIP LPS RRC DISE MAR NUR
black willow	yes	3.1	low	FLO	DRO AIP RRC MAR WIN DISE
blackjack oak	no	2.9	low	DRO	FLO AIP LPS
boxelder	yes	4.3	medium	DRO FLO TEM	INS AIP INPO ICE
bur oak	yes	4.9	high	DRO TEM AIP LPS NUP FLO ESP	DISE
Callery pear	no	4.2	medium	DRO TEM RRC NUP SAL AIP	INS INPO DISE
cedar elm	no	5.8	high	NUP FLO	--
cherry plum	no	3.8	medium	NUP	AIP INS
chestnut oak	no	4.5	high	DRO LPS SAL	AIP DISE RRC
Chinese chestnut	no	3.6	medium	TEM	--
Chinese juniper	no	4.5	high	--	--
Chinese willow	no	3.7	medium	FLO	--
chinkapin oak	yes	4.7	high	DRO TEM LPS ESP	--
chokecherry	yes	3.6	medium	NUP	DISE FLO AIP
cockspur thorn	yes	4.5	medium	DRO TEM LPS RRC NUP	INS AIP DISE FLO
Colorado spruce	no	4	medium	NUP	INS FLO AIP
common hackberry	yes	4.6	high	DRO TEM LPS NUP ESP	MAR WIN
common horse chestnut	no	4.2	medium	TEM	--
common lilac	no	3.9	medium	NUP	AIP
common lime	no	4.3	medium	TEM	--
common oak	no	4.2	medium	DRO TEM	--
common persimmon	no	4.8	high	NUP RRC TEM ESP FLO DRO	--

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
cornelian cherry dogwood	no	4.1	medium	TEM	AIP
Crimean linden	no	5.3	high	TEM LPS RRC NUP	--
dawn redwood	no	4.1	medium	TEM FLO	AIP COL
Douglas-fir	no	2.7	low	NUP	DRO FLO TEM LPS ESP SAL INS DISE
downy serviceberry	yes	5	high	TEM NUP	AIP
eastern cottonwood	yes	3.6	medium	TEM NUP FLO SAL PLE TEM	DISE INS AIP LPS RRC WIN ICE
eastern hemlock	yes	2.7	low	NUP	DRO AIP LPS INS MAR RRC SAL
eastern hophornbeam (ironwood)	yes	5.4	high	DRO TEM LPS RRC NUP	FLO AIP
eastern red cedar	yes	4.7	high	DRO TEM LPS RRC	AIP
eastern redbud	yes	3.9	medium	FLO TEM NUP	AIP LPS
eastern white pine	yes	2.9	low	NUP	DISE INS DRO TEM AIP LPS RRC
English walnut	no	3.7	medium	--	--
European ash	no	3.8	medium	FLO	INS LPS
European beech	no	3.8	medium	NUP	DRO RRC LPS
European buckthorn	no	5.9	high	DRO TEM ESP NUP	INPO
European hornbeam	no	4.4	medium	--	SAL
European larch	no	3.7	medium	--	DRO TEM AIP
European mountain ash	no	3.7	medium	LPS RRC NUP	ESP DRO SAL AIP DISE INS
European pear	no	3.5	medium	--	AIP
flowering dogwood	yes	3.8	medium	TEM NUP	DRO FLO AIP RRC LPS
Freeman maple	yes	4.5	medium	LPS NUP	INS WIN MAR
fringetree	no	4.9	high	DRO TEM LPS RRC NUP	--
ginkgo	no	6	high	DRO TEM LPS RRC NUP	FLO
glossy buckthorn	no	5.8	high	FLO TEM ESP NUP	INPO

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
goldenrain tree	no	4.7	high	DRO TEM LPS RRC NUP	INPO
gray alder	yes	4.2	medium	FLO	AIP
gray birch	no	3.2	low	--	DISE INS AIP LPS
gray dogwood	yes	4.5	medium	--	--
green ash	yes	3.9	medium	FLO LPS NUP	INS MAR
green hawthorn 'Winter King'	no	4.2	medium	LPS RRC	FLO
hardy pecan	no	3.2	low	NUP	--
hardy rubber tree	no	4.7	high	DRO	FLO
hedge maple	no	4.5	medium	NUP	INS LPS
Heritage® oak	no	5.2	high	DRO TEM LPS NUP	INS
Higan cherry	no	4	medium	SAL DRO	FLO AIP RRC
honeylocust	no	4.3	medium	DRO TEM RRC NUP	--
honeylocust (thornless)	no	4.3	medium	DRO TEM RRC NUP	--
jack pine	yes	3.4	low	--	--
Japanese cherry	no	4.3	medium	TEM LPS NUP	--
Japanese maple	no	3.9	medium	NUP	DRO AIP LPS
Japanese pagoda tree	no	5.3	high	DRO TEM LPS RRC NUP SAL ESP AIP	FLO
Japanese tree lilac	no	4.6	high	LPS RRC NUP ESP PLE	AIP FLO INPO DISE
Japanese white birch	no	3.9	medium	--	--
Japanese white pine	no	4	medium	--	LPS
Japanese zelkova	no	4.9	high	TEM LPS RRC NUP SAL DRO	--
katsura tree	no	3.3	low	DISE NUP	DRO WIN AIP RRC
Kentucky coffeetree	yes	4.6	high	DRO LPS NUP	AIP
kousa dogwood	no	4.6	high	NUP	DRO AIP

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
lacebark elm	no	5.5	high	DRO TEM ESP LPS RRC NUP	INPO
lacebark pine	no	4.2	medium	DRO AIP NUP	--
littleleaf linden	no	5.2	high	LPS NUP PLE ESP AIP	INS SAL WIN
London planetree	no	4.3	medium	DRO FLO TEM NUP	DISE INS AIP
Miyabe maple	no	5.1	high	SAL	AIP
mockernut hickory	yes	3.5	medium	TEM	AIP NUP
mountain silverbell	yes	3.8	medium	DRO TEM	NUP
mugo pine	no	4.4	medium	WIN AIP RRC	FLO
musclewood (American hornbeam)	yes	4.8	high	FLO TEM NUP COL	DRO AIP
nannyberry	yes	5.2	high	NUP	--
northern catalpa	yes	4.3	medium	DISE LPS INS PLE	AIP RRC
northern pin oak	yes	3.2	low	DRO LPS	TEM AIP DISE ESP
northern red oak	yes	4.1	medium	TEM LPS NUP	DISE FLO RRC ESP
northern white cedar	yes	4.8	high	NUP ESP FLO	DRO AIP ICE BRO WIN
Norway maple	yes	5.1	high	DRO FLO ESP LPS RRC NUP	INS INPO
Norway spruce	yes	3.6	medium	NUR	INS FLO AIP
Ohio buckeye	yes	3.7	medium	--	AIP DRO ESP
Osage-orange	yes	4.5	medium	DRO TEM ESP RRC NUP	AIP
overcup oak	no	4.6	high	DRO FLO	--
pagoda dogwood	yes	4.3	medium	NUP	AIP
paper birch	yes	3.7	medium	NUP	DISE INS DRO TEM AIP
paperbark maple	no	3.3	low	--	DRO TEM AIP NUP

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
paradise apple	no	4	medium	TEM LPS RRC NUP	DISE INS AIP
pawpaw	yes	4.3	medium	--	NUP
peach	no	3.6	medium	NUP	--
Persian parrotia	no	5.5	high	DRO TEM LPS RRC NUP	SAL
Persian silk tree	no	2.9	low	DRO FLO TEM ESP	AIP LPS INPO
pignut hickory	yes	3.9	medium	TEM	NUR
pin oak	yes	3.5	medium	FLO RRC NUP	AIP DRO SAL ESP DISE
post oak	no	2.9	low	TEM	FLO AIP RRC NUP
princess tree	no	5.6	high	NUP	INPO
pussy willow	yes	3.9	medium	FLO TEM NUP	INS AIP
quaking aspen	yes	3.9	medium	TEM WIN MAR PLE	INS DRO AIP RRC INPO
red horse chestnut	no	3.9	medium	--	--
red maple	yes	4.7	high	FLO TEM NUP COL LPS	INS DRO AIP
red mulberry	yes	4	medium	TEM NUP	AIP
red pine	yes	2.7	low	--	INS DRO AIP RRC
red spruce	no	4.2	medium	DRO TEM	--
river birch	yes	3.7	medium	TEM LPS NUP	DISE DRO PLE
rose of Sharon	no	4.6	high	NUP	--
Russian olive	no	5	high	DRO TEM NUP SAL PLE LPS ESP	INPO WIN ICE DISE
Sargent cherry	no	3.8	medium	DRO TEM RRC LPS	WN AIP
sassafras	yes	4.1	medium	DRO TEM ESP	FLO AIP NUP RRC
saucer magnolia	no	4.6	high	TEM NUP	DRO FLO
sawtooth oak	no	5.5	high	DRO FLO TEM LPS RRC NUP	INPO
scarlet oak	yes	3.8	medium	TEM LPS	AIP ESP FLO DISE
Scots pine	no	4.4	medium	TEM RRC NUP	INS
shagbark hickory	yes	3.2	low	TEM	AIP PLE NUP

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
shellbark hickory	yes	3.3	low	--	AIP
shingle oak	yes	4.5	high	DRO NUP	AIP ESP DISE
Shumard oak	yes	4	medium	DRO FLO TEM LPS RRC NUP	DISE PLE ESP
Siberian elm	no	3.8	medium	DRO TEM DISE	WIN INPO
silver birch	no	3.2	low	--	INS AIP
silver linden	no	4.2	medium	TEM NUP	AIP
silver maple	yes	3.8	medium	FLO TEM NUP	INS RRC MAR
slippery elm	yes	4.3	medium	TEM LPS FLO DRO	DISE INS
smoketree	no	4.9	high	DRO RRC LPS NUP	FLO
sourwood	no	4.6	high	--	--
southern hackberry (sugarberry)	no	3.7	medium	DRO FLO TEMP	AIP NUP
southern magnolia	no	4	medium	NUP	RRC
staghorn sumac	yes	4	medium	DRO TEM	--
star magnolia	no	4.4	medium	NUP	--
sugar maple	yes	4.4	medium	NUP MAR COL	INS FLO AIP RRC SAL
swamp white oak	yes	5.2	high	TEM RRC NUP SAL LPS TEM FLO	AIP
sweet cherry	no	4	medium	TEM	FLO INPO DISE
sweetbay magnolia	no	5	high	TEM LPS RRC NUP PLE	AIP
sweetgum	no	3.5	low	FLO	INS DRO RRC LPS
sycamore maple	no	4.3	medium	NUP	INS, AIP
tamarack	yes	3.9	medium	FLO NUP	DRO AIP
Tatarian maple	no	3.9	medium	DRO	AIP INPO
tree of heaven	no	4.9	high	DRO TEM AIP ESP LPS RRC	LPS NUP INPO ESP
trident maple	no	4.2	medium	RRC	FLO LPS
tulip tree	yes	3.5	low	NUP	DRO AIP RRC
turkey oak	no	3.9	medium	DRO TEM	--

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

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Table 8 (continued).—Adaptability scores for trees in planted areas¹ in the Detroit region

Common name	Native? ²	Planted Adapt score	Planted Adapt class	Positive factors	Negative factors
Turkish hazel (Turkish filbert)	no	4.3	medium	DRO TEM LPS RRC	SAL NUP
umbrella magnolia	no	4.4	medium	--	AIP
Virginia pine	no	3.4	low	NUP	AIP
water locust	yes	4.2	medium	FLO	--
weeping willow	no	3.6	medium	FLO TEM NUP	INS LPS RRC
white ash	yes	3.2	low	NUP	INS AIP RRC
white fir	no	3.9	medium	--	FLO AIP
white mulberry	no	4.1	medium	TEM NUP SAL	LPS INPO
white oak	yes	3.3	low	TEM NUP SAL DRO	FLO AIP ESP LPS RRC DISE PLE
white poplar	no	3.6	medium	DRO TEM ESP NUP	--
white spruce	yes	4.2	medium	--	INS
willow oak	no	4.8	high	FLO LPS RRC NUP	--
winged elm	no	4.2	medium	FLO LPS RRC	AIP
yellow birch	yes	4.6	high	NUP	TEM DRO BRO INS
yellowwood	no	4.3	medium	TEM RRC	AIP DRO
Yoshino cherry	no	3.2	low	--	AIP LPS

¹ See Appendix 6 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is in the low Adapt class, above 4.5 is in the high Adapt class, and between 3.5 and 4.5 is in the medium Adapt class. See Table 6 for trait codes.

² Native trees are considered those historically native to Michigan growing in natural populations using the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023).

Overall Vulnerability of Trees in the Detroit Region

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. The overall vulnerability of trees in the Detroit region was estimated by considering the impacts on individual tree species using the zone suitability and the adaptive capacity of tree species as described in the previous section (“Adapt class” in Tables 7 and 8) together in a matrix (Table 9).

Table 9.—Vulnerability scoring matrix based on Brandt et al. (2017)

Habitat or zone suitability at end of century	Low Adapt class	Medium Adapt class	High Adapt class
not suitable	high vulnerability	moderate-high vulnerability	moderate vulnerability
suitable	moderate vulnerability	low-moderate vulnerability	low vulnerability

We evaluated 187 species and cultivars for their vulnerability. This overall approach is meant to give a coarse picture of vulnerability and to be combined with local expertise about the suitability of a species for a given site. We gave each species a vulnerability rating under a low climate change scenario and a high climate change scenario (Table 10). Under the low climate change scenario, 23 percent of species fell into the low vulnerability category, 51 percent fell into the low-moderate category, 20 percent fell into the moderate category, 5 percent fell into the moderate-high category, and 1 percent fell into the high category. Under the high climate change scenario, nearly 14 percent of species fell into the low vulnerability category, 21 percent fell into the low-moderate category, 20 percent fell into the moderate category, 35 percent fell into the moderate-high category, and nearly 10 percent fell into the high category.

The most vulnerable native species (moderate-high vulnerability under both climate change scenarios, or high vulnerability under the high climate change scenario) include American chestnut, American mountain ash, balsam fir, bigtooth aspen, black ash, black oak, eastern hemlock, eastern white pine, jack pine, red pine, shagbark hickory, shellbark hickory, tamarack, white oak, and white spruce. The least vulnerable species (low vulnerability under both climate change scenarios) include bur oak, common hackberry, downy serviceberry, eastern hophornbeam, eastern redcedar, Kentucky coffeetree, musclewood, and red maple.

When we examine the prevalence of tree species in the Detroit region, the most vulnerable (moderate-high to high vulnerability) common native species under a high climate change scenario include silver maple, sugar maple, American linden, pin oak, northern catalpa, common horse chestnut, and box elder. Other common species with moderate-high vulnerability under a high climate change scenario include Callery pear and white mulberry. The least vulnerable (low or low-moderate vulnerability) common native species under both climate change scenarios include red maple, American sycamore, green ash, common hackberry, northern red oak, and honeylocust (thornless). Other common species with low-moderate vulnerability under both scenarios include London planetree and Siberian elm. Rare (fewer than 50 individuals) species or not planted species with low or low-moderate vulnerability under both scenarios include blackgum, common persimmon, Chinese juniper, downy serviceberry, European buckthorn, fringetree, goldenrain tree, Heritage® oak, Japanese pagoda tree, Kentucky coffeetree, mockernut hickory, Osage-orange, saucer magnolia, smoketree, sourwood, sweetbay magnolia, umbrella magnolia, water locust, and willow oak.

Table 10.—Vulnerability ratings for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Estimated number of trees in Detroit	Vulnerability - low climate change scenario	Vulnerability - high climate change scenario
Accolade™ elm	--	low	moderate
American beech	37	low-moderate	low-moderate
American chestnut	4	moderate	high
American elm	2,509	low-moderate	low-moderate
American linden (basswood)*	2,482	low-moderate	moderate-high
American mountain ash	--	moderate-high	moderate-high
American sycamore*	5,771	low-moderate	low-moderate
Amur corktree	9	low-moderate	moderate-high
Amur maackia	2	low	moderate
amur maple	107	low-moderate	moderate-high
apple	--	low-moderate	low-moderate
apple serviceberry	--	low-moderate	moderate-high
Austrian pine	535	low-moderate	moderate-high
bald cypress*	36	low	low
balsam fir	13	moderate-high	moderate-high
balsam poplar*	--	moderate	moderate
bigtooth aspen	2	moderate-high	moderate-high
bitternut hickory**	26	low-moderate	low-moderate
black alder	--	low-moderate	moderate-high
black ash*	--	moderate	high
black cherry	31	moderate	moderate
black hickory**	--	moderate	moderate
black locust**	324	low-moderate	low-moderate
black maple	67	low-moderate	moderate-high
black oak**	20	moderate	high
black poplar	--	low-moderate	low-moderate
black walnut	181	moderate	moderate
black willow*	13	moderate	moderate
blackgum	42	low	low
blackjack oak**	--	moderate	moderate
boxelder***	1,002	low-moderate	moderate-high

*Flood-tolerant, **Drought-tolerant, ***Flood- and drought-tolerant.

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Table 10 (continued).—Vulnerability ratings for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Estimated number of trees in Detroit	Vulnerability - low climate change scenario	Vulnerability - high climate change scenario
bur oak**	595	low	low
Callery pear	2,936	low-moderate	moderate-high
cedar elm***	--	moderate	moderate
cherry plum	12	low-moderate	low-moderate
chestnut oak**	8	low	moderate
Chinese chestnut	1	low-moderate	moderate-high
Chinese juniper	10	low	low
Chinese willow	--	moderate	moderate
chinkapin oak**	6	low	moderate
chokecherry	12	low-moderate	moderate-high
cockspur thorn	27	low-moderate	moderate-high
Colorado spruce	450	low-moderate	moderate-high
common hackberry**	2,270	low	low
common horse chestnut	1,180	low-moderate	moderate-high
common lilac	16	low-moderate	moderate-high
common lime	--	low-moderate	moderate-high
common oak	530	low-moderate	moderate-high
common persimmon	1	low	low
cornelian cherry dogwood	31	low-moderate	moderate-high
Crimean linden	6	moderate	moderate
dawn redwood	108	low-moderate	low-moderate
Douglas-fir	26	moderate	high
downy serviceberry	8	low	low
eastern cottonwood	885	low-moderate	low-moderate
eastern hemlock	5	moderate	high
eastern hophornbeam or ironwood*	95	low	low
eastern redbud*	416	low-moderate	low-moderate
eastern redcedar**	107	low	low
eastern white pine	106	moderate	high
English walnut	--	low-moderate	moderate-high
European ash	--	low-moderate	moderate-high

*Flood-tolerant, **Drought-tolerant, ***Flood- and drought-tolerant.

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Table 10 (continued).—Vulnerability ratings for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Estimated number of trees in Detroit	Vulnerability - low climate change scenario	Vulnerability - high climate change scenario
European beech	21	low-moderate	moderate-high
European buckthorn**	19	low	low
European hornbeam	171	low-moderate	moderate-high
European larch	2	moderate-high	moderate-high
European mountain ash	26	low-moderate	moderate-high
European pear	--	low-moderate	low-moderate
flowering dogwood	99	low-moderate	low-moderate
Freeman maple	873	low-moderate	moderate-high
fringetree	--	low	low
ginkgo	1,220	low	low
glossy buckthorn*	--	low	moderate
goldenrain tree**	48	low	low
gray alder*	1	low-moderate	moderate-high
gray birch	40	high	high
gray dogwood	4	low-moderate	moderate-high
green ash*	5,705	low-moderate	low-moderate
green hawthorn 'Winter King'	1	low-moderate	moderate-high
hardy pecan	7	moderate	moderate
hardy rubber tree	--	moderate	moderate
hedge maple	304	low-moderate	moderate-high
Heritage® oak	--	low	low
Higan cherry	3	low-moderate	moderate-high
honeylocust (thornless)	22,971	low-moderate	low-moderate
honeylocust**	187	low-moderate	low-moderate
jack pine	5	high	high
Japanese cherry	29	moderate-high	moderate-high
Japanese maple	235	low-moderate	moderate-high
Japanese pagoda tree	18	low	low
Japanese tree lilac	556	moderate	moderate
Japanese white birch	--	low-moderate	moderate-high
Japanese white pine	--	low-moderate	low-moderate

*Flood-tolerant, **Drought-tolerant, ***Flood- and drought-tolerant.

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Table 10 (continued).—Vulnerability ratings for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Estimated number of trees in Detroit	Vulnerability - low climate change scenario	Vulnerability - high climate change scenario
Japanese zelkova	528	low	low
katsura tree	49	moderate	high
Kentucky coffeetree**	12	low	low
kousa dogwood	71	low	moderate
lacebark elm**	136	low	low
lacebark pine	3	low-moderate	moderate-high
littleleaf linden	5,396	low	moderate
London planetree	6,971	low-moderate	low-moderate
Miyabe maple	17	low	moderate
mockernut hickory	3	low-moderate	low-moderate
mountain silverbell	2	low-moderate	moderate-high
mugo pine	--	low-moderate	moderate-high
musclewood (American hornbeam)	200	low	low
nannyberry	1	low	moderate
northern catalpa	1,238	low-moderate	moderate-high
northern pin oak**	--	moderate	high
northern red oak	2,234	low-moderate	low-moderate
northern white cedar	594	moderate	moderate
Norway maple***	30,157	moderate	moderate
Norway spruce	90	low-moderate	moderate-high
Ohio buckeye	31	low-moderate	moderate-high
Osage-orange**	6	low-moderate	low-moderate
overcup oak	--	low	moderate
pagoda dogwood	6	low-moderate	moderate-high
paper birch	130	low-moderate	moderate-high
paperbark maple	5	moderate	high
paradise apple	64	low-moderate	low-moderate
pawpaw	6	low-moderate	moderate-high
peach	5	low-moderate	low-moderate
Persian parrotia	4	low	moderate
Persian silk tree***	--	moderate	moderate

*Flood-tolerant, **Drought-tolerant, ***Flood- and drought-tolerant.

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Table 10 (continued).—Vulnerability ratings for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Estimated number of trees in Detroit	Vulnerability - low climate change scenario	Vulnerability - high climate change scenario
pignut hickory	9	low-moderate	moderate-high
pin oak*	2,033	low-moderate	moderate-high
post oak**	--	moderate	moderate
princess tree	14	low	moderate
pussy willow	15	low-moderate	moderate-high
quaking aspen	20	low-moderate	moderate-high
red horse chestnut	--	low-moderate	moderate-high
red maple*	7,287	low	low
red mulberry	41	moderate	moderate
red pine	11	moderate	high
red spruce	3	moderate-high	moderate-high
river birch	202	low-moderate	low-moderate
rose of Sharon	--	low	low
Russian olive	11	low	moderate
Sargent cherry	4	low-moderate	low-moderate
sassafras	31	low-moderate	low-moderate
saucer magnolia	--	low	low
sawtooth oak	4	low	moderate
scarlet oak	38	low-moderate	low-moderate
Scots pine	--	low-moderate	moderate-high
shagbark hickory	70	moderate	high
shellbark hickory	1	moderate	high
shingle oak**	181	low	moderate
Shumard oak***	34	low-moderate	low-moderate
Siberian elm**	4,897	low-moderate	low-moderate
silver birch	24	moderate	high
silver linden	198	low-moderate	low-moderate
silver maple*	20,476	low-moderate	moderate-high
slippery elm**	729	low-moderate	low-moderate
smoketree	29	low	low
sourwood	1	low	low
southern hackberry (sugarberry)**	--	low-moderate	low-moderate

*Flood-tolerant, **Drought-tolerant, ***Flood- and drought-tolerant.

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Table 10 (continued).—Vulnerability ratings for tree species that are currently found in the Detroit region or are being considered for planting in the area

Common name	Estimated number of trees in Detroit	Vulnerability - low climate change scenario	Vulnerability - high climate change scenario
southern magnolia	1	moderate-high	moderate-high
staghorn sumac**	1	low-moderate	moderate-high
star magnolia	34	low-moderate	low-moderate
sugar maple	5,240	low-moderate	moderate-high
swamp white oak	858	low	moderate
sweet cherry	--	low-moderate	moderate-high
sweetbay magnolia	18	low	low
sweetgum*	632	moderate	moderate
sycamore maple	58	low-moderate	moderate-high
tamarack	--	moderate-high	moderate-high
Tatarian maple	--	low-moderate	moderate-high
tree of heaven**	984	low	moderate
trident maple	7	low-moderate	low-moderate
tulip tree	509	moderate	moderate
turkey oak	--	low-moderate	moderate-high
Turkish hazel (Turkish filbert)	11	low-moderate	moderate-high
umbrella magnolia	1	low-moderate	low-moderate
Virginia pine	10	moderate	high
water locust	-	low-moderate	low-moderate
weeping willow	93	low-moderate	low-moderate
white ash	855	moderate	moderate
white fir	2	low-moderate	moderate-high
white mulberry	2,308	low-moderate	moderate-high
white oak	232	moderate	high
white poplar	52	low-moderate	low-moderate
white spruce	82	moderate-high	moderate-high
willow oak	3	low	low
winged elm	--	low-moderate	moderate-high
yellow birch	--	moderate	moderate
yellowwood	79	low-moderate	low-moderate
Yoshino cherry	6	moderate	high

*Flood-tolerant, **Drought-tolerant, ***Flood- and drought-tolerant.

Summary

Results from species distribution modeling suggest that habitat suitability for many tree species found in the Detroit area will shift across the region, leading to declines in some species, increases in others, and the potential to colonize new habitats. Shifts in projected hardiness and heat zones, adaptive capacity of urban trees, and overall vulnerability ratings can be used to help inform decisions about what tree species may be suitable for planting in the future and which may require additional care as the climate warms. Not all factors are considered in the models, and the vulnerability of urban trees will need to be gauged based on the complex interaction of multiple stressors and benefits.

Key Points

- **Projected habitat suitability for native trees:** Species distribution modeling of native species suggests that suitable habitat will decrease for 19 species (31 percent) and remain stable for 8 species (13 percent). Suitable habitat is expected to increase for 8 species (13 percent), and 16 species (26 percent) may be able to colonize new, suitable habitats. The rest of the species evaluated had mixed results (17 percent).
- **Projected shifts in hardiness zones, heat zones, and species ranges:** Under a low climate change scenario, the vast majority of the 187 evaluated species are projected to be in a suitable range (94 percent), while 6 percent are not projected to be in a suitable range. Under a high climate change scenario, 42 percent are projected to be in a suitable range, and 58 percent are not projected to be in a suitable range.
- **Adaptive capacity of urban trees:** Adaptive capacity of 187 species was evaluated using scoring systems for planted (187 species) and natural (92 species) environments. For natural areas (both native and naturalized), 41 species received a high adaptability score, 8 received a low adaptability score, and 43 received a medium adaptability score. For planted or developed conditions, 50 species received a high adaptability score, 30 received a low adaptability score, and the remaining 107 received a medium adaptability score.
- **Overall vulnerability of the trees in the Detroit region:** Under a low climate change scenario, most Detroit tree species fell into the low-moderate vulnerability category (51 percent). Twenty-three percent were categorized as low vulnerability, 20 percent as moderate vulnerability, 5 percent as moderate-high vulnerability, and 1 percent as high vulnerability. Under a high climate change scenario, more trees were considered vulnerable. Nearly 14 percent were categorized as low vulnerability, 21 percent as low-moderate vulnerability, 20 percent as moderate vulnerability, 35 percent as moderate-high vulnerability, and nearly 10 percent as high vulnerability.
 - Common species with moderate-high to high vulnerability under a high climate change scenario include boxelder, silver maple, sugar maple, common horse chestnut, northern catalpa, white mulberry, Callery pear, pin oak, and American linden.
 - Common species with low to low-moderate vulnerability under both climate change scenarios include red maple, green ash, honeylocust (thornless), American sycamore, London planetree, and Siberian elm.
 - Uncommon species with low to low-moderate vulnerability under both climate change scenarios include common persimmon, downy serviceberry, fringetree, mockernut hickory, Osage-orange, sourwood, southern hackberry, umbrella magnolia, and water locust.

CHAPTER 5: HUMAN HEALTH IMPACTS

Urban forests and their associated benefits have become more important for human health, as more than half of the Nation's population resides in cities. Urban trees provide ecosystem services, such as cooling the air, absorbing rainfall, providing oxygen, intercepting ultraviolet light, storing carbon, and reducing air pollution. Forest Service scientists and collaborators estimate that trees are saving over 850 lives and preventing 670,000 cases of acute respiratory symptoms each year, in addition to providing monetary savings valued at up to \$13 billion (Nowak and Greenfield 2015).

The interaction between trees and a changing climate will have important implications for protecting human health. A changing climate has the potential to worsen existing health issues and create new issues. The presence and intensity of allergens, biogenic VOCs (volatile organic compounds), and pests and pathogens are projected to be altered by climate stressors. Changes in climate are also projected to affect incidence of and mortality from heat-related illnesses and mortality, frequency and intensity of flooding and other extreme weather events, food prices, and social, mental, and physical well-being. Adopting proactive management to maintain or adjust species composition can help reduce harmful impacts. The following is a summary of some of the key human health impacts for the Detroit region in relation to the changing urban forest.

The Michigan Department of Health and Human Services and GLISA (a collaboration between the University of Michigan and Michigan State University supported by the National Oceanic and Atmospheric Administration) identified five high-priority climate-related health effects for Michigan: respiratory diseases, heat-related illnesses, waterborne and vector-borne diseases, and injuries, particularly carbon monoxide poisoning (Cameron et al. 2015).

Air Pollution

A changing climate can increase ground-level ozone and particulate matter air pollution, associated with health issues such as asthma, diminished lung function, increased hospital visits, and premature deaths (Centers for Disease Control and Prevention [CDC] 2020). Ozone formation is affected by heat, methane emissions, and concentrations of precursor chemicals. Particulate matter is affected by factors such as wildfire emissions, air stagnation episodes, and anthropogenic sources. The concentration of a refinery, manufacturing facilities, and vehicles in southwest Detroit is often cited as a major factor contributing to high levels of air pollution. This section of the city has an oil refinery, steel mill, wastewater treatment plant, power plants, several heavily used highways, and a six-lane bridge (IQAir 2021). These sources combine to produce dangerous emissions, which lead to unhealthy concentrations of particulate matter. As the climate continues to warm, premature deaths related to ozone and particle pollution are projected to increase (CDC 2020).

Airborne Allergens

Climate change impacts the presence of airborne allergens (aeroallergens such as tree, grass, and weed pollen) by shifting the production, allergenicity, distribution, and timing (Nolte et al. 2018). In other words, climate change can alter when the pollen season starts and ends, how much pollen plants create, how much pollen is in the air, how pollen impacts our health, and the overall risk of allergy symptoms (CDC 2020). Children and those with respiratory diseases such as asthma are vulnerable to aeroallergens, which have the ability to cause allergic rhinitis and aggravate asthma and sinusitis (Fann et al. 2016). In addition, higher winter and spring temperatures can bring earlier flowering for trees such as oak, which produces a common allergen that can cause severe reactions.

Pollen production varies greatly among tree species, and climate change can affect the timing and production of allergens. Oak pollen in particular is expected to cause an increase in asthma-related visits to the emergency department (Nolte et al. 2018). Birch pollen production and peak values are also projected to increase by a factor of 1.3 to 2.3 relative to 2000 by 2100, with the start and peak pollen release dates coming 2 to 4 weeks earlier (Fann et al. 2016). Common ragweed, the most common aeroallergen in the United States, is expected to continue its longer pollen season in central North America (Ziska et al. 2011). Increases in carbon dioxide and temperature have been found to cause earlier flowering and higher floral numbers and pollen production, along with increased allergenicity in ragweed (Fann et al. 2016). However, not all pollen seasons will be extended; as some areas become drier, there is potential for pollen seasons to shorten as a result of increased plant stress. Allergenicity can be considered when determining which tree species to plant in the Detroit region (Table 11). See Appendix 8 for the allergenicity of tree species considered suitable for planting in the Detroit region.

Table 11.—Allergenicity of the 25 most common tree species in Detroit (source: IMS Health Inc. 2022)

Common name	Estimated number of trees in Detroit	Allergenicity
Norway maple	30,157	moderate allergen
honeylocust (thornless)	22,971	mild allergen
silver maple	20,476	moderate allergen
red maple	7,287	moderate allergen
London planetree	6,971	moderate allergen
American sycamore	5,771	moderate allergen
green ash	5,705	severe allergen
littleleaf linden	5,396	moderate allergen
sugar maple	5,240	moderate allergen
Siberian elm	4,897	moderate allergen
Callery pear	2,936	mild allergen
American elm	2,509	moderate allergen
American linden (basswood)	2,482	moderate allergen
white mulberry	2,308	severe allergen
common hackberry	2,270	moderate allergen
northern red oak	2,234	severe allergen
pin oak	2,033	severe allergen
northern catalpa	1,238	mild allergen
ginkgo	1,220	mild allergen
common horse chestnut	1,180	no allergy reported
boxelder	1,002	severe allergen
tree of heaven	984	mild allergen
eastern cottonwood	885	moderate allergen
Freeman maple	873	moderate allergen
swamp white oak	858	severe allergen

Biogenic Volatile Organic Compounds

Biogenic VOCs (volatile organic compounds) are chemical compounds produced naturally by trees and other plants. The amount of BVOC emissions varies by species and by environmental conditions such as temperature, plant water stress, solar radiation, and ozone and carbon dioxide concentrations (Yang et al. 2003). The interaction between BVOCs, chemistry, and climate is heavily influenced by anthropogenic changes in land cover and by pollution, as well as by the physical climate (Unger 2014). BVOC emissions release fine particulate matter (PM_{2.5}) and ground-level ozone pollution, both of which can harm human health (Ren et al. 2017).

BVOC emissions are particularly prevalent in urban green spaces, where the urban core has been found to be the hotspot of regional emissions intensity (Ren et al. 2017). Urban green spaces play a greater role in human health issues related to BVOC emissions compared to green spaces in rural areas, and account for 62 percent of total health damage caused by BVOC emissions. BVOC emissions from urban green spaces are expected to at least triple by 2050 due to tree growth, urban expansion, and environmental changes (Ren et al. 2017). Some tree species in the Detroit region, such as apple, elm, ash, hawthorn, serviceberry, and basswood, emit few or no BVOCs; others such as sweetgum, oak, black locust, sycamore, poplar, and willow have very high emission rates (Nowak et al. 2002). Thus, local species composition can interact with temperature changes to influence human exposure to BVOCs.

Pest and Pathogen Effects on Humans

Climate change may affect pests and pathogens that may have direct or indirect effects on human health. Ticks, which are vectors of disease-causing agents, are projected to expand in range, seasonal distribution, and abundance under a changing climate (Sonenshine 2018). Consequently, more people and wildlife will be exposed to diseases carried by ticks, such as Lyme disease. Similarly, West Nile virus and its mosquito vector are projected to increase in response to warmer winters, earlier springs, and warmer summers in Detroit (Cameron et al. 2015).

Pests and pathogens of urban trees may also affect human health through loss of ecosystem services. For example, the spread of emerald ash borer (EAB) and associated loss of trees increase the risk of mortality related to cardiovascular and lower respiratory tract illnesses (Donovan et al. 2013). There is also a safety risk from hazard trees, which include those that are damaged or dying due to pests and pathogens. Proper care and maintenance, such as insecticide treatments and removal of hazard trees, may be necessary to ensure the long-term health benefits that trees provide and reduce human health hazards (Janowiak et al. 2021). Not all potential pests and pathogens are known, and there is uncertainty about the future habitat range of those that have been identified.

Extreme Heat

Increased day and night temperatures are associated with death and heat-related diseases such as dehydration and heatstroke. Extreme heat in urban centers, like Detroit, can cause dangerous living conditions. Many factors can put people at an increased risk from extreme heat. People who are older, very young, less educated, have a lower income, are socially isolated, lack air conditioning, suffer from chronic physical or mental illness, or are without access to a vehicle are the most vulnerable (Angel et al. 2018, GLISA 2023, Gregg et al. 2012). Urban, low-income households are at a higher risk from exposure to extreme heat because they may lack air conditioning or live in areas with a greater urban heat island effect. Detroit is the lowest-income

major city in the country, with more than 39 percent of its residents living below the poverty level (GLISA 2023). Extreme heat events increase electricity demand for air conditioning, which can lead to brownouts and power outages that disrupt the availability of electricity. Further, increased demand for air conditioning results in increased energy production and greenhouse gas emissions, leading to greater air pollution and a compound impact on human health.

Tree canopy coverage tends to be lower in urban heat islands. A heat vulnerability assessment was created for Detroit to identify locations that are at a greater risk from extreme heat. The assessment combined elements that influence exposure to extreme heat, such as tree canopy and impervious surfaces, with demographic factors related to the sensitivity of community members including poverty, educational attainment, household access to a vehicle, and residents who are 65 and older. This index identified areas of higher heat risk for residents in census block groups (Fig. 19). Many vulnerable groups are concentrated downtown; however, risk is noticeably lower in northwest Detroit, where there is higher tree canopy coverage and more parkland.

A study examining mortality rates in three climate scenarios found that Detroit is projected to endure more heat-related deaths than many southern cities (Lo et al. 2019). A higher overall cumulative relative risk, or cumulated mortality risk over a period of 21 days relative to that at the minimum mortality temperature, was found to be associated with extreme heat for northern cities than for southern cities, such as Atlanta, GA, Houston, TX, and Phoenix, AZ. The difference in relative risk demonstrates that relationships between temperature and mortality depend partly on latitude (Lo et al. 2019). The study also modeled the avoidable fraction of heat-related deaths under the 1.5 °C (2.7 °F) and 2 °C (3.6 °F) thresholds in the Paris Agreement. Detroit is one of the cities projected to see a significant attributable fraction of avoided heat-related deaths if the 2 °C threshold is met, compared to the 3 °C (5.4 °F) trajectory. Enhancing tree canopy cover along with other measures such as improved heat-related healthcare, wider availability of cooling centers and air conditioning, and increased awareness of heat-related illnesses and mortality can help mitigate heat-related risks.

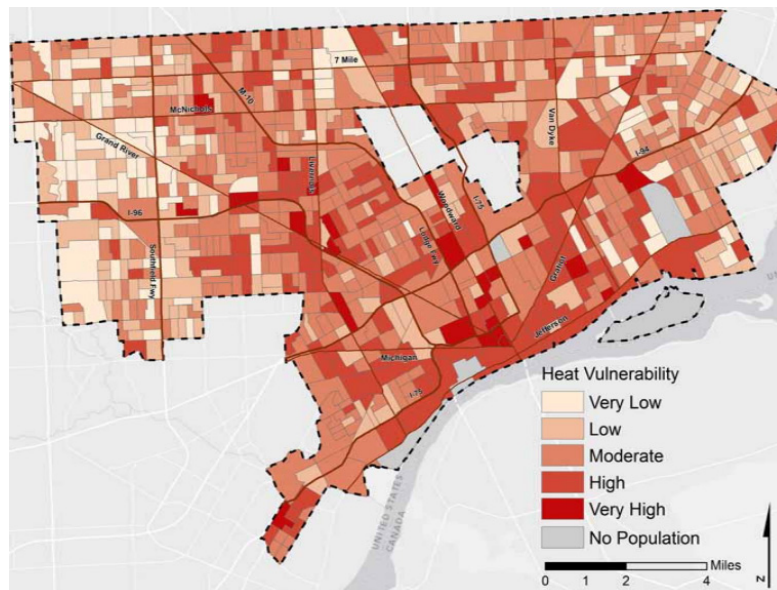


Figure 19.—Heat Vulnerability Index of Detroit, MI. The darkest red shade indicates the greatest heat vulnerability; the lighter shades indicate relatively lower vulnerability. Cartographer: University of Michigan Detroit Climate Capstone; data sources: U.S. Geological Survey GloVis LandSat 7 ETM+; American Community Survey; U.S. Census 2010. From Gregg et al. (2012), used with permission.

Water Quality

In the Great Lakes region, waterborne diseases and beach closings are projected to increase because of changes in heavy precipitation events and lake temperatures. Areas in Detroit vulnerable to runoff and failure of septic and sewage systems will be more at risk for algal blooms and waterborne diseases (Cameron et al. 2015, CDC 2020). In addition to indicators such as the capacity of water treatment systems, combined sewer outflow release, and waterborne illnesses, water quality can be measured by the amount of vegetation, as vegetation can reduce impacts to water quality. For example, leaf surfaces on street trees intercept and catch small-particle pollution, some of which is washed onto ground surfaces, while some is caught in leaf surface waxes (Nowak and Greenfield 2015). Riparian forests can also help maintain and enhance water quality. Trees and other vegetation can function as a buffer to filter out debris and sediments, offer habitats for organisms that improve water health, and slow down streamflow by promoting infiltration and introducing barriers to the lateral flow of surface water. Increasing temperatures can have negative impacts on vegetation, reducing the capacity to mitigate water pollution.

Food Security

A changing climate is expected to result in food shortages and food insecurity by threatening global food production in addition to affecting food prices, distribution systems, and aspects of food quality (CDC 2020). Crop yields are projected to decline from changes in precipitation, extreme weather events, and competition from weeds and pests. The nutritional value of foods is also projected to decrease because of increased atmospheric carbon dioxide, which can ultimately decrease protein content in crops such as soy, barley, and sorghum. Lower soil nitrogen levels are also associated with a decline in essential nutrients such as iron, zinc, calcium, and vitamins, and sugars.

Increases in food prices—the result of declining food production and other factors—generally have a negative effect on the community, especially low-income residents. When food prices increase, humans often go without eating or select nutrient-poor, calorie-rich foods, resulting in health issues from micronutrient malnutrition to obesity (CDC 2020). These issues are further exacerbated within neighborhoods classified as food deserts, a term that describes an urban area lacking accessibility to high-quality, nutritious, and affordable food. The Detroit Food Policy Council's 2019 "Food Metrics Report" states that 39 percent of Detroit households are food insecure, an increase of 6 percentage points from 2018 (Hill 2020). In addition, 40 percent of households are using the Supplemental Nutrition Assistance Program (SNAP), and 18 percent of eligible households are not enrolled. There are also fewer grocery stores and less area devoted to groceries per store within the city, notably in district 2 and district 3 (Fig. 20). As a result, some Detroit residents with a lack of reliable transportation walk miles to find affordable food.

Urban agriculture and food forests can play an important role in food justice for socioeconomically disadvantaged populations by increasing access to fresh food, improving health, and building skills and communities (Horst et al. 2017). However, societal inequities can be exacerbated while planning for urban agriculture. For example, urban agriculture may benefit people who have greater access to land, those who already own land, and other people and organizations with greater monetary and other resources; it may ultimately contribute to the displacement of low-income residents. Orienting efforts to include explicit food justice goals, prioritize long-term planning, develop relationships with food justice organizations and diverse participants, and target city investment in urban farms and gardens to benefit disadvantaged communities can help to implement equitable urban agriculture (Horst et al. 2017).

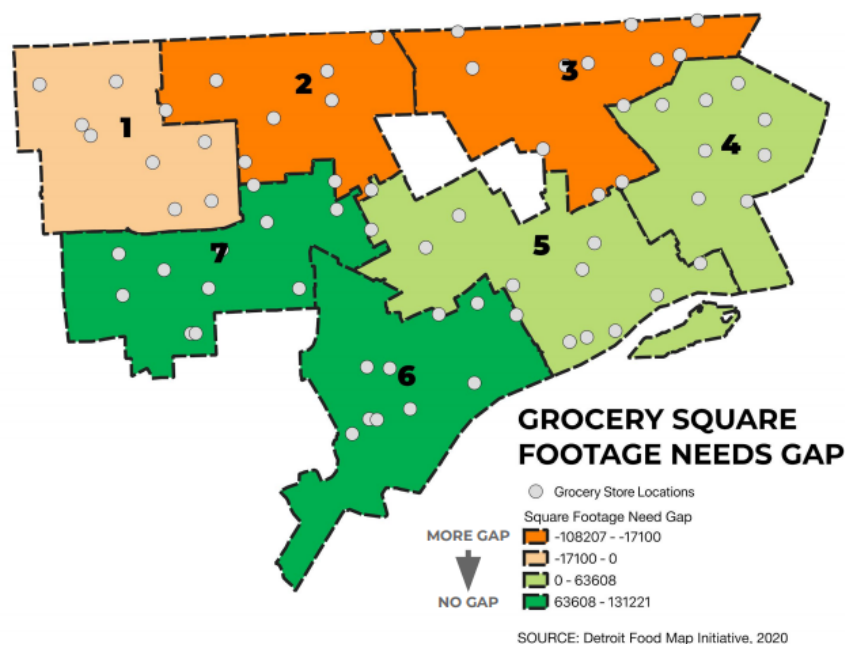


Figure 20.—Grocery square footage needs gap in Detroit, MI. Source: Hill (2020), used with permission.

Detroit has 374 community gardens and 14 farmers markets and farm stands, which have helped expand food access and provide employment opportunities (Hill 2020). Numerous community-based programs are underway that are focused on reducing social inequities through urban agriculture. For example, the Oakland Avenue Urban Farm, located in the North End and starting with a single plot in 2000, is considered the Nation’s first “Agri-Cultural” urban landscape. A program of North End Christian Community Development Corporation, Oakland Avenue Urban Farm is a nonprofit, community-based organization focused on growing healthy foods, developing a sustainable economy, and enhancing cultural environments. Keep Growing Detroit, founded in 2013, operates a number of programs such as the Garden Resource Program supporting nearly 2,000 urban gardens and farms in the city. This organization also operates Grown in Detroit, which provides low-barrier opportunities to urban growers to sell fruits and vegetables. Keep Growing Detroit has also established a 1.5-acre farm and teaching facility in the Eastern Market District. The Michigan Urban Farming Initiative is focused on redeveloping 3 acres of land in the area to be positioned as a center of urban agriculture, serving as a model for best practices, strategies for increasing food security, and improvement of green infrastructure (Michigan Urban Farming Initiative 2013). Local food production is a means of strengthening resilience and reducing dependence on global supply chains that contribute to climate change.

Social and Mental Health

A changing climate can alter human health in indirect ways as well. For example, extreme weather events and natural disasters can displace residents from their homes, jobs, and communities. Displacement can create cascading negative effects on well-being, such as chronic stress, anxiety, post-traumatic stress disorder, or other mental health issues. Detroit has a high population of low-income residents and communities of color, which presents additional concerns because these populations are often more adversely affected by climate change due to their housing situation, lack of access to a vehicle, and overall quality of life (Gregg et al. 2012). Without air conditioning or household access to a vehicle, individuals are less able to find refuge during extreme heat or

precipitation events. Even as climate change threatens human health in a variety of ways, urban trees can fulfill a deep need in the human psyche and are beneficial for our social, mental, and physical well-being.

Psychologically, street trees and maintained green spaces can provide stronger social cohesion in neighborhoods and can relieve “nature-deficit disorder,” a term that refers to the malaise resulting from excessive time and focus inside—especially when there are no views of the outside via windows (Nowak and Greenfield 2015). Health benefits are also associated with green spaces for employees and students. In a study examining the relationship between nature contact and employee health, researchers found that as nature contact increased during the workday, there was a decrease in employees’ perceived stress and complaints about health (Largo-Wight et al. 2011). Another study showed that students who could see green spaces from their classrooms had less stress and mental fatigue, performed better on attention tests, and were better able to recover from stressful situations (Li and Sullivan 2016).

Urban trees can provide benefits related to overall safety and decreases in crime. Studies have shown that the presence of trees and grass surrounding residences corresponds with decreased crime compared to more barren areas (Gilstad-Hayden et al. 2015, Kondo et al. 2017, Kuo and Sullivan 2001). Well-cared-for green spaces indicate that the community cares about its space and that residents are also more likely to be actively involved in protecting this space. Green spaces can also lower aggression and increase perceived personal safety. In a study of tree canopy and crime in New Haven, CT, areas with greater tree canopy coverage had lower crime rates; these results support previous studies that have suggested trees can help prevent crime (Gilstad-Hayden et al. 2015).

Urban forests can promote an active lifestyle, addressing various mental and physical issues. Residents who live near parks and green spaces have better mental health, are more physically active, and are expected to have a longer lifespan (USDA Forest Service 2018, White et al. 2019). Trees help shade humans from ultraviolet light, a contributing factor of skin cancer. In addition, studies have demonstrated that people exercise at greater intensities and for longer periods of time when they are in natural outdoor environments. Healthcare professionals are increasingly promoting the use of outdoor green spaces as a way to support healthy living, reduce obesity, improve stress, and combat chronic diseases (Ellaway et al. 2005, Nutsford et al. 2013). As climate change alters the current landscape, tree planting lists remain critical for replacing urban trees with adaptable species.

Green infrastructure can help mitigate climate change and provide health co-benefits. Communities use green infrastructure to develop park space, provide habitat for wildlife, reduce urban heat island effects, manage stormwater, and create climate change resilience overall (Cochran et al. 2018). Natural green infrastructure, such as trees, streams, and wetlands, can also be protected. However, these projects tend to be distributed inequitably by class and race. A Detroit study used interviews and ethnographic observations with residents who had experienced both extreme weather events (e.g., flooding) and green infrastructure projects to understand their perspectives (Carmichael et al. 2019). Although green infrastructure was widely supported, residents were also concerned about the unintended health issues from climate change as well as green spaces that are not maintained over the long term. Improvements in equity and environmental justice can be made by prioritizing green infrastructure in vulnerable communities and focusing on community-driven plans (Georgetown Climate Center 2021). The integration of both human health and climate perspectives into green infrastructure projects can help improve access to a wider array of urban forest benefits for communities, from offering universally accessible green space, to creating opportunities for leadership in the stewardship of urban forests (Cochran et al. 2018, Janowiak et al. 2021).

Summary

A changing climate has the potential to worsen existing health issues and create new issues, such as increases in food prices, flooding and other extreme weather events, heat-related illnesses and mortality, the presence and intensity of allergens, and pests and pathogens, along with declining overall air quality. Urban forests have the potential to help overcome some of these challenges by reducing human health impacts and increasing social cohesion and mental health if strategies are implemented in an inclusive and equitable manner.

Key Points

- The population and urban forest in the Detroit region are both at risk from a changing climate, and urban forests can play a role in mitigating risks to human health from a changing climate.
- Climate change can increase ground-level ozone and particulate matter air pollution, which are associated with health issues such as asthma, diminished lung function, increased hospital visits, and premature deaths. Changing conditions can also shift biogenic VOC (volatile organic compound) emissions from plants and the production, allergenicity, distribution, and timing of aeroallergens, or airborne substances, such as tree, grass, and weed pollen.
- Oak, birch, and ragweed pollen are projected to increase under a changing climate and allergenicity is an important human health component to consider when selecting climate-adapted tree species.
- Human health is impacted by pests and pathogens such as emerald ash borer and ticks, which may shift their range, distribution, and abundance under changing conditions. Another concern is hazard trees, which may occur in the presence of tree pests and pathogens.
- Extreme heat is associated with heat-related diseases and mortality and poses a serious threat to Detroit residents, particularly those who are low-income, young, or socially isolated; lack air conditioning; or suffer from chronic illness.
- Changes in heavy precipitation events and lake temperatures can increase waterborne diseases, beach closings, and vulnerability to runoff and failure of septic or sewage treatment.
- Climate change is expected to cause food shortages and food insecurity, negatively impacting the community as food prices increase and availability decreases. Urban agriculture and food forests aid in food justice by increasing access to fresh foods, improving health, and building communities.
- While extreme weather events and natural disasters can cause secondary negative health effects, street trees and green spaces are linked to stronger social cohesion, stress relief, decreased crime, and an active lifestyle.

CHAPTER 6: URBAN FOREST VULNERABILITY

Drawing on information from the previous chapters, Chapter 6 examines the vulnerability of each city council district in Detroit and summarizes the potential climate impacts and adaptive capacity factors in the Detroit region to provide an overview of urban forest vulnerability. 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. Adaptive capacity refers to the ability of a species or ecosystem to accommodate or cope with potential climate change impacts with minimal disruption. It is strongly related to the concept of resilience, which refers to the ability to predict, prepare for, respond to, and recover from climate disturbances. Potential climate impacts are considered the direct and indirect consequences of climate change on systems. Impacts are a function of exposure of a system to climate change and its sensitivity to any resulting changes, and could be beneficial or harmful to a particular forest or ecosystem type.

District-level Vulnerability Assessment

Detroit is subdivided into seven city council districts, each of which has its own unique features (Fig. 21, Table 12). The district-level vulnerability assessment uses key climate change impacts and adaptive capacity factors to determine a vulnerability level for each district. This assessment can help determine how each can adjust to projected damage and take advantage of opportunities to strategically implement adaptation strategies.

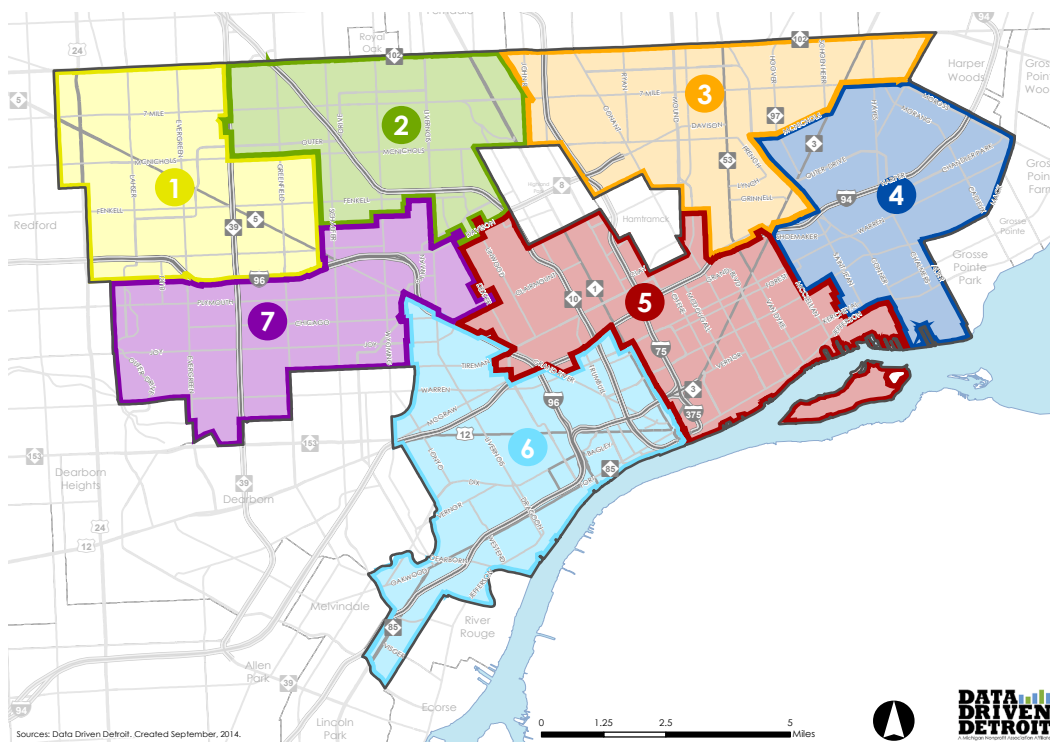


Figure 21.—The city council districts of Detroit, MI. Source: Data Driven Detroit (2014).

Table 12.—Overview of Detroit city council districts (adapted from The Neighborhoods.org, n.d.)

District	Description	Homes	Neighborhoods	Parks
District 1, Northwest	The thriving business corridor stretches along Grand River Avenue, one of the oldest commercial areas in Michigan. The wide-ranging interests of this eclectic community span activities from shows in the theater district to community gardening. Residents have well-established working relationships and partnerships with community leaders and other residents in the district.	36,582	31	31
District 2, North Central	This historic district with beautiful tree-lined streets encompasses strong communities, active organizations, stable homes, vibrant businesses, and a variety of neighborhoods, including the notable Avenue of Fashion. It contains several high-quality educational institutions and high-end neighborhoods.	32,621	24	20
District 3, Northeast	This district is the location of City Airport (Coleman A. Young Municipal Airport), contains Gratiot Avenue as one of the main streets, and is home to many successful business leaders, elected officials, and singing groups. In the southwestern section, Banglatown is a flourishing neighborhood where many Bangladeshi immigrants live.	29,149	25	48
District 4, East	This district has houses bordering canals, along with many homeowners associations, block clubs, and longtime businesses that reflect the city's history of immigration. The canal-lined neighborhoods invite waterfront parks, activities, youth sports, and small businesses, and are also areas that experience heavy flooding.	27,812	20	21
District 5, Central	As the heart of Detroit, this district is the largest district and contains the city's "downtown" as well as Belle Isle, the largest island park in the country. It is considered the epicenter of Detroit, rich in culture, education, medicine, business, entertainment, and historic neighborhoods.	10,899	51	60
District 6, Southwest	This district is one of Detroit's most diverse and culturally rich areas, home to many Latino, African American, and Middle Eastern communities and some of the city's oldest Black-owned businesses. Midtown has a developing millennial population and also contains Wayne State, the largest university in Detroit. It is heavily industrialized, and more than 150 facilities are regulated for air emissions by the U.S. Environmental Protection Agency in a 4-mile area. When the Gordie Howe International Bridge is completed, vehicle emissions will increase considerably in the district.	13,786	23	74
District 7, West	Community-centric neighborhoods and parks such as Rouge Park, one of the area's centerpieces, are found in this district. It is home to active community organizations, a variety of architectural styles, and a large population of Middle Eastern immigrants.	34,969	25	30

Key Climate Change Impacts by District

As identified in previous chapters, two primary climate change impacts on the Detroit region are extreme heat and increased precipitation. Both of these impacts have the potential to increase public health challenges and amplify hotspots of socioeconomic and racial inequality in Detroit. Here, we consider key climate change impacts at the district level. Extreme heat is examined in terms of the urban heat island effect, and increased precipitation is examined in terms of both runoff and poorly drained soil in each district.

Extreme Heat: Urban Heat Island Effect

Heat differs among urban neighborhoods due to local landscape features, which results in varied distribution of temperature and humidity throughout Detroit. Wide, asphalt roadways absorb heat and remain hot during the day and hotspots are created by residential stretches of low levels of tree canopy coverage. Cooler areas of the city are seen in shaded, residential neighborhoods where high levels of canopy coverage help moderate temperatures during heat waves (Fig. 22). Examining hotspots of urban heat islands can help determine the overall vulnerability of each city council district.



Figure 22.—Volunteer tree planters in a Detroit, MI, neighborhood, April 2021. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.

On August 8, 2020, local organizers and volunteers in Detroit collected over 130,000 temperature and humidity datapoints in the morning, afternoon, and evening to create a “heat watch” report for the area (CAPA Strategies 2020). A geographic information systems (GIS) web application allows users to explore the distribution of heat at different times of the day. The distribution of heat throughout the city varies among the morning, afternoon, and evening models. The hottest areas in the morning are throughout district 5 and district 6 and reaching district 3, while the west edges of districts 1 and 7 experience cooler temperatures. During this time district 2 and district 4 experience intermediate conditions. In the afternoon, the heat is distributed relatively evenly across the city, with some of the highest temperatures in district 2. There are few cool areas in the city at this time of day. In the evening, the hottest areas are on the west side of the city, in district 1, district 2, and district 7.

Cooling centers are designated annually by the city and may help alleviate heat exposure in areas of greatest vulnerability (Gregg et al. 2012). However, a 2019 study found that approximately half of Detroit households living below the poverty level or depending on public assistance income were not within walking distance of a cooling center (Sanchez and Reames 2019). In addition, most of these households were within the heat risk zone. This study revealed that more than half of the Detroit population living below the poverty level and more than half of the population living with public assistance are identified as urban heat island vulnerable.

A report on climate change vulnerability in Detroit included a heat assessment that combined exposure factors (areas with high percentages of impervious surfaces relative to pervious surfaces and low tree coverage) and sensitivity factors (number of people over the age of 65, the number of households without access to a vehicle, household income, and educational attainment) (Gregg et al. 2012). The assessment indicated that the greatest areas of vulnerability include the downtown core (district 5) and the adjacent neighborhoods northwest of the downtown.

Increased Precipitation: Runoff and Soil Drainage

Precipitation events paired with runoff and poor soil drainage can cause water pollution, threaten water resources, and result in severe flooding. During a heavy rain event, surface runoff can flow into the street and cause urban street flooding and property damage, which can threaten human health and well-being. Runoff can be exacerbated by poor soil drainage in yards and other green spaces. Examining areas of the city with the greatest exposure to runoff and poor soil drainage can point to districts that are most vulnerable in the face of a changing climate.

A flood assessment in the Detroit climate change vulnerability report examined the vulnerability of infrastructure systems and household-level vulnerability to flooding (Gregg et al. 2012) (Fig. 23). The analysis of infrastructure focused on exposure factors. The primary factor was the runoff burden (determined by land cover, soil type, and slope) that is created during intense storm events. The exposure factor at the household level is determined from floodplain designations (100- and 500-year events), and household sensitivity is determined by the age of housing stock and the median household income. System flood vulnerability, similar to the heat assessment, is concentrated around the downtown core, extending northward (district 5 and district 3). Household flood vulnerability is greatest in southeast Detroit and along the Rouge River in the northwest (Gregg et al. 2012). In terms of total exposure to runoff, district 1 and district 7 are the least vulnerable and districts 5 and 6 are the most vulnerable.

As discussed in Chapter 1, much of the soil throughout Detroit is poorly drained. In the spring and fall when the ground is already wet and less likely to be able to hold more water, Detroit is expected to receive more rainfall under many climate projections. The aging stormwater systems in Detroit could be overwhelmed by increased precipitation, resulting in flooded streets and basements, both of which can lead to sewage overflows in the Detroit River and Lake Erie.

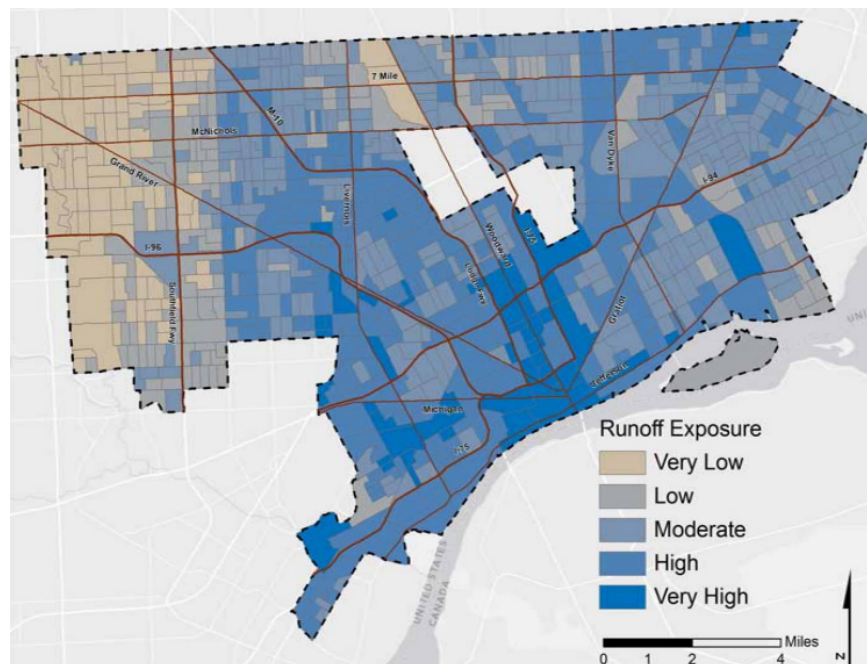


Figure 23.—Total runoff exposure by block group, Detroit, MI. Cartographer: University of Michigan Detroit Climate Capstone. Data sources: Michigan Geographic Data Library; Michigan Digital Elevation Model; U.S. Geological Survey GloVis LandSat 7 ETM+; U.S. Census 2010. From Gregg et al. (2012), used with permission.

Extreme weather events, such as the storm that caused flooding across the region in August 2014, are also projected to become more frequent. District 3, district 4, district 5, district 6, and district 7 have high percentages of land area with poor soil drainage, while district 1 has a moderate percentage of area with poor soil drainage and district 2 has a relatively low percentage of area with poor soil drainage. Flooding combined with runoff potential and poorly drained soil contribute to the overall climate vulnerability of each city council district.

Key Adaptive Capacity Factors by District

Although climate change impacts will affect all districts, there are several districts less equipped to handle change. Examining adaptive capacity factors can help determine the ability of a district to accommodate or cope with climate change impacts. Adaptive capacity is also related to how a district will be able to predict, prepare for, respond to, and recover from climate disturbances. Key adaptive capacity factors in the Detroit region include canopy cover, extent of vacant land and impervious surfaces, and poverty rates.

Canopy Cover

Urban tree canopy refers to the layer of stems, leaves, and branches that provide tree coverage of the ground (USDA Forest Service 2019). Tree canopy cover provides many benefits, from wildlife habitat to reduced air pollution. Given projections of extreme heat and increased precipitation, tree canopy is expected to play an important role in the adaptive capacity and resilience of communities.

Districts with lower canopy coverage may experience warmer temperatures and an increase in stormwater runoff, as there are fewer trees to help mitigate the urban heat island effect and intercept rainfall. The average canopy coverage in Detroit is 25.1 percent. Canopy coverage varies by district; the highest canopy coverage is in district 1 (38 percent), followed by district 2, district 4, and district 7 at nearly 27 percent. The lowest canopy coverage is found in district 3 (23 percent), district 5 (20 percent), and district 6 (16 percent) (Fig. 24).

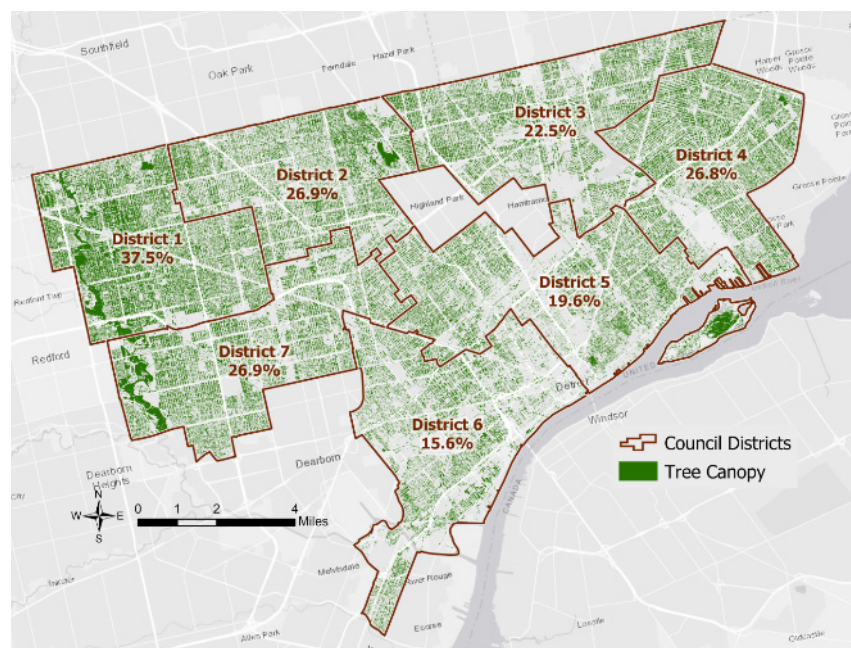


Figure 24.—Tree canopy coverage in Detroit, MI, by city council district. Darker shades of green indicate higher percentages of surface with canopy cover. Credit: American Forests.

Vacant Land and Impervious Surfaces

Land and climate interact in intricate ways and play a role in how communities will experience key climate effects such as extreme heat and increased precipitation. Most vacant land in Detroit is residential. Vacant land can be considered an asset in the city, but it can also contribute to the urban heat island effect and current lack of green space and canopy cover. Impervious surfaces, such as roads, driveways, sidewalks, and parking lots, cannot absorb or infiltrate rainfall; as a result, these surfaces can contribute to both increased street flooding and the urban heat island effect. Understanding the extent of vacant land and impervious surfaces can help us anticipate the potential effects of the key climate change impacts on each district.

Each district has a notable amount of vacant residential land, and different amounts of vacant commercial land or vacant industrial land. District 3 has the highest number of acres of vacant land, followed by district 4, district 5, district 6, district 7, district 1, and district 2 (Fig. 25). The Detroit Residential Parcel Survey (DRPS) from Data Driven Detroit (2010) found that all seven districts ranked “Vacant Land Not Cared For” (“vacant” indicating parcels with no structure present) in their top 10 issues. Uncared-for vacant land is a prominent issue in most districts, with the exception of areas in district 2, the Grandmont Rosedale neighborhood, and the eastside neighborhoods bordering the Pointes. The availability of vacant land presents an adaptive capacity opportunity for expansion and scaling-up of green infrastructure, which could reduce the stormwater runoff and flooding that lead to combined sewage overflows into rivers.

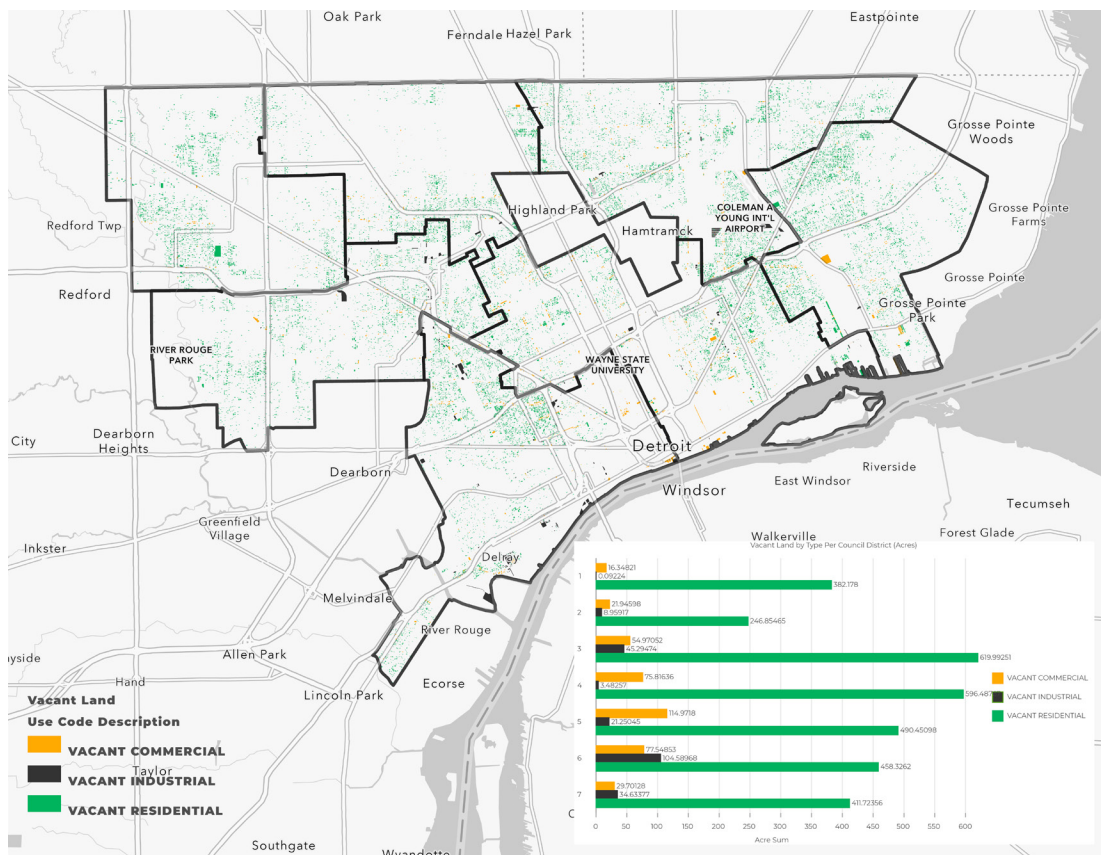


Figure 25.—Vacant commercial, industrial, and residential land in Detroit, MI. Black outlines show the boundaries of the seven city council districts. Figure prepared by Thomas Veldman, GIS analyst, Detroit Department of Innovation and Technology.

A high percentage of land in Detroit is impervious surfaces, and this percentage varies little among city council districts. District 6 has the highest percentage (51 percent) and district 1 (40 percent) has the lowest (Fig. 26). It is important to note that this calculation does not include roads, which would increase the percentage in each district. The extent of vacant land and impervious surfaces suggests that Detroit may experience extreme urban heat islands and street flooding due to runoff and lack of infiltration.

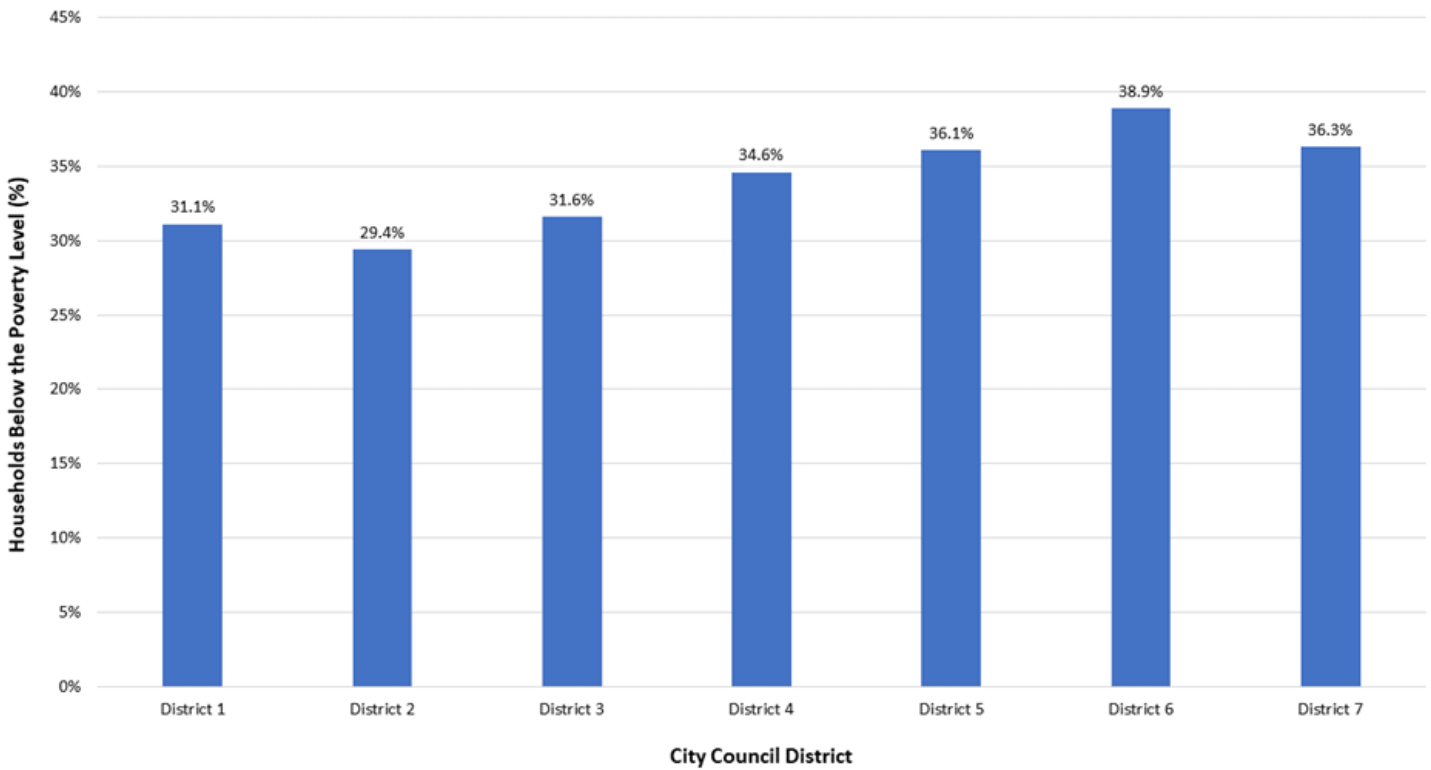


Figure 26.—Percentage of land area with impervious cover in Detroit, MI, by city council district. Data obtained from the city of Detroit.

Poverty

Detroit has experienced a sharp population loss and economic decline since the 1950s and filed for bankruptcy in 2013. Depopulation and disinvestment paired with vacant buildings and climate impacts have required Detroit leaders to think about how to allocate scarce municipal resources to meet the needs of residents. The burden of key climate change impacts such as extreme heat and increased precipitation typically falls harder on areas with low-income populations and Detroit has one of the highest populations of low-income residents in the Nation. The poverty rate in Detroit is 30.6 percent, more than twice that of Michigan as a whole (13 percent) and nearly three times the U.S. average (10.5 percent) (U.S. Census Bureau 2019b). Households below the poverty level by district range from 29 to 39 percent (Fig. 27).

Though the poverty rate is high throughout Detroit, certain areas within districts may have more-concentrated wealth. For example, in a study examining the cooling benefits of green roofs in Detroit, green roofs were found in the affluent, predominantly white part of the urban core (Sanchez and Reames 2019). The study also found that the city's current green space plans fail to adequately address heat-vulnerable communities. Insufficient planning combined with the anticipated key climate change impacts may exacerbate the city's poverty issues. As residential cooling expenses increase, households may be unable to afford their energy bills and experience shutoffs, further exposing residents to extreme heat. Increased peak energy demand from urban heat islands may also overload energy systems, which can lead to utility blackouts (U.S. EPA 2022).

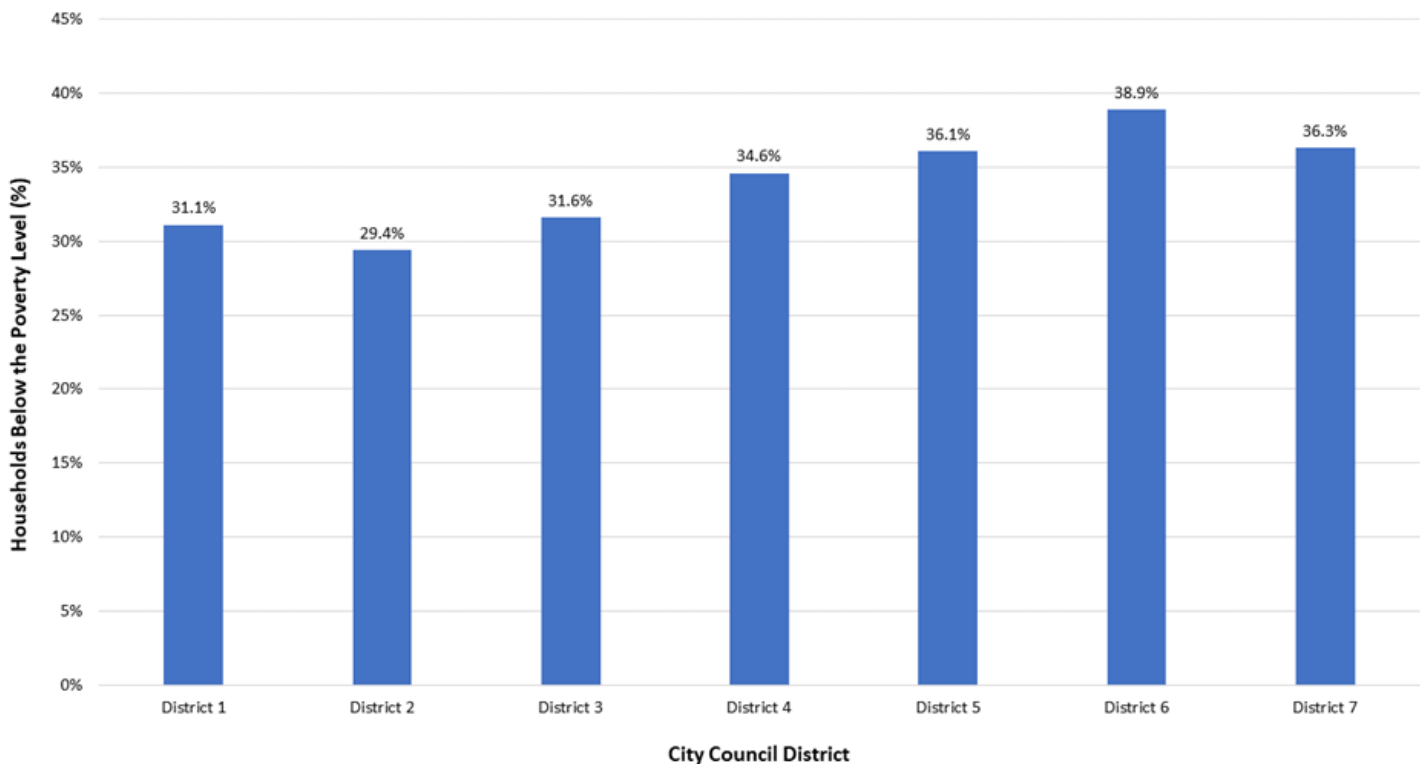


Figure 27.—Percentage of households below the poverty level in Detroit, MI, by city council district. Data obtained from the city of Detroit.

Tree Species Vulnerability

We determined the number of vulnerable trees for each city council district using the tree species vulnerability assessment in Chapter 4 (Fig. 28). Under a low climate change scenario, there are few trees at the moderate-high or high vulnerability level in the seven districts and the majority fall into the low-moderate category. Although district 5 has one of the lower tree canopy cover percentages, it also has the most trees in the low-moderate and moderate vulnerability categories. Under a high climate change scenario, vulnerability shifts to a higher level, with many trees in the moderate to moderate-high category. District 1 is home to the highest number of trees in the moderate-high vulnerability category, followed by district 4 and district 5. District 5 continues to have the most trees in the low-moderate and moderate vulnerability category under a high climate change scenario.

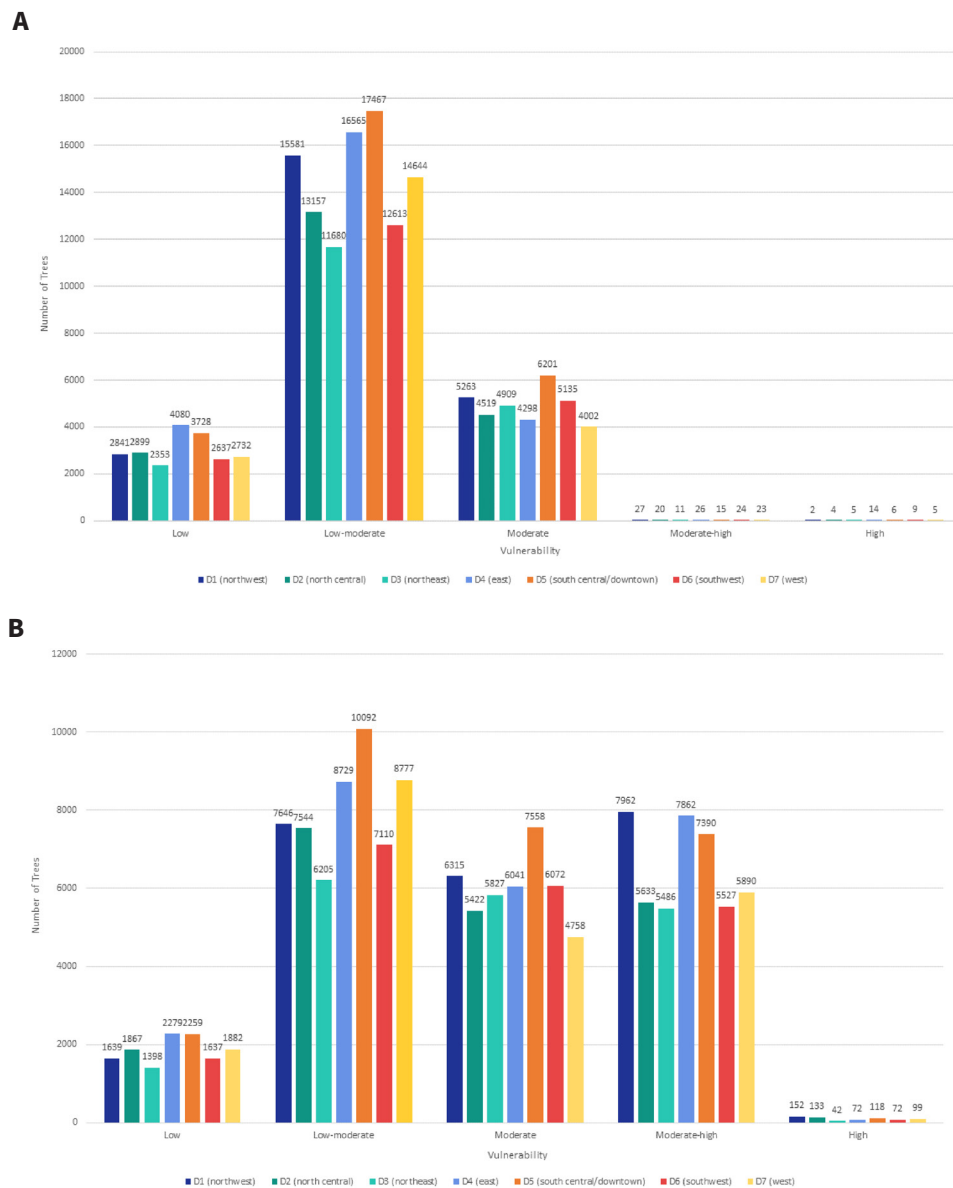


Figure 28.—Number of trees by Detroit, MI, city council district and vulnerability (low, low-moderate, moderate, moderate-high, high) under (A) low and (B) high climate change scenarios.

Vulnerability by District

To assess the overall vulnerability of each city council district, we summarized key climate change impacts and adaptive capacity factors (Table 13). A category was assigned to each factor (low, low-moderate, moderate, moderate-high, or high) based on the district-level information and a score (low: 1, low-moderate: 2, moderate: 3, moderate-high: 4, and high: 5) was assigned to each category. Each district was given a total score by adding up each factor and an overall vulnerability level was determined for each district.

Key climate change impacts resulting from increased heat and precipitation include the urban heat island effect, surface runoff, and soil drainage. Adaptive capacity factors help determine how an individual district will adjust to climate change and potential damage. Key factors include the amount of canopy cover, vacant land, and impervious surfaces, and the poverty rate. Districts with high canopy coverage will better protect the ground from extreme precipitation, preventing additional runoff, and will also provide a cooling effect by reducing the overall urban heat island. Conversely, districts with a large amount of vacant land and impervious surfaces may experience a greater urban heat island effect due to surface heating and may also experience more runoff due to the lack of infiltration. Climate change and poverty are deeply intertwined; districts with higher poverty rates have an increased chance of experiencing the negative effects of climate change due to fewer resources, weaker infrastructure, and increased exposure to key climate change impacts.

By examining key climate change impacts and adaptive capacity factors, we can provide a qualitative assessment of the vulnerability of each district. Based on this analysis, most districts in Detroit are in the moderate-high and high vulnerability categories (Table 13). District 5, containing the epicenter of Detroit, and district 6, one of the most diverse areas in Detroit, are both classified in the high vulnerability category. District 5 and district 6 have notable heat islands present, less canopy cover, and a high percentage of households below the poverty level. They also have higher exposure to runoff, as they are situated along the Detroit River. However, climate change vulnerability is complex and there are additional factors to consider in planning and adaptation efforts. For example, the social and physical traits of greater downtown Detroit may make it more resilient to climate change, and while some of the most vulnerable neighborhoods are concentrated in southwest Detroit, this area is also ideal for building green infrastructure (Molnar 2015).

Table 13.—Summary of key impacts (urban heat island, runoff, and poorly drained soil), adaptive capacity factors (canopy cover, vacant land and impervious surfaces, and poverty rate), and the overall vulnerability of Detroit city council districts (see Table 12 for location and description of each district)

District	Urban heat island	Runoff	Poorly drained soil	Canopy cover	Vacant land and impervious surfaces	Poverty rate	Total score	Overall vulnerability
1	low-moderate	low	moderate	high	moderate-high	high	20	moderate
2	moderate	moderate	low	moderate	low-moderate	high	17	moderate
3	moderate	moderate	high	moderate	high	high	24	moderate-high
4	moderate	moderate	high	moderate	high	high	24	moderate-high
5	high	high	high	low	moderate-high	high	25	high
6	high	high	high	low	moderate-high	high	25	high
7	moderate	low-moderate	high	moderate	moderate-high	high	22	moderate-high

Vulnerability Synthesis of the Detroit Region Urban Forest

In this section we build on the previous chapters and the district-level analysis to describe the vulnerability of the urban forest as a whole. The following summary includes the potential impacts of climate change on the Detroit region urban forest over the next century based on the current scientific consensus of published literature, which is described in more detail in the preceding chapters.

After each statement is a confidence statement, phrased according to IPCC guidance (Mastrandrea et al. 2010). Confidence was determined by gauging both the level of evidence and level of agreement among information. Evidence was considered robust when multiple observations or models were available and there was an established theoretical understanding to support a statement. “Agreement” referred to the agreement among the multiple lines of evidence. Agreement was rated as high if theories, observations, and models tended to suggest similar outcomes. Agreement does not refer to the level of agreement among the authors of this assessment.

Climate Change Vulnerability Synthesis: Detroit Region Urban Forest

- Temperatures in Detroit are projected to increase over the next century (robust evidence, high agreement, Chapter 2). Detroit has been warming at a rate of about 0.4 °F per decade since 1960 and the last two decades have been the warmest on record for Detroit. From 1959 to 2011, average overnight temperatures increased by 4.3 °F, the number of hot, humid summer days increased by 3.5 (172 percent), the number of hot, dry summer days increased by 3 (338 percent), and the number of cool, dry days decreased by 10.5 (70 percent). Temperatures in Detroit are projected to increase by 5 to 13 °F by the end of this century compared to the average for 1980 through 2009.
- Precipitation in Detroit is projected to increase over the next century, varying by season (robust evidence, medium agreement, Chapter 2). Precipitation in Detroit has been increasing by about 1 inch per decade since 1960. Comparing the average for 1961 through 1990 to the average for 1981 through 2010, the total annual precipitation in southeast Michigan increased by 11 percent. In the SEMCOG region, precipitation has increased in each season from 1960 through 2019. The increasing trend is the greatest in March to May (+0.42 inch per decade) and September to November (+0.43 inch per decade), and the least in June to August (+0.15 inch per decade). Average annual precipitation is expected to increase by 16 percent on average, equivalent to about 5 inches. Although the projected increase varies by season and climate scenario, spring precipitation is projected to increase in each scenario. Higher summer temperatures may also reduce late season moisture availability.
- Extreme heat is expected to increase, with decreases in extreme cold (robust evidence, medium agreement, Chapter 2). By the end of the century, Detroit could potentially no longer have any days below zero in an average year, compared to the current average of 4.3 days. By the end of the century, Detroit could experience up to 3 months of days above 90 °F, compared to a current average of just over 1 week.
- Heavy precipitation events causing inland flooding are expected to increase in frequency and intensity (medium evidence, high agreement, Chapter 2). Heavy rain events (1 inch or greater per day) are projected to become more frequent on average through the end of the century. Heavy rain events (2 inches or greater per day) are also projected to increase on average through the end of the century. Increased flooding can cause stress in trees, resulting in defoliation, leaf yellowing, crown dieback, and potential mortality.
- Climate shifts may impact soils and hydrology in the region (medium evidence, medium agreement, Chapter 2). Detroit is expected to experience more soil erosion and nutrient runoff from heavy rain events. A combination of increased precipitation and soil moisture can lead to loss of soil carbon and surface water quality, and waterlogged soils could lead to a reduction in planting season work days. Reduced snowpack will make soils more susceptible to freezing, which has the ability to kill thin roots, decrease plant productivity, and alter nutrient and water cycling.
- Hardiness zones and heat zones are projected to shift by the end of the century (robust evidence, high agreement, Chapter 2). As winter temperatures increase, hardiness zones will shift, influencing which tree and other plant species are suitable for planting in a

particular location. In the SEMCOG region, the hardiness zone is projected to shift from zone 6 (-23.3 to -17.8 °F) to zone 7 (-17.7 to -12.2 °F) by mid-century. By the end of the century, the hardiness zone is projected to shift to zone 8 (-12.1 to -6.7 °F). Regions are also projected to see notable increases in the number of hot days per year, resulting in shifting heat zones. In the SEMCOG region, the heat zone is projected to shift from zones 4 and 5 (more than 14 up to 30 days, and more than 30 up to 45 days, respectively, exceeding 86 °F) to zone 7 (more than 61 up to 90 days exceeding 86 °F) by mid-century, and to zone 9 (more than 21 up to 150 days exceeding 86 °F) by the end of the century.

- Nonnative invasive plants may shift their range in the face of a changing climate (medium evidence, medium agreement, Chapter 3). Under a range of future models in the SEMCOG region, Japanese chaff flower is projected to expand, European buckthorn is projected to retract in most counties, and garlic mustard, multiflora rose, common burdock, tree of heaven, Japanese knotweed, purple loosestrife, spotted knapweed, and wild parsnip are projected to remain stable across the region.
- The range and abundance of pests and pathogens may increase due to more suitable climate conditions and increased climate stressors on trees (medium evidence, medium agreement, Chapter 3). The European oak borer attacks weakened or recently dead oaks, which increases the risk for trees under stress. Milder winters may be more beneficial for the emerald ash borer, a well-established pest in Detroit. Asian longhorned beetle, although not currently in Michigan, may be well adapted to warming temperatures and poses an infestation threat to the region. Under four climate models and under an intermediate climate change scenario, the climate suitability of oak wilt remains relatively high in the Detroit region through this century.
- Species vulnerability depends on the degree of projected temperature increases (medium evidence, medium agreement, Chapter 4). Under a low climate change scenario, most tree species are considered to have a low to moderate vulnerability (94 percent), while just 6 percent have a moderate-high or high vulnerability. Under a high climate change scenario, most are considered to have a low to moderate vulnerability (55 percent), while 45 percent are considered to have a moderate to high vulnerability.
- Native species habitat suitability will shift (medium evidence, high agreement, Chapter 4). Species distribution modeling for trees suggests that suitable habitat will decrease for 19 species, increase for 8 species, and remain stable for 8 species; 16 species may be able to colonize new, suitable habitats.
- A changing climate has the potential to worsen existing health issues and create new issues (medium evidence, high agreement, Chapter 5). Health issues include heat-related illnesses and mortality, flooding and extreme weather events, increases in food prices, mental and physical well-being, social human impacts, and the presence and intensity of allergens, biogenic VOCs (volatile organic compounds), and pests and pathogens.

Adaptive Capacity Factors of the Detroit Region

Summarized next are factors that could affect the adaptive capacity of the Detroit region, influencing overall vulnerability to climate change.

- Key impacts on city council districts in Detroit include urban heat islands, runoff, and poorly drained soil (medium evidence, medium agreement, Chapter 6). Key climate change impacts contribute to the overall vulnerability of each city council district. District 5 and District 6 are the districts most impacted by high urban heat island effects, high runoff, and high percentages of poorly drained soil.
- Adaptive capacity of tree species in planted and natural environments in Detroit varies (medium evidence, medium agreement, Chapter 4). For planted or developed conditions, 27 percent of species received a high adaptability score, 16 percent received a low adaptability score, and the remaining 57 percent received a medium adaptability score. For natural areas (both native and naturalized), 45 percent of species received a high adaptability score, 9 percent received a low adaptability score, and 46 percent received a medium adaptability score.
- Detroit has a high species richness, but a high abundance of maples (medium evidence, high agreement, Chapter 4). The temperate climate in Detroit supports a wide range of species, as reflected in the tree inventory, which includes over 144 species and 75 genera. However, maple species account for 43 percent of street trees, and this concentration in one genus could reduce the ability of the tree canopy to adapt if a pest or pathogen targeting maples becomes prevalent.
- Adaptive capacity factors vary by city council district in Detroit (medium evidence, medium agreement, Chapter 6). Key adaptive capacity factors include amount of canopy cover, vacant land, and impervious surfaces, and the poverty rate. Districts with high vulnerability are district 5 and district 6. Districts with moderate-high vulnerability are district 3, district 4, and district 7. District 1 and district 2 are considered to have moderate vulnerability.
- A variety of private, nonprofit, academic, and governmental organizations in the Detroit region and beyond have an opportunity to build climate resilience (robust evidence, high agreement, Chapter 1). Many organizations are already taking action and creating additional partnerships to navigate efforts toward planning, resource allocation, management, and strategy implementation that will be crucial in the face of a changing climate (Fig. 29).



Figure 29.—Example of community and volunteer groups that bring refreshments in appreciation for a welcomed tree planting event organized by The Greening of Detroit at Brightmoor Community Playground in the Brightmoor neighborhood, Detroit, MI, November 2020. Courtesy photo by Fai Foen, used with permission.

Summary

Understanding the key climate change impacts and adaptive capacity factors in each of the seven districts in Detroit is important for adaptation efforts and resources. Extreme heat and increased precipitation are the top climate impacts threatening the residents and urban trees in Detroit. Public health challenges paired with deep inequality in the city are a primary concern and can help guide climate strategies at the district and neighborhood level.

Key Points

- Understanding district-level vulnerabilities can help guide resource allocation and climate adaptation strategies, and attention to the relationship between public health and inequality is critical in the planning and implementation process.
- Tree species diversity is largely comparable across Detroit, contributing to similar patterns of urban tree vulnerability across districts. All districts have a projected pattern of species vulnerability across low and high climate change scenarios.
- The most vulnerable neighborhoods are located in southwest Detroit. Vacant lots and impervious surfaces are an issue throughout the city. District 5 and district 6 have notable heat islands present, high poverty rates, and greater exposure to runoff. The higher runoff exposure reflects the location of these districts along the Detroit River.
- The Detroit region urban forest as a whole is vulnerable to temperature increases, more frequent and intense heavy rain events, and shifts in composition for native and nonnative invasive species, but the region has the capacity to adapt through its robust community urban forestry efforts.

CHAPTER 7: MANAGEMENT IMPLICATIONS

A changing climate presents both challenges and opportunities for urban forest management. Increases in temperature, drought, and extreme precipitation events can affect tree species planting lists and current management of existing trees—both native and nonnative species—as well as alter public outreach and engagement efforts. This chapter provides an overview of climate change impacts on management decisions and practices related to urban and community forestry in the Detroit 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 decision-making process to adapt their land management to projected impacts. Another report, “Climate Adaptation Actions for Urban Forests and Human Health” (Janowiak et al. 2021), provides information for optimizing the climate and health outcomes of urban forestry projects. It provides professionals working at the intersection of climate, public health, and urban forestry with resources to support climate adaptation planning and actions. Management considerations in this chapter are summarized by theme and include a range of issues that urban foresters face. The description for each theme is intended to provide a jumping-off point for thinking about the management implications of climate change in an urban setting and is not intended to be comprehensive. Additional resources are provided for each theme.

Street Trees

As temperature increases associated with climate change exacerbate urban heat island effects, street trees will take on increased importance to the communities that live within these areas. Selecting trees that withstand climate-related stressors such as drought, extreme precipitation, and pest and disease outbreaks is likely to become an even more important part of decision making for urban foresters. Areas that lack diversity in species or age classes can be more vulnerable to climate change impacts and can increase the vulnerability of residents living within these areas to heat-related illness and other negative health outcomes.

Street tree managers often have goals that include diversifying species planted, increasing and maintaining canopy cover, supporting urban forest health through best practices, and providing up-to-date decision-making information to the public. These goals can be met by promoting tree planting and maintenance along the public right-of-way, developing a proactive inspection and maintenance program, and regularly updating tree planting lists and public engagement materials (Fig. 30). Tree planting lists may be based on the available nursery stock (see Nursery Industry section). Updating lists using projections of future conditions may help reduce risks if sufficient nursery stock can be acquired. There will always be some uncertainty concerning which species to recommend for planting in a given location. However, there will be an opportunity to introduce new species that are more heat- and drought-tolerant and create materials to engage residents in planting recommended tree species on their property.

More Information

- The Greening of Detroit has an interactive tree map providing an inventory of trees in the community and the associated ecological and economic benefits that they provide: <https://www.opentreemap.org/thegreeningofdetroitstreemap/map/>.
- The Greening of Detroit also offers a recommended tree list that includes tolerance of species to drought and flooding: <https://www.greeningofdetroit.com/caring-for-trees>.



Figure 30.—Daffodils in Farwell Field, Detroit, MI, April 2021. The city of Detroit planted more than 1 million daffodils between 2018 and 2020 and continues to add more (City of Detroit 2023). Courtesy photo by The Greening of Detroit, used with permission.

Wildlife

The urban trees, parks, and vacant lands in Detroit provide habitat to a wide variety of wildlife species. However, climate change poses substantial risks. Changes in species diversity and ecosystem function are expected with warmer, wetter, and more extreme climate conditions. Increased runoff, decreased ice cover, and warmer lakes, tributaries, and terrestrial ecosystems can cause stress to existing wetlands, invite threats from invasive species, shift the range and distribution of various bird and fish species, and potentially displace or eliminate native species (Pryor et al. 2014). In addition, transitions from extreme drought to floods can increase nitrogen levels in waterways, potentially leading to harmful algal blooms and negative impacts on humans, fish species, and bird species.

Shifts in the phenological patterns of trees and the spread of nonnative invasive species may reduce the capacity of Detroit trees and urban forests to provide wildlife habitat. Changing climate trends will decrease habitat for some species of wildlife and increase habitat for others. The phenological patterns of trees, such as spring leaf-out, flowering, fruiting, and leaf drop, are expected to be affected by climate change (Lipton et al. 2018). Many animals use environmental cues for migration, hibernation, or reproduction. The degree to which different species will be affected by shifts in resource availability will vary based on their level of specialization as well as life history traits. However, there is an emerging trend: The rate of phenological change varies between trophic levels, causing resource mismatches and altered species interactions. Migratory species are more vulnerable to phenological mismatch if their primary food sources are unavailable when they migrate to their feeding grounds and if they are unable to shift to other sources (Lipton et al. 2018).

Loss of native tree species could also have implications for the wildlife that rely on them. Trees play an essential role in the food web of urban forests, as they provide habitat value for a range of wildlife, especially insect and bird species. Insect herbivores, such as Lepidoptera (moth and

butterfly) larvae, play a critical role in terrestrial food webs. A reduction in their biomass or diversity due to loss of host plants can reduce the production of insectivores at higher trophic levels (Tallamy and Shropshire 2009). In a study examining the relationship between native plant landscaping and bird and caterpillar communities, properties with native species supported a significantly greater population of caterpillars and caterpillar species, along with significantly greater bird weight, diversity, abundance, species richness, and breeding pairs (Burghardt et al. 2009). An understanding of the insects that plant species attract and their role in wildlife food webs can help inform selection of species for planting.

More Information

- The Detroit River International Wildlife Refuge, containing 6,000 acres and located 20 miles south of Detroit, aims to protect the fish and wildlife habitat of the Detroit River, support international efforts to conserve native aquatic and terrestrial communities, and facilitate partnerships among stakeholders: https://www.fws.gov/refuge/detroit_river.
- The Detroit Zoological Society works to conserve wildlife locally, nationally, and internationally by caring for and rescuing animals, conducting field research and conservation projects, responding to environmental emergencies, and supporting other conservation organizations: <https://detroitzoo.org/animals/wildlife-conservation>.
- The National Audubon Society has developed interactive visualizers to view the projected impacts of climate change on bird populations across the Nation: <https://www.audubon.org/climate/survivalbydegrees>.
- The National Phenology Network provides resources for analyzing phenological change and for participating in monitoring activities: <https://www.usanpn.org>.
- The National Wildlife Federation provides a Native Plant Finder that ranks native plants in a given area based on the number of moth and butterfly species that use them as host plants: <https://www.nwf.org/NativePlantFinder/Plants/Trees-and-Shrubs>.

Municipal Parks

Municipal parks, found in developed as well as more natural areas, provide active and passive recreational opportunities while simultaneously reducing the urban heat island effect. Like street trees, park trees are affected by increasing temperatures and altered precipitation events, but may be buffered by lower temperatures and greater soil volumes than experienced by street trees. Increases in heat may attract more visitors who want to utilize the shade and water features of municipal parks. Projected increases in extreme precipitation events could result in flooding of parks, leading to a reduction in park use or availability. As park use shifts in response to a changing climate, planting and stormwater management decisions may shift as well.

More Information

- Detroit Parks and Recreation provides news, events, recreation tips, and information about local parks: <https://detroitmi.gov/departments/parks-recreation>.
- The City of Detroit Park Finder is an interactive tool to find the nearest city recreation center, partner recreation center, or after-school center: <https://data.detroitmi.gov/apps/park-finder>.

- “How Cities Use Parks for Climate Change Management” discusses the benefits that city parks provide, such as storing carbon and reducing the urban heat island effect: <https://www.planning.org/publications/document/9148693>.

Biodiversity

One of the primary management challenges for urban foresters will be maintaining and increasing diversity of native and cultivated tree species. As the climate warms, the composition of forests changes. Areas of suitable habitat conditions for many tree species are moving northward. As suitable habitat in an area declines for some species, new species adapted to a warmer future climate may expand their ranges or can be introduced. The introduction of new species, often called “assisted migration,” can create new risks, however. These species may suffer mortality if a cold snap occurs or if they are unable to adapt to local soils or moisture regimes. If they do survive, they could outcompete native species, alter wildlife and pollinator habitat, or potentially introduce novel pests or diseases. An increasingly accepted approach is “assisted range expansion,” or “the human-assisted movement of species to areas just outside of their natural established range in response to climate change, facilitating or mimicking natural range expansion” (Dumroese et al. 2015).

Regeneration techniques that promote genetic diversity of native trees may also need to be expanded, especially in natural areas. Compared to cultivated areas, there is more genetic variation in natural areas and larger remnant forests such as Belle Isle, which can lead to more adaptive capacity and reduced vulnerability overall. There are also the challenges of promoting a diverse age structure if it becomes harder to establish young trees or if mortality of older trees increases. Finally, the spread of nonnative invasive species in a changing climate could lead to losses of native species, altering existing ecological communities and the composition of the tree canopy in Detroit. How climate change impacts the future diversity and vitality of trees in Detroit still depends, in part, on land-use and tree planting decisions that residents, businesses, and city government make today.

Caution should be exercised when substituting potentially invasive trees for native trees that are highly susceptible to pests, as some genotypes of native trees can become invasive. Monitoring invasive species is expensive and the list of invasive species is constantly changing. In a survey of natural resource managers across the country, most were concerned about how climate change will affect invasive species management, but they reported that a lack of funding, personnel, and information limits their ability to manage invasive species and incorporate climate change in their decision making (Beaury et al. 2020b). Managers also noted that they prioritize research pointing to range-shifting invasive species and native communities that are more resilient to both invasions and climate change. To gather up-to-date information about invasive species in the region, check with local arboretums, botanical gardens, or natural area programs, or use online resources such as the Invasive Plant Atlas of the United States or the EDDMapS tool.

More Information

- The Michigan Department of Natural Resources provides information about Michigan plants and trees including identification, uses, and wildlife: https://www.michigan.gov/dnr/0,4570,7-350-79135_79218_79615---,00.html.
- Michigan Flora provides an online database containing information about all vascular plants known in the state, outside of cultivation: <https://lsa-miflora-p.lsa.umich.edu>.

- The Invasive Plant Atlas compiles lists of invasive plant species for agencies and organizations across the country: <https://www.invasiveplantatlas.org/index.cfm>.
- EDDMaps (Early Detection and Distribution Mapping System) is a web-based mapping system for documenting invasive species and pest distribution across the United States: <https://www.eddmaps.org>.

Private Properties

Larger private properties such as cemeteries, college and corporate campuses, and commercial and industrial holdings will also be subject to the stressors of a changing climate. Changes in habitat suitability will influence which trees and other plants can be grown in these places. Green infrastructure incorporated into these locations, such as green roofs or rain gardens, may also need to be adapted to changing temperature and precipitation regimes. For example, rain gardens could be designed to absorb more precipitation and green roofs could be designed to withstand higher temperatures than they had in the past. Development pressures can also decrease the amount of urban green space and put an increased demand on existing trees and spaces to provide essential ecosystem services.

Homeowners and renters often lack the expert knowledge, skills, and resources to manage trees on their property in relation to a changing climate. With increasing temperatures, trees will provide more value to residential properties by supplying cooling and shade, therefore reducing energy costs. Educating members of the public will be important to ensure that they are providing adequate care for their existing tree canopy, are planting species expected to survive in the projected climate, and are adequately managing invasive species, pests, and pathogens. Training and assistance can help support homeowners and renters in tree species selection and tree care and maintenance efforts. Additional support may be needed for residents who lack the time or financial resources to care for trees. Community engagement processes that identify these barriers so that efforts can be tailored to community needs are likely to take on even more importance.

More Information

- The city of Detroit provides guidelines for how to determine whether a tree is on city or private property, and how to manage tree removal: <https://detroitmi.gov/departments/general-services-department/tree-services>.
- “The Climate-Friendly Gardener: a Guide to Combating Global Warming from the Ground Up” gives practical tips for cultivating a climate-friendly garden to help reduce climate change impacts: <https://www.ucsusa.org/resources/climate-friendly-gardener>.
- The Detroit Biodiversity Network (DBN) engages students in hands-on projects to support sustainable, urban ecosystems on the Wayne State University campus and in surrounding communities: <https://www.detroitbiodiversitynetwork.com>.

Nursery Industry

With projected changes in habitat suitability and shifts in hardiness zones and heat zones, land managers and homeowners may want to select species expected to be less vulnerable to these changes. However, species selection will be largely dependent on nursery stock available. Small, local nurseries often rely on large, wholesale nurseries for their supply. Wholesalers can be located in different regions of the country and may not be familiar with local needs. Economic incentives

for nursery growers such as contract growing can encourage the production of new species or cultivars. Challenges arise, however, because of uncertainty among climate model projections and because of the financial risks tied to expanding the diversity of species offered for changing conditions. For example, it may be difficult to anticipate when and where new markets may develop. As a result, nursery growers may choose to develop cultivars adapted to a wide range of climate conditions rather than specific habitat niches.

More Information

- Walter Meyers Nursery is a 72-acre parcel of land in the largest park in Detroit, Rouge Park, managed by The Greening of Detroit: <https://www.greeningofdetroit.com/meyers-tree-nursery>.
- The Native Plant Nursery LLC provides a database of plants native to Michigan, including information about light, moisture, height, and blooming season: <http://nativeplant.com/plants/search/input>.
- Organizations such as the Wildflower Association of Michigan and Wild Ones maintain current lists of native plant nurseries: <https://wildflowersmich.org> and <https://wildones.org/chapters/chapters-in-michigan>.

Landscaping Features and Green Infrastructure

Green infrastructure can range from site design approaches (e.g., rain gardens and green roofs) to regional planning approaches (e.g., land conservation and urban tree canopy) (U.S. Environmental Protection Agency 2019). In the face of a changing climate, green infrastructure becomes more important while also requiring new approaches to adapt, such as berms, mulching, bioswales, and refugia. By reducing the rate of surface runoff, berms can help with erosion control and sedimentation. Mulching techniques can help retain soil moisture, contribute to soil health, and protect against temperature changes. Bioswales can assist with improving water quality, reducing flood potential, and moving stormwater away from critical infrastructure. Recognizing which features to use and where to employ them will be an ongoing land management component for urban foresters.

More Information

- The Greening of Detroit has a green infrastructure program, focused on developing green and productive landscapes in the region through community forestry, the Walter Meyers nursery, stormwater management, and special services: <https://www.greeningofdetroit.com/services-1>.
- The Detroit Water and Sewerage Department has developed and implemented a variety of green stormwater infrastructure projects in the Detroit region in municipal parks and properties, roadways and parking lots, and greening vacant properties: <https://detroitmi.gov/departments/water-and-sewerage-department/dwsd-projects/green-infrastructure-projects>.
- The Detroit Stormwater Hub is a tool for understanding and tracking the progress and impact of green stormwater infrastructure in the region: <https://detroitstormwater.org>.

Equity and Environmental Justice

Climate change is a social, scientific, economic, political, historical, and equity issue. Climate adaptation practices can offer opportunities to improve quality of life, and intentional efforts are needed to ensure that there is equitable distribution of benefits among communities. Low-income residents and communities of color are expected to be more adversely affected by climate change than other populations because they are often living in areas with less canopy coverage and older infrastructure that is more vulnerable to failure. For example, in Detroit, heat-related illness and mortality are associated with community-level socioeconomic status and demographics such as income and educational attainment. Inequitable access to green space can lead to health disparities, and lingering inequities will only be exacerbated by a changing climate (Jennings et al. 2017, Mate and Wyatt 2017). Health equity can be promoted through affordable housing, food security, job creation, youth engagement, neighborhood walkability, and overall community revitalization (Jennings et al. 2017).

When individuals or groups are thinking about actions to increase canopy cover or incorporate green infrastructure, consideration of historical issues of racial segregation and environmental effects on disparate populations can help these efforts be more effective in the long run. Equity is becoming increasingly recognized in urban forestry, as there are often disparities in the distribution of tree canopy and green infrastructure (Greene et al. 2018). Research has demonstrated that historical experience has led to a level of tension, uncertainty, and lack of trust among some residents (Carmichael and McDonough 2018), resulting in barriers to policies meant to create equity. These conditions indicate that there is a need to provide relevant information to partners and residents participating in the long-term stewardship of trees, and to include residents in the decision-making process to identify and attain shared goals.

Low-income communities of color are the population most vulnerable to the urban heat effect in Detroit. A 2019 study examining green roof equity as an urban heat island mitigation strategy found that green roofs are present in the affluent part of the Detroit urban core, where the majority of residents are white (Sanchez and Reames 2019). Though green infrastructure such as green roofs can help reduce the urban heat island effect, the benefits are not experienced equally among residents. Mapping to ensure that green roofs and tree cover are placed in the most heat-vulnerable neighborhoods in Detroit may help alleviate extreme heat. Policies and actions can be designed to increase urban forest access to all community members, and provide adequate support and inclusivity.

More Information

- Detroiters Working for Environmental Justice is a nonprofit organization working on environmental justice matters in the Detroit region through advocacy, green jobs, and community action: <https://detroitenvironmentaljustice.org>.
- The Detroit Equity Action Lab is a hub for media, research, and programming focused on dismantling structural racism in Detroit: <https://sites.google.com/view/detroitequity/home>.
- The Michigan Environmental Justice Coalition is a statewide network aimed at achieving a clean, safe, and healthy environment for all through community education and climate and energy justice: <https://www.michiganej.org>.

- The Michigan Environmental Council is a nonprofit coalition of nearly 70 organizations that works to drive the environmental agenda, linking their work to environmental justice in each issue that they focus on: https://www.environmentalcouncil.org/environmental_justice.
- “Community-driven Climate Resilience Planning: a Framework” is a resource developed by community-based organizations that outlines a structure for engaging vulnerable communities in both defining and building climate resilience: <https://www.adaptationclearinghouse.org/resources/community-driven-climate-resilience-planning-a-framework.html>.

Planning and Partnerships

Climate change will remain an important component of planning as new challenges are created by droughts, flooding, extreme temperatures, wildfires, pests, pathogens, nonnative invasive species, runoff, soil erosion, tree mortality, and shifting vegetation. Detroit has made notable progress in planning for climate change and an extensive tree canopy through its “Tree Management Plan” (Davey Resource Group 2016), establishment of the Detroit Climate Action Collaborative (DCAC, now Detroit Climate Action), and development of the “Sustainability Action Agenda.” Several organizations, such as The Greening of Detroit and Detroiters Working for Environmental Justice (DWEJ), are working to integrate climate change considerations into aspects of planning. There are opportunities to implement additional regional and statewide efforts aimed at addressing climate change and the urban tree canopy.

Climate change puts pressure on limited economic resources, elevating the importance of partnerships. Creating partnerships and working groups to coordinate large, regional planning efforts can aid climate adaptation and increase landscape connectivity through strategic land acquisitions and restoration. Campaigns tied to various stakeholders, such as nonprofit groups, schools, and private companies, can be beneficial to increase awareness and interest. Volunteer-based organizations can assist with the planting and care of trees in cities, parks, and natural areas (Fig. 31). Land managers can also work with utility companies to create educational programs and rebates to retain tree canopy. Collaborating with others to expand public outreach to diverse audiences may also help overcome challenges.



Figure 31.—Volunteers at a public community tree planting event, Detroit, MI, April 2021. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.

More Information

- Detroit’s “Tree Management Plan” (Davey Resource Group 2016) identifies short- and long-term maintenance needs for public trees and provides inventory data and a maintenance schedule recommendation.
- Detroit Climate Action is a resource to identify short- and long-term climate actions in Detroit and across the Nation: <https://detroitclimateaction.org/about-us>.
- The city of Detroit’s “Sustainability Action Agenda” was developed as the result of research, community engagement, and interdepartmental collaboration: <https://detroitmi.gov/government/departments/general-services-department/office-sustainability/sustainability-action-agenda>.

Businesses and Institutions

A changing climate heightens risks associated with business operations, and some businesses will choose to incorporate adaptation strategies to mitigate those risks. Adaptation strategies not only improve business practices, but also could contribute to the Detroit community both economically and ecologically. By evaluating current business practices and risk, green jobs, programs, and markets can be established, allowing for long-term sustainability. Businesses may want to consider policy reform, take regulatory action, identify areas for capital investment, and establish preparedness lists in case of a climate-related emergency, such as an extreme weather event.

Businesses and institutions also play an important role in planning and partnerships by working with colleges and universities, building strong relationships with stakeholders, engaging with the community, and developing a coalition committed to climate action. By providing opportunities to engage in philanthropic work, such as planning a tree planting event, businesses and institutions can boost their influence, enhance their image, and give to the community.

More Information

- The Design Core, formerly known as the Detroit Creative Corridor Center (DC3), is a partnership between Business Leaders for Michigan and the College for Creative Studies, aiming to establish Detroit as a pinnacle of creative talent, business, and innovation: <https://designcore.org>.
- Green Garage Detroit is a coworking community in midtown Detroit that fosters a home for businesses and nonprofit organizations. Located in a green-designed building, Green Garage aims to make decisions with the environment, community, and economy at the forefront: <https://greengaragedetroit.com>.
- Businesses and institutions can invest in City Forest Credits as an option for offsetting emissions and contributing to more trees for their communities: <https://www.cityforestcredits.org/carbon-credits>.

Public Health

A changing climate will threaten public health as extreme heat and precipitation events become more frequent. Low-income households are at a higher risk of extreme heat exposure and reduced water quality from extreme events, which is of great concern as Detroit is the major city with the

lowest average per capita income in the United States. The effects of urban heat islands in the Detroit region can be mitigated through strategies such as increasing tree and vegetative cover (Fig. 32) and providing access to cooling centers and parks. Emergency preparedness will become more important than ever in the face of projected increases in storm damage, flooding events, and day and night temperatures. Rising average high temperatures can cause heat-related diseases and mortality.

More Information

- The city of Detroit provides information about shelters and warming and cooling centers, including locations, tips for preventing illness, and emergency declarations: <https://detroitmi.gov/departments/homeland-security-emergency-management-detroit/shelters-warming-and-cooling-centers>.
- Michigan Syndromic Surveillance System is a tool designed to facilitate a quick public health response to outbreaks of illness due to bioterrorism, infectious diseases, and other health threats and emergencies using real-time detection: https://www.michigan.gov/mdhhs/0,5885,7-339-71550_5104_31274-107091--,00.html.
- “Michigan Hazard Mitigation Plan” is a plan to address overall emergency preparedness and reduce risks and vulnerabilities: https://www.michigan.gov/documents/msp/MHMP_480451_7.pdf.
- The National Integrated Heat Health Information System is a tool developed by various governmental agencies to analyze heat threats for specific regions, providing information to forecast extreme heat and plan public health responses: <https://nihhis.cpo.noaa.gov>.
- The Climate & Health Action Guide is a tool designed to help promote human health and the benefits that urban forests provide to communities while reducing risks associated with climate change: <https://www.vibrantcitieslab.com/guides/climate-health-action-guide>.



Figure 32.—Participants in a community tree planting event in a residential neighborhood, Detroit, MI, April 2021. Courtesy photo by Fai Foen, The Greening of Detroit, used with permission.

Summary

A changing climate will influence the management of urban forests in the Detroit region. Maintaining species diversity and selecting appropriate species for the projected changes in habitat suitability will become more of a challenge for everyone, from land managers to the nursery industry. Increased short-term financial investments may be needed for the development of nursery stock, green infrastructure, and restoration practices that will help maintain the urban forest in the long term. Climate change challenges will also present opportunities for land managers and other decision makers to further engage with their communities, develop new partnerships and programs, expand their volunteer bases, work to develop adaptation practices with businesses and institutions, and make investments in resilient landscapes—while keeping equity and environmental justice at the forefront.

Key Points

- Maintaining species diversity and selecting appropriate, adaptable species for the projected changes in habitat suitability will become more of a challenge for those managing green spaces in Detroit.
- Given the uncertainties around the effects of climate change, it will be important for land managers to continue to observe and document impacts on tree species and refine models and management strategies.
- Climate change challenges will present opportunities for land managers and other decision makers to further engage with their communities, develop new partnerships and programs, expand their volunteer base, and make investments in resilient landscapes.

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.

aeroallergen

an airborne substance that can trigger an allergic reaction, such as pollen.

allergenicity

degree to which a substance induces allergy.

arbuscular mycorrhizal fungi (AMF)

symbiotic soil microorganisms that can play a key role in long-term maintenance of soil health and fertility by helping host plants grow under stressful conditions. AMF can mediate communication events between the fungus and plant, enhancing the photosynthetic rate and water uptake.

berm

a narrow shelf, path, or ledge typically at the top or bottom of a slope.

biogenic volatile organic compounds (BVOCs)

volatile organic compounds, or organic chemicals, emitted by plants, animals, or microorganisms.

bioswales

linear channels designed to concentrate and convey stormwater runoff while removing debris and pollution.

cultivar

a plant variety that has been produced in cultivation by selective breeding.

crown dieback

recent mortality of branches with fine twigs, which begins at the terminal portion of a branch and proceeds toward the trunk.

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.

environmental justice

the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards, and equal access to the decision-making process to have a healthy environment in which to live, learn, and work (U.S. Environmental Protection Agency 2023).

food justice

conditions such that communities have access to foods that are affordable, healthy, culturally relevant, and safe.

food insecurity

household-level economic and social condition of limited or uncertain access to adequate food, or a lack of consistent access to enough food for every person in a household to live an active, healthy life. This can be a temporary situation for a family or can last a long time.

fragmentation

the process during which a large expanse of habitat is transformed into a number of smaller patches of smaller total area isolated from each other by a matrix of habitats unlike the original.

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.

importance value

an index of the relative abundance of a species in a given community (0 = least abundant, 50 = most abundant).

microclimate

the climate of a very small or restricted area, especially when this differs from the climate of the surrounding area.

mycorrhizal

pertaining to the symbiotic association between a fungus and a plant.

overstory

the uppermost layer of foliage in a forest, forming the canopy.

phenology

the study of the timing of the biological events in plants and animals.

refugia

areas in which a population of organisms can survive through a period of unfavorable conditions.
Singular: refugium.

representative concentration pathway (RCP)

a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change for its “Fifth Assessment Report” in 2014.

riparian

relating to or situated on the banks of a river.

statistically downscaled

adjusted by using a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution general circulation models by deriving statistical relationships between observed small-scale (measured on-the-ground) variables and larger-scale variables.

transpiration

the process of water movement through a plant, including the loss of water primarily through the stomates of leaves.

trophic level

the position that an organism occupies in a food web.

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.

understory

a layer of vegetation beneath the main canopy of a forest.

urban heat island

an urban area that 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.

water table

the upper level of an underground surface in which the soil or rocks are permanently saturated with water.

wildland-urban interface

a zone of transition between wilderness and land developed by human activity; an area where a built environment meets or intermingles with a natural environment.

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APPENDIX 1: LISTS OF SPECIES NAMES

FLORA

Common name	Scientific name
Accolade™ elm	<i>Ulmus davidiana</i> var. <i>japonica</i> 'Morton'
American beech	<i>Fagus grandifolia</i>
American chestnut	<i>Castanea dentata</i>
American elm	<i>Ulmus americana</i>
American hophornbeam	<i>Ostrya virginiana</i>
American linden (basswood)	<i>Tilia americana</i>
American mountain-ash	<i>Sorbus americana</i>
American sycamore	<i>Platanus occidentalis</i>
Amur corktree	<i>Phellodendron amurense</i>
Amur maackia	<i>Maackia amurensis</i>
Amur maple	<i>Acer tataricum ginnala</i>
apple	<i>Malus</i> spp.
apple serviceberry	<i>Amelanchier ×grandiflora</i>
Ashe juniper	<i>Juniperus ashei</i>
Austrian pine	<i>Pinus nigra</i>
bald cypress	<i>Taxodium distichum</i>
balsam fir	<i>Abies balsamea</i>
balsam poplar	<i>Populus balsamifera</i>
beech	<i>Fagus</i> spp.
big bluestem	<i>Andropogon gerardii</i>
bigtooth aspen	<i>Populus grandidentata</i>
birch	<i>Betula</i> spp.
bitternut hickory	<i>Carya cordiformis</i>
black alder	<i>Alnus glutinosa</i>
black ash	<i>Fraxinus nigra</i>
black cherry	<i>Prunus serotina</i>
blackgum	<i>Nyssa sylvatica</i>
black hickory	<i>Carya texana</i>
blackjack oak	<i>Quercus marilandica</i>
black locust	<i>Robinia pseudoacacia</i>
black maple	<i>Acer nigrum</i>
black oak	<i>Quercus velutina</i>

FLORA

Common name	Scientific name
black poplar	<i>Populus nigra</i>
black walnut	<i>Juglans nigra</i>
black willow	<i>Salix nigra</i>
blazing star	<i>Liatis</i> spp.
blueberry	<i>Vaccinium</i> spp.
buttonbush	<i>Cephalanthus occidentalis</i>
Callery pear	<i>Pyrus calleryana</i>
cedar elm	<i>Ulmus crassifolia</i>
cherry plum	<i>Prunus cerasifera</i>
chestnut oak	<i>Quercus prinus</i>
Chinese chestnut	<i>Castanea mollissima</i>
cockspur thorn	<i>Crataegus crusgalli</i>
Colorado spruce	<i>Picea pungens</i>
common burdock	<i>Arctium</i> spp.
common hackberry	<i>Celtis occidentalis</i>
common horse chestnut	<i>Aesculus hippocastanum</i>
common persimmon	<i>Diospyros virginiana</i>
cordgrass	<i>Spartina pectinata</i>
cornelian cherry dogwood	<i>Cornus mas</i>
cottonwood	<i>Populus</i> spp.
Crimean linden	<i>Tilia ×euchlora</i>
dawn redwood	<i>Metasequoia glyptostroboides</i>
Douglas-fir	<i>Pseudotsuga menziesii</i>
downy serviceberry	<i>Amelanchier arborea</i>
eastern cottonwood	<i>Populus deltoides</i>
eastern hemlock	<i>Tsuga canadensis</i>
eastern redbud	<i>Cercis canadensis</i>
eastern redcedar	<i>Juniperus virginiana</i>
eastern white pine	<i>Pinus strobus</i>
elderberry	<i>Sambucus canadensis</i>
elm	<i>Ulmus</i> spp.
English elm	<i>Ulmus procera</i>
English walnut	<i>Juglans regia</i>
European ash	<i>Fraxinus excelsior</i>

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FLORA

Common name	Scientific name
European beech	<i>Fagus sylvatica</i>
European buckthorn	<i>Rhamnus cathartica</i>
European hornbeam	<i>Carpinus betulus</i>
European pear	<i>Pyrus communis</i>
flowering dogwood	<i>Cornus florida</i>
Freeman maple	<i>Acer ×freemanii</i>
fringetree	<i>Chionanthus virginicus</i>
garlic mustard	<i>Alliaria petiolata</i>
giant hogweed	<i>Heracleum mantegazzianum</i>
ginkgo	<i>Ginkgo biloba</i>
glossy buckthorn	<i>Rhamnus frangula</i>
goldenrain tree	<i>Koelreuteria paniculata</i>
grape	<i>Vitis</i> spp.
gray alder	<i>Alnus rugosa</i>
gray birch	<i>Betula populifolia</i>
gray dogwood	<i>Cornus racemosa</i>
green ash	<i>Fraxinus pennsylvanica</i>
green hawthorn 'Winter King'	<i>Crataegus viridis</i> 'Winter King'
hardy pecan	<i>Carya illinoensis</i>
hardy rubber tree	<i>Eucommia ulmoides</i>
hedge maple	<i>Acer campestre</i>
Heritage™ oak	<i>Quercus macrocarpa</i> × <i>robur</i>
hickory	<i>Carya</i> spp.
Higan cherry	<i>Prunus subhirtella</i>
honeylocust (thornless)	<i>Gleditsia triacanthos inermis</i>
honeylocust	<i>Gleditsia triacanthos</i>
Indian grass	<i>Sorghastrum nutans</i>
jack pine	<i>Pinus banksiana</i>
Japanese chaff flower	<i>Achyranthes japonica</i>
Japanese cherry	<i>Prunus serrulata</i>
Japanese honeysuckle	<i>Lonicera japonica</i>
Japanese knotweed	<i>Polygonum cuspidatum</i>
Japanese maple	<i>Acer palmatum</i>
katsura tree	<i>Cercidiphyllum japonicum</i>

FLORA

Common name	Scientific name
Kentucky coffeetree	<i>Gymnocladus dioica</i>
kousa dogwood	<i>Cornus kousa</i>
lacebark elm	<i>Ulmus parvifolia</i>
lacebark pine	<i>Pinus bungeana</i>
little bluestem	<i>Schizachyrium scoparium</i>
littleleaf linden	<i>Tilia cordata</i>
live oak	<i>Quercus virginiana</i>
London planetree	<i>Platanus ×acerifolia</i>
maple	<i>Acer</i> spp.
Miyabe maple	<i>Acer miyabei</i>
mockernut hickory	<i>Carya tomentosa</i>
northern catalpa	<i>Catalpa speciosa</i>
northern pin oak	<i>Quercus ellipsoidalis</i>
northern red oak	<i>Quercus rubra</i>
northern white-cedar	<i>Thuja occidentalis</i>
Norway maple	<i>Acer platanoides</i>
Norway spruce	<i>Picea abies</i>
Ohio buckeye	<i>Aesculus glabra</i>
Osage-orange	<i>Maclura pomifera</i>
overcup oak	<i>Quercus lyrata</i>
pagoda dogwood	<i>Cornus alternifolia</i>
paperbark maple	<i>Acer griseum</i>
paper birch	<i>Betula papyrifera</i>
paradise apple	<i>Malus pumila</i>
pawpaw	<i>Asimina triloba</i>
peach	<i>Prunus persica</i>
Pennsylvania sedge	<i>Carex pensylvanica</i>
Persian parrotia	<i>Parrotia persica</i>
Persian silk tree	<i>Albizia julibrissin</i>
pignut hickory	<i>Carya glabra</i>
pin oak	<i>Quercus palustris</i>
planetree	<i>Platanus</i> spp.
poplar	<i>Populus</i> spp.
post oak	<i>Quercus stellata</i>
princess tree	<i>Paulownia tomentosa</i>

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FLORA

Common name	Scientific name
pumpkin ash	<i>Fraxinus profunda</i>
purple loosestrife	<i>Lythrum salicaria</i>
pussy willow	<i>Salix discolor</i>
quaking aspen	<i>Populus tremuloides</i>
ragweed	<i>Ambrosia</i> spp.
red horse chestnut	<i>Aesculus ×carnea</i>
red maple	<i>Acer rubrum</i>
red mulberry	<i>Morus rubra</i>
red oak	<i>Quercus rubra</i>
red pine	<i>Pinus resinosa</i>
red spruce	<i>Picea rubens</i>
river birch	<i>Betula nigra</i>
rose of Sharon	<i>Hibiscus syriacus</i>
Russian olive	<i>Elaeagnus angustifolia</i>
Sargent cherry	<i>Prunus sargentii</i>
sassafras	<i>Sassafras albidum</i>
saucer magnolia	<i>Magnolia ×soulangiana</i>
sawtooth oak	<i>Quercus acutissima</i>
scarlet oak	<i>Quercus coccinea</i>
Scots pine	<i>Pinus sylvestris</i>
sedge	<i>Carex aquatilis</i>
shagbark hickory	<i>Carya ovata</i>
shellbark hickory	<i>Carya laciniata</i>
shingle oak	<i>Quercus imbricaria</i>
Shumard oak	<i>Quercus shumardii</i>
Siberian elm	<i>Ulmus pumila</i>
silver birch	<i>Betula pendula</i>
silver linden	<i>Tilia tomentosa</i>
silver maple	<i>Acer saccharinum</i>
slippery elm	<i>Ulmus rubra</i>
smoketree	<i>Cotinus coggygria</i>
sourwood	<i>Oxydendrum arboreum</i>
southern hackberry (sugarberry)	<i>Celtis laevigata</i>
southern magnolia	<i>Magnolia grandiflora</i>
spicebush	<i>Lindera benzoin</i>

FLORA

Common name	Scientific name
spotted knapweed	<i>Centaurea stoebe</i> ssp. <i>micranthos</i>
staghorn sumac	<i>Rhus typhina</i>
star magnolia	<i>Magnolia stellata</i>
sugar maple	<i>Acer saccharum</i>
swamp white oak	<i>Quercus bicolor</i>
sweetbay magnolia	<i>Magnolia virginiana</i>
sweet cherry	<i>Prunus avium</i>
sweetgum	<i>Liquidambar styraciflua</i>
switchgrass	<i>Panicum virgatum</i>
sycamore maple	<i>Acer pseudoplatanus</i>
sycamore	<i>Platanus</i> spp.
tamarack	<i>Larix laricina</i>
Tatarian maple	<i>Acer tataricum</i>
tree of heaven	<i>Ailanthus altissima</i>
trident maple	<i>Acer buergerianum</i>
tulip tree	<i>Liriodendron tulipifera</i>
turkey oak	<i>Quercus cerris</i>
Turkish hazel (Turkish filbert)	<i>Corylus colurna</i>
tussock sedge	<i>Carex stricta</i>
twig-rush	<i>Cladium mariscoides</i>
umbrella magnolia	<i>Magnolia tripetala</i>
Virginia mountain mint	<i>Pycnanthemum virginianum</i>
Virginia pine	<i>Pinus virginiana</i>
water locust	<i>Gleditsia aquatica</i>
weeping willow	<i>Salix babylonica</i>
white ash	<i>Fraxinus americana</i>
white fir	<i>Abies concolor</i>
white mulberry	<i>Morus alba</i>
white oak	<i>Quercus alba</i>
white poplar	<i>Populus alba</i>
white spruce	<i>Picea glauca</i>
wild parsnip	<i>Pastanaca sativa</i>
willow oak	<i>Quercus phellos</i>
willow	<i>Salix</i> spp.
winged elm	<i>Ulmus alata</i>

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FLORA

Common name	Scientific name
winterberry	<i>Ilex verticillata</i>
yellow birch	<i>Betula alleghaniensis</i>
yellowwood	<i>Cladrastis kentukea</i>
Yoshino cherry	<i>Prunus ×yedoensis</i>

FAUNA

Common name	Scientific name
American elm bark beetle	<i>Hylurgopinus rufipes</i>
Asian longhorned beetle	<i>Anoplophora glabripennis</i>
emerald ash borer	<i>Agrilus planipennis</i>
European elm bark beetle	<i>Scolytus multistriatus</i>
European fallow deer	<i>Dama dama dama</i>
European oak borer	<i>Agrilus sulcicollis</i>
moths and butterflies	Order <i>Lepidoptera</i>
spotted lanternfly	<i>Lycorma delicatula</i>
white-tailed deer	<i>Odocoileus virginianus</i>

BACTERIAL AND FUNGAL PATHOGEN SPECIES

Common name	Scientific name
Dutch elm disease	caused by three species of ascomycete fungi: <i>Ophiostoma ulmi</i> , <i>Ophiostoma himal-ulmi</i> , <i>Ophiostoma novo-ulmi</i>
Biscogniauxia (Hypoxylon) canker	fungal pathogen: <i>Biscogniauxia (Hypoxylon) atropunctata</i>
oak wilt	fungal pathogen: <i>Bretziella fagacearum</i>
plum curculio	<i>Conotrachelus nenuphar</i>

APPENDIX 2: SEASONAL TEMPERATURE AND PRECIPITATION TRENDS IN THE SOUTHEAST MICHIGAN COUNCIL OF GOVERNMENTS REGION, 1960–2018

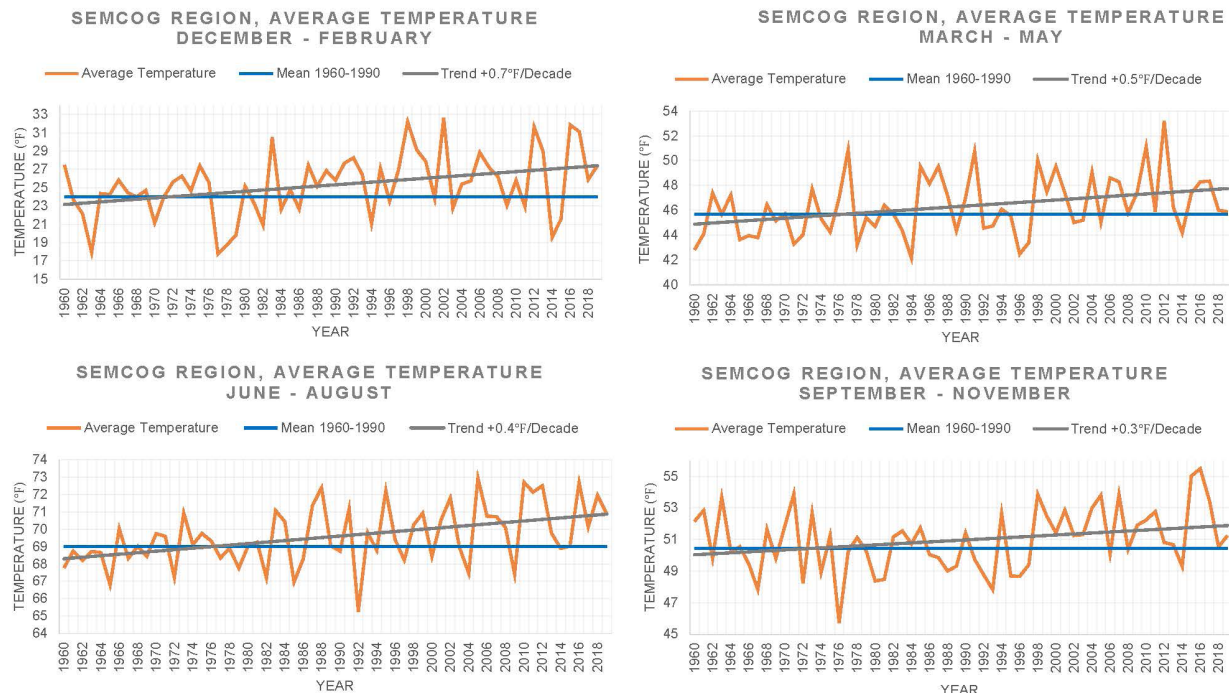


Figure 33.—Seasonal trends in mean temperature in the Southeast Michigan Council of Governments (SEMCOG) region, 1960 through 2018. Source: National Oceanic and Atmospheric Administration, National Centers for Environmental Information (2020).

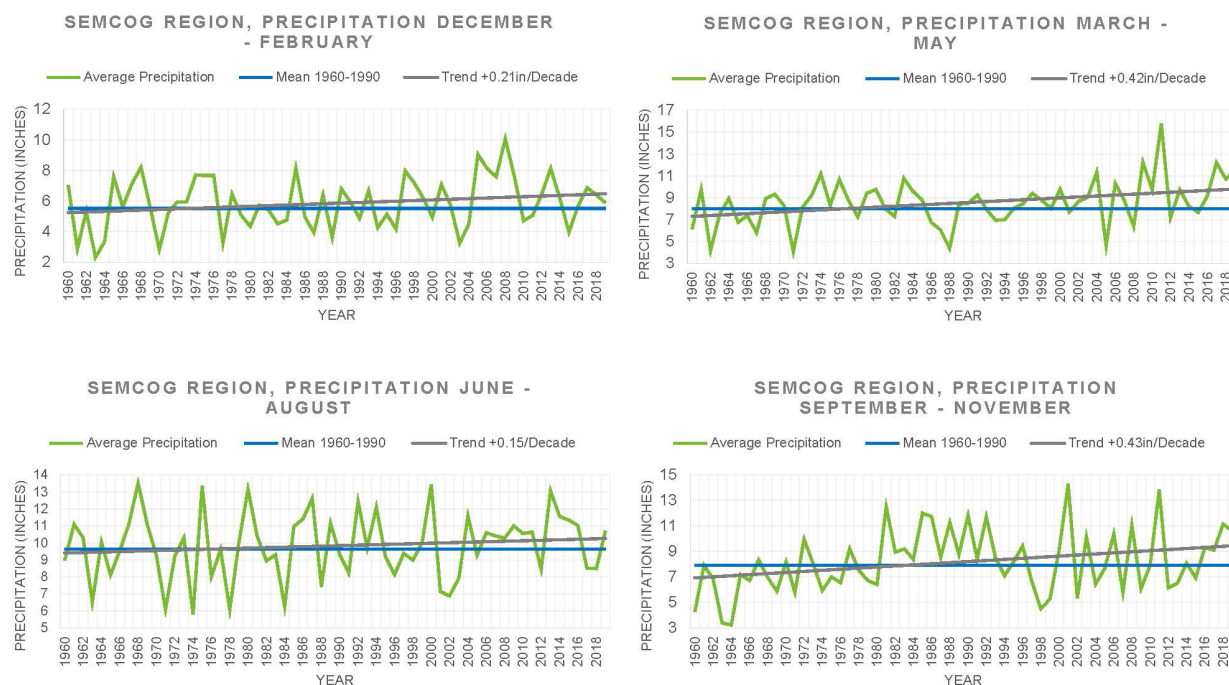


Figure 34.—Seasonal trends in total precipitation in the Southeast Michigan Council of Governments (SEMCOG) region, 1960 through 2018. Source: National Oceanic and Atmospheric Administration, National Centers for Environmental Information (2020).

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Climate at a glance. <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/>
(accessed November 30, 2022).

APPENDIX 3: CLIMATE PROJECTIONS FOR THE SOUTHEAST MICHIGAN COUNCIL OF GOVERNMENTS REGION

Climate observations from the GRIDMET dataset and future projections from the daily and monthly summaries for the MACAv2-METDATA datasets (Abatzoglou 2013) were processed using Google Earth Engine (Gorelick et al. 2017) to obtain various indices. A 30-year baseline period of 1980 through 2009 and three future periods (2010 through 2039, 2040 through 2069, 2070 through 2099) from the HadGEM2-ES (Jones et al. 2011) and IPSL-CM5A-MR (Dufresne et al. 2013) general circulation models under the representative concentration pathways (RCPs; Moss et al. 2008) 4.5 and 8.5 represent combinations of warming and precipitation. The HadGEM2-ES model represents a warm-dry scenario under RCP 4.5 and a hot-wet scenario under RCP 8.5 at the end of the 21st century. The IPSL-CM5A-MR model represents a warm-wet and hot-dry scenario, under RCP 4.5 and RCP 8.5, respectively, at end of century. Climate projections were processed using the delta method to remove bias among the simulated historical periods from the different models and between the observed data. For each climate scenario, the potential change in temperature and precipitation from the simulated baseline period to the future periods was used to adjust observed data prior to calculating the climate indices.

Climate indices included both seasonal and annual mean temperatures and precipitation totals (Figs. 35–38), along with the average number of days above or below specific thresholds of temperature and precipitation to represent extreme events. Four seasonal values were produced for the respective meteorological months (e.g., December, January, and February for winter) rather than using astronomical divisions. Extreme temperature events of 0 °F or below or 90 °F or above were calculated from daily projections and averaged for the 30-year periods, as were extreme precipitation events of 1 inch or greater or 2 inches or greater. Averaging the 30-year total occurrence of these events reduces some uncertainty within the daily projections and indicates how frequent these events could be for any given year.

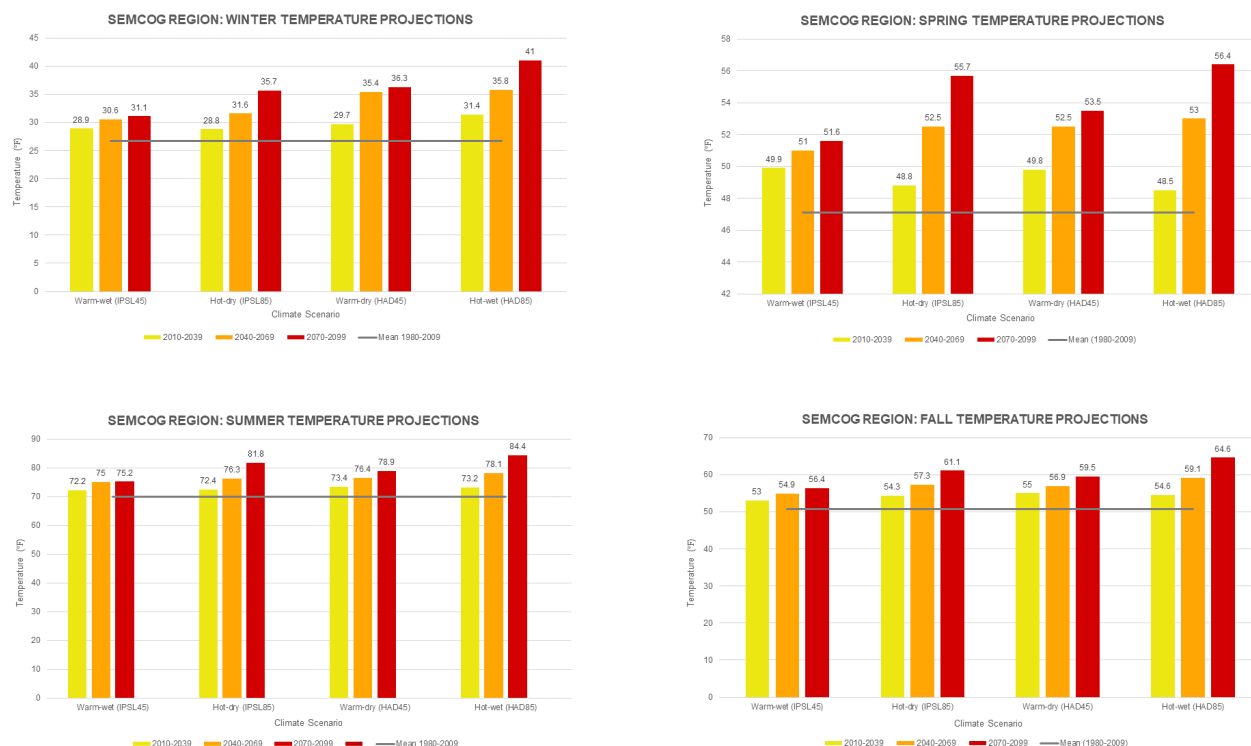


Figure 35.—Temperature projections by season under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

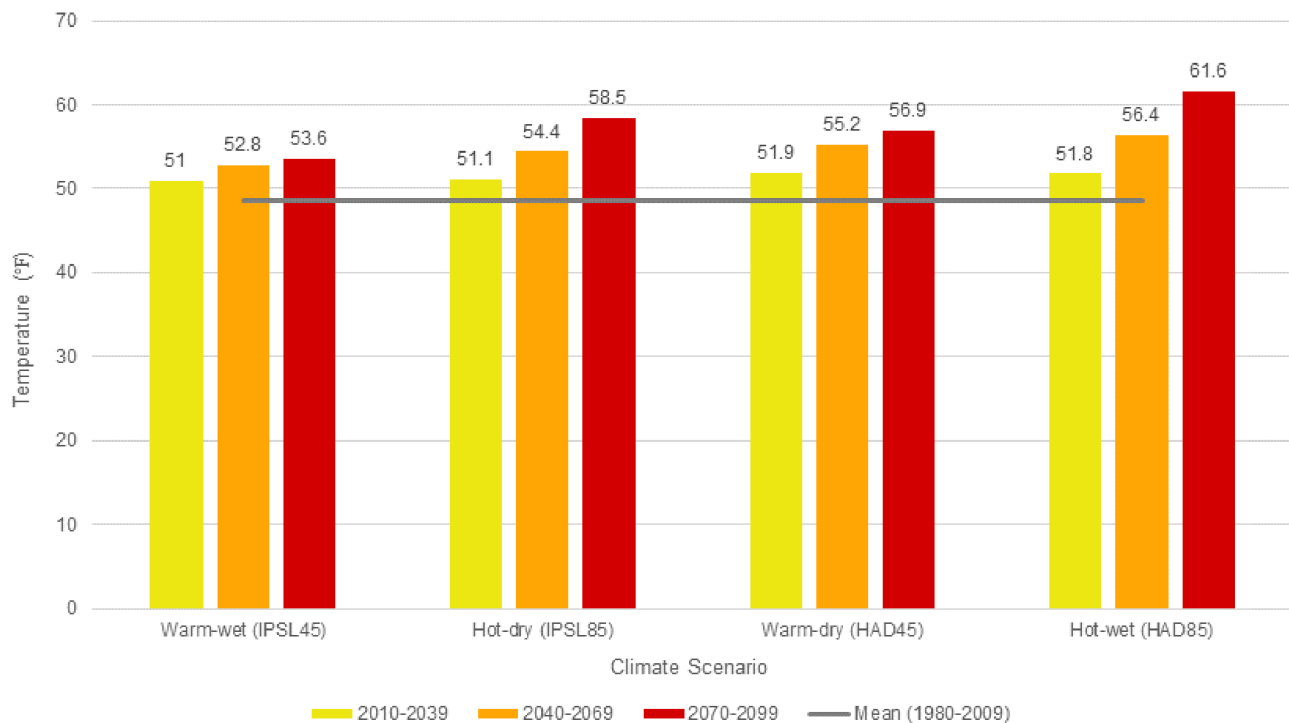


Figure 36.—Annual temperature projections under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).



Figure 37.—Precipitation projections by season under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

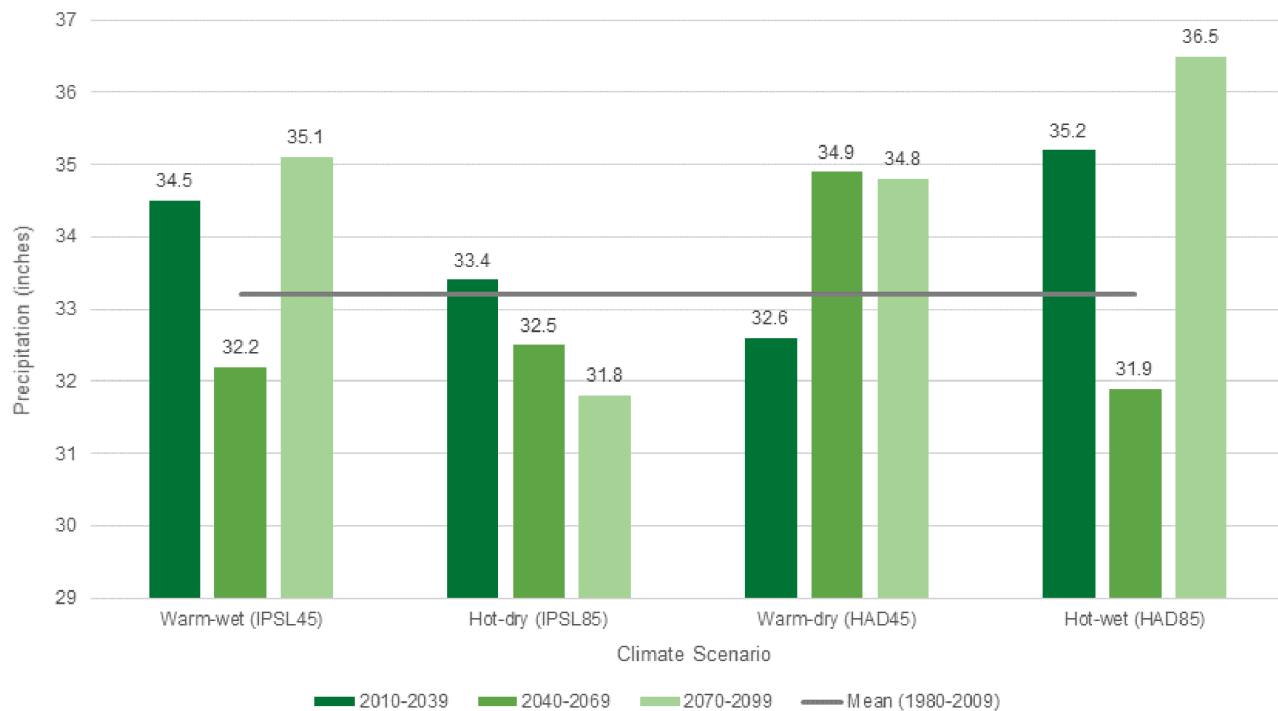


Figure 38.—Annual precipitation projections under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099 in the SEMCOG region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

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APPENDIX 4: PROJECTION DATA FOR TEMPERATURE, PRECIPITATION, AND EXTREME EVENTS IN THE SOUTHEAST MICHIGAN COUNCIL OF GOVERNMENTS REGION AND BY COUNTY

Table 14.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in the Southeast Michigan Council of Governments (SEMCOG) region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties; seven-county average)

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	28.9	28.8	29.7	31.4	30.6	31.6	35.4	35.8	31.1	35.7	36.3	41.0	26.7
Spring	49.9	48.8	49.8	48.5	51.0	52.5	52.2	53.0	51.6	55.7	53.5	56.4	47.1
Summer	72.2	72.4	73.4	73.2	75.0	76.3	76.4	78.1	75.2	81.8	78.9	84.4	70.0
Fall	53.0	54.3	55.0	54.6	54.9	57.3	56.9	59.1	56.4	61.1	59.5	64.6	50.8
Annual	51.0	51.1	51.9	51.8	52.8	54.4	55.2	56.4	53.6	58.5	56.9	61.6	48.6

Table 15.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in the Southeast Michigan Council of Governments (SEMCOG) region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties; seven-county average)

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	5.8	6.0	6.3	6.4	5.7	5.8	7.3	7.5	9.8	4.7	7.0	8.8	6.1
Spring	9.3	9.4	8.5	9.1	8.9	9.5	10.5	9.6	9.8	10.0	10.2	11.3	8.3
Summer	10.0	9.3	8.8	9.6	8.6	8.5	8.0	6.7	10.3	7.7	8.7	7.0	9.9
Fall	9.4	8.8	9.0	10.1	9.0	8.7	9.0	8.3	9.2	9.3	8.9	9.4	8.9
Annual	34.5	33.4	32.6	35.2	32.2	32.5	34.9	31.9	35.1	31.8	34.8	36.5	33.2

Table 16.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in the Southeast Michigan Council of Governments (SEMCOG) region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties; seven-county average)

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.7	2.3	1.9	1.0	1.5	0.4	0.5	0.5	0.5	0.0	0.4	0.5	4.3
Temperature ≥90 °F	15.5	19.5	29.7	27.7	31.8	42.2	47.4	59.3	32.7	72.4	61.5	86.9	7.8
Precipitation ≥1 inch	3.7	3.7	3.6	3.8	3.1	3.5	4.3	3.5	4.3	4.1	4.3	5.2	3.3
Precipitation ≥2 inches	0.3	0.3	0.2	0.2	0.2	0.4	0.3	0.3	0.4	0.4	0.4	0.6	0.1

Table 17.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Livingston County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	28.0	27.9	28.8	30.5	29.6	30.7	34.4	34.9	30.2	34.9	35.4	40.1	25.7
Spring	49.2	48.1	49.1	47.8	50.3	51.8	51.5	52.3	51.0	55.0	52.8	55.7	46.4
Summer	71.3	71.5	72.6	72.4	74.1	75.5	75.5	77.4	74.3	81.0	78.1	83.7	69.0
Fall	52.0	53.4	54.1	53.7	53.9	56.4	56.0	58.2	55.4	60.2	58.6	63.8	49.8
Annual	50.2	50.2	51.1	51.0	51.9	53.6	54.4	55.6	52.7	57.7	56.1	60.9	47.4

Table 18.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Macomb County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	29.1	28.9	30.0	31.7	30.7	31.7	35.7	36.2	31.2	35.8	36.6	41.4	26.9
Spring	49.6	48.6	49.5	48.3	50.8	52.3	52.0	52.8	51.4	55.4	53.3	56.2	46.9
Summer	72.3	72.4	73.4	73.2	75.0	76.3	76.3	77.8	75.2	81.7	78.8	84.1	70.0
Fall	53.1	54.4	55.1	54.7	55.1	57.4	57.0	59.1	56.6	61.2	59.6	64.7	50.9
Annual	51.1	51.1	51.9	51.8	52.8	54.4	55.2	56.4	53.6	58.5	56.9	61.6	48.6

Table 19.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Monroe County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	30.0	29.9	30.6	32.3	31.7	32.7	36.2	36.6	32.2	36.8	37.1	41.5	27.8
Spring	51.1	50.0	51.0	49.7	52.1	53.8	53.4	54.2	52.8	56.9	54.7	57.4	48.4
Summer	73.4	73.7	74.6	74.4	76.2	77.7	77.8	79.8	76.5	83.2	80.2	86.0	71.2
Fall	54.1	55.3	56.0	55.8	55.9	58.3	58.0	60.3	57.5	62.3	60.6	65.7	51.8
Annual	52.2	52.2	53.0	52.9	53.9	55.6	56.4	57.6	54.7	59.7	58.0	62.7	49.8

Table 20.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Oakland County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010– 2039	2010– 2039	2010– 2039	2010– 2039	2040– 2069	2040– 2069	2040– 2069	2040– 2069	2070– 2099	2070– 2099	2070– 2099	2070– 2099	1980– 2009
	Warm- wet (IPSL45)	Hot-dry (IPSL85)	Warm- dry (HAD45)	Hot-wet (HAD85)	Warm- wet (IPSL45)	Hot-dry (IPSL85)	Warm- dry (HAD45)	Hot-wet (HAD85)	Warm- wet (IPSL45)	Hot-dry (IPSL85)	Warm- dry (HAD45) 2070– 2099	Hot-wet (HAD85) 2070– 2099	Average
Winter	28.3	28.2	29.1	30.8	29.9	30.9	34.8	35.3	30.4	35.1	35.8	40.5	26.1
Spring	49.5	48.4	49.5	48.1	50.6	52.2	51.9	52.7	51.3	55.4	53.2	56.1	46.8
Summer	71.9	72.0	73.1	72.9	74.6	76.0	76.0	77.6	74.8	81.4	78.5	84.0	69.6
Fall	52.5	53.9	54.5	54.2	54.4	56.8	56.4	58.6	56.0	60.7	59.1	64.2	50.3
Annual	50.6	50.6	51.5	51.4	52.4	54.0	54.8	56.0	53.1	58.1	56.5	61.2	48.2

Table 21.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in St. Clair County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010– 2039	2010– 2039	2010– 2039	2010– 2039	2040– 2069	2040– 2069	2040– 2069	2040– 2069	2070– 2099	2070– 2099	2070– 2099	2070– 2099	1980– 2009
	Warm- wet (IPSL45)	Hot-dry (IPSL85)	Warm- dry (HAD45)	Hot-wet (HAD85)	Warm- wet (IPSL45)	Hot-dry (IPSL85)	Warm- dry (HAD45)	Hot-wet (HAD85)	Warm- wet (IPSL45)	Hot-dry (IPSL85)	Warm- dry (HAD45) 2070– 2099	Hot-wet (HAD85) 2070– 2099	Average
Winter	28.3	28.2	29.3	31.0	29.9	30.9	35.0	35.5	30.4	34.9	36.0	40.8	26.1
Spring	48.5	47.5	48.4	47.2	49.7	51.1	50.9	51.7	50.3	54.3	52.3	55.2	45.8
Summer	71.3	71.4	72.3	72.1	73.9	75.2	75.2	76.5	74.1	80.5	77.7	82.9	68.9
Fall	52.3	53.8	54.3	54.0	54.4	56.6	56.2	58.3	55.9	60.4	58.9	63.9	50.2
Annual	50.1	50.2	51.0	50.9	51.9	53.4	54.3	55.4	52.6	57.4	56.1	60.7	47.7

Table 22.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Washtenaw County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85) ¹	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	28.7	28.6	29.4	31.1	30.4	31.4	35.1	35.5	30.9	N/A	36.0	40.6	26.5
Spring	50.3	49.2	50.2	48.9	51.3	53.0	52.5	53.3	52.0	56.1	53.8	56.6	47.5
Summer	72.1	72.3	73.4	73.1	74.9	76.3	76.4	78.3	75.1	81.8	78.9	84.6	69.9
Fall	52.8	54.1	54.8	54.5	54.7	57.2	56.8	59.0	56.2	61.0	59.4	64.5	50.6
Annual	51.0	51.1	51.9	51.8	52.8	54.4	55.2	56.5	53.6	N/A	56.9	61.6	48.6

¹ N/A: not available.

Table 23.—Average projected temperatures (degrees Fahrenheit) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Wayne County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	30.0	29.8	30.7	32.4	31.7	32.7	36.3	36.8	32.1	36.8	37.3	41.9	27.8
Spring	50.9	49.8	50.8	49.5	52.0	53.6	53.3	54.1	52.7	56.7	54.6	57.4	48.2
Summer	73.2	73.4	74.4	74.2	76.0	77.4	77.5	79.2	76.3	82.9	79.9	85.5	71.0
Fall	54.0	55.2	55.9	55.6	55.8	58.2	57.9	60.1	57.4	62.1	60.5	65.5	51.7
Annual	52.1	52.1	52.9	52.8	53.8	55.4	56.2	57.5	54.6	59.6	57.9	62.6	49.6

Table 24.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Livingston County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	5.3	5.4	5.8	5.8	5.2	5.2	6.8	6.9	5.3	4.2	6.5	8.0	5.6
Spring	8.8	9.0	8.1	8.7	8.4	8.9	10.3	9.2	9.3	9.5	9.7	10.9	8.0
Summer	9.7	9.0	8.4	9.5	8.4	8.4	8.0	6.6	10.0	7.3	8.5	6.9	9.7
Fall	9.4	8.9	9.1	10.1	8.7	8.8	8.9	8.4	9.3	9.1	8.8	9.5	8.8
Annual	33.2	32.3	31.5	34.1	30.7	31.3	34.0	31.1	33.8	30.2	33.4	35.3	32.1

Table 25.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Macomb County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	6.0	6.2	6.5	6.6	5.9	6.0	7.5	7.7	6.0	4.9	7.2	9.1	6.2
Spring	9.2	9.4	8.5	9.0	8.6	9.4	10.5	9.6	9.6	9.9	10.1	11.3	8.3
Summer	9.9	9.3	9.0	9.8	8.5	8.4	8.2	6.7	10.4	7.7	8.8	7.1	10.1
Fall	9.4	8.7	9.1	10.1	9.0	8.9	9.1	8.2	9.1	9.4	8.9	9.4	8.9
Annual	34.5	33.5	33.0	35.5	32.0	32.7	35.3	32.2	35.2	32.0	35.1	36.9	33.5

Table 26.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Monroe County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	6.1	6.3	6.6	6.8	6.2	6.2	7.7	7.8	6.1	5.0	7.4	9.2	6.5
Spring	10.1	9.9	9.0	9.6	9.9	10.3	11.0	10.0	10.5	10.7	11.0	11.9	8.9
Summer	10.7	9.7	9.0	9.6	9.2	8.9	8.0	6.8	10.7	8.3	8.8	7.0	10.2
Fall	9.1	8.5	8.7	9.7	9.0	8.2	8.9	8.0	9.3	8.9	8.8	9.1	8.6
Annual	36.1	34.4	33.4	35.7	34.2	33.6	35.6	32.6	36.6	32.8	35.9	37.3	34.2

Table 27.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Oakland County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	5.5	5.7	6.1	6.1	5.4	5.5	7.1	7.2	5.5	4.5	6.7	8.4	5.8
Spring	9.0	9.1	8.3	8.9	8.5	9.1	10.3	9.3	9.5	9.7	9.9	11.0	8.1
Summer	9.5	9.0	8.5	9.3	8.3	8.2	7.8	6.5	9.9	7.4	8.5	6.8	9.6
Fall	9.3	8.8	9.1	10.1	8.8	8.7	9.0	8.2	9.0	9.2	8.8	9.4	8.8
Annual	33.3	32.6	31.9	34.4	31.0	31.5	34.1	31.1	34.0	30.9	33.8	35.6	32.3

Table 28.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in St. Clair County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	5.5	5.7	5.9	5.9	5.4	5.6	6.9	7.1	5.6	4.6	6.7	8.5	5.7
Spring	8.8	9.1	8.2	8.6	8.1	9.1	10.1	9.3	9.4	9.6	9.7	11.1	8.0
Summer	9.4	8.8	9.0	9.9	8.1	8.0	8.1	6.8	10.2	7.5	8.5	7.2	9.7
Fall	9.6	8.9	9.2	10.4	9.2	9.2	9.3	8.4	9.3	9.9	9.1	9.5	9.1
Annual	33.4	32.6	32.2	34.9	31.0	32.0	34.5	31.6	34.4	31.6	34.0	36.3	32.5

Table 29.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Washtenaw County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	6.0	6.1	6.5	6.7	5.9	6.0	7.6	7.8	6.0	4.8	7.2	9.0	6.3
Spring	9.6	9.5	8.6	9.3	9.2	9.7	10.6	9.7	9.9	10.3	10.4	11.3	8.5
Summer	10.6	9.8	9.0	9.9	9.2	9.0	8.2	6.8	10.7	8.0	9.0	7.1	10.3
Fall	9.5	8.9	9.1	10.3	9.0	8.6	9.2	8.6	9.4	9.2	9.1	9.7	9.0
Annual	35.7	34.3	33.3	36.1	33.3	33.3	35.6	32.8	36.1	32.4	35.7	37.2	34.1

Table 30.—Average projected precipitation (inches) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, in Wayne County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Winter	6.1	6.3	6.6	6.8	6.1	6.2	7.7	7.9	6.2	5.0	7.4	9.3	6.4
Spring	9.8	9.7	8.8	9.4	9.5	10.0	10.7	9.8	10.1	10.4	10.5	11.6	8.6
Summer	10.1	9.5	8.6	9.4	8.7	8.5	7.7	6.5	10.3	7.8	8.8	6.8	9.8
Fall	9.2	8.7	8.8	9.9	9.0	8.4	8.9	8.1	9.2	9.2	8.8	9.3	8.8
Annual	35.2	34.2	32.8	35.4	33.3	33.0	35.0	32.2	35.7	32.4	35.4	37.0	33.6

Table 31.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for Livingston County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.9	2.8	2.2	1.2	1.6	0.6	0.6	0.5	0.6	0.03	0.5	0.4	5.0
Temperature ≥90 °F	12.6	16.5	27.4	26.2	28.4	38.2	44.9	56.5	28.6	68.1	58.9	84.7	5.7
Precipitation ≥1 inch	3.2	3.3	3.2	3.6	2.7	3.2	4.2	3.2	3.7	3.6	4.0	4.9	3.0
Precipitation ≥2 inches	0.2	0.3	0.1	0.2	0.1	0.4	0.3	0.2	0.3	0.3	0.3	0.5	0.1

Table 32.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for Macomb County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.6	2.2	1.8	0.9	1.3	0.3	0.5	0.5	0.4	-0.18	0.4	0.5	4.1
Temperature ≥90 °F	15.5	19.4	28.7	26.5	31.5	41.3	46.1	56.9	32.1	71.1	60.1	85.1	7.7
Precipitation ≥1 inch	3.4	3.4	4.1	4.2	2.5	3.4	4.7	3.6	4.0	3.9	4.6	5.4	3.3
Precipitation ≥2 inches	0.3	0.4	0.2	0.2	0.2	0.4	0.3	0.2	0.3	0.3	0.3	0.5	0.1

Table 33.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for Monroe County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.6	2.2	1.8	1.0	1.5	0.3	0.3	0.4	0.6	-0.05	0.3	0.4	3.7
Temperature ≥90 °F	19.9	24.4	34.7	31.6	37.4	49.4	53.7	67.7	39.4	80.9	67.8	92.6	10.8
Precipitation ≥1 inch	4.3	4.1	3.7	3.7	4.3	3.9	4.2	3.6	5.1	4.7	4.4	5.3	3.6
Precipitation ≥2 inches	0.4	0.4	0.3	0.2	0.2	0.4	0.4	0.3	0.5	0.4	0.6	0.8	0.2

Table 34.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for Oakland County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.8	2.3	2.0	0.9	1.4	0.4	0.5	0.5	0.5	-0.02	0.5	0.5	4.5
Temperature ≥90 °F	13.9	17.9	28.2	26.0	29.9	40.0	45.6	56.6	30.4	69.6	59.5	84.9	6.5
Precipitation ≥1 inch	3.3	3.3	3.8	3.8	2.6	2.9	4.4	3.4	3.9	3.6	4.3	5.0	3.1
Precipitation ≥2 inches	0.3	0.3	0.1	0.2	0.2	0.4	0.3	0.2	0.4	0.4	0.3	0.4	0.2

Table 35.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for St. Clair County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.9	2.5	2.1	1.0	1.5	0.5	0.6	0.7	0.6	0.01	0.5	0.6	4.7
Temperature ≥90 °F	12.7	16.1	25.4	24.2	27.6	35.9	41.2	51.2	27.5	64.6	55.5	81.6	6.5
Precipitation ≥1 inch	2.9	3.2	3.8	3.9	2.4	3.4	4.4	3.3	3.7	3.8	4.3	5.1	3.0
Precipitation ≥2 inches	0.4	0.4	0.2	0.2	0.2	0.4	0.4	0.3	0.4	0.4	0.3	0.4	0.2

Table 36.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for Washtenaw County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.9	2.6	2.1	1.1	1.8	0.6	0.5	0.4	0.8	0.15	0.5	0.4	4.6
Temperature ≥90 °F	16.2	20.2	31.5	29.5	33.3	44.6	50.2	63.1	34.7	75.7	64.2	89.5	8.0
Precipitation ≥1 inch	4.2	4.2	3.3	3.8	3.7	3.8	3.9	3.6	4.7	4.5	4.2	5.0	3.6
Precipitation ≥2 inches	0.4	0.3	0.2	0.2	0.1	0.4	0.4	0.3	0.3	0.5	0.5	0.7	0.1

Table 37.—Average projections for extreme events (average days per year) under warm-wet (IPSL45), hot-dry (IPSL85), warm-dry (HAD45), and hot-wet (HAD85) climate change scenarios for periods 2010 through 2039, 2040 through 2069, and 2070 through 2099, and 30-year historical average, for Wayne County, one of the seven counties in the Southeast Michigan Council of Governments (SEMCOG) region

Season	2010–2039	2010–2039	2010–2039	2010–2039	2040–2069	2040–2069	2040–2069	2040–2069	2070–2099	2070–2099	2070–2099	2070–2099	1980–2009
	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45)	Hot-wet (HAD85)	Warm-wet (IPSL45)	Hot-dry (IPSL85)	Warm-dry (HAD45) 2070–2099	Hot-wet (HAD85) 2070–2099	Average
Temperature ≤0 °F	1.4	1.7	1.6	0.8	1.1	0.0	0.5	0.6	0.3	-0.15	0.4	0.6	3.2
Temperature ≥90 °F	17.5	22.0	32.1	29.6	34.8	45.7	50.2	63.3	36.2	76.7	64.8	89.6	9.1
Precipitation ≥1 inch	4.3	4.4	3.6	3.9	3.6	4.0	4.2	3.7	4.8	4.6	4.4	5.5	3.6
Precipitation ≥2 inches	0.4	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.7	0.1

APPENDIX 5: PROJECTED SHIFTS IN HARDINESS ZONES AND HEAT ZONES

Projected hardiness zones and heat zones under two climate change scenarios are depicted in the following maps (Figs. 40 and 41) for a 30-year baseline period of 1980 through 2009 and for three future periods: 2010 through 2039, 2040 through 2069, and 2070 through 2099.

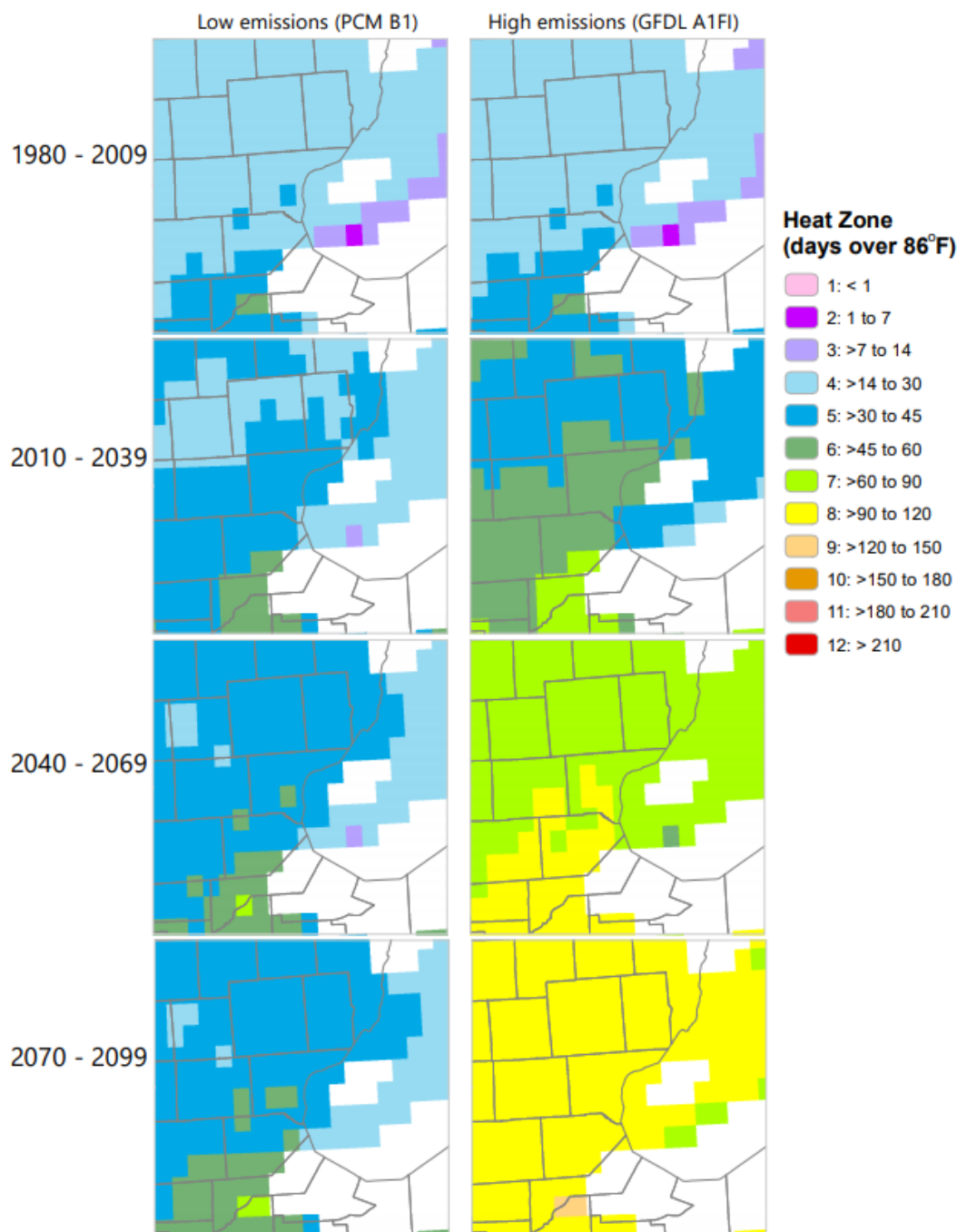


Figure 40.—Heat zones in Detroit, MI, modeled under low and high climate change scenarios for periods 1980 through 2009, 2010 through 2039, 2040 through 2069, and 2070 through 2099. Adapted from Matthews et al. (2018).

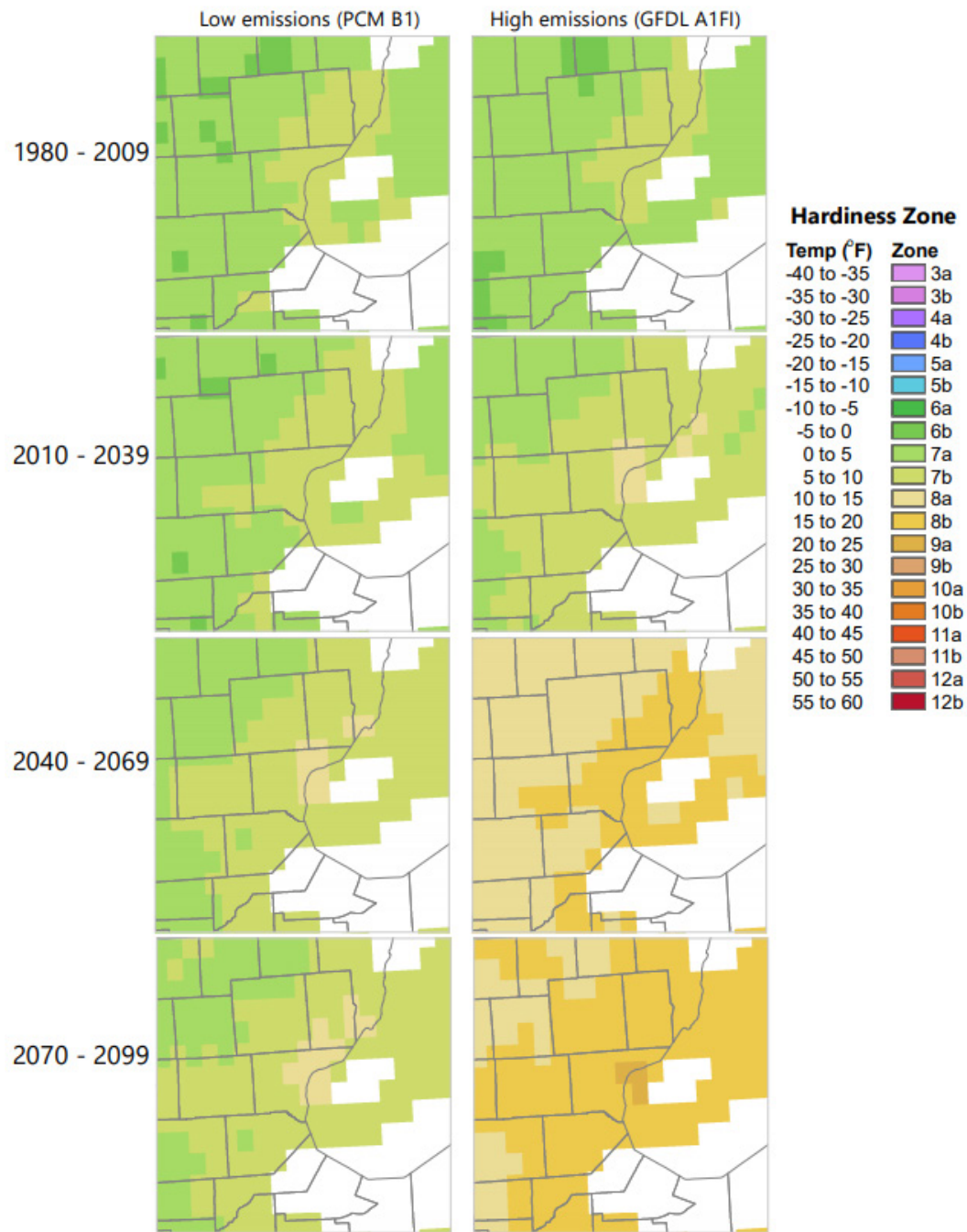


Figure 41.—Plant hardiness zones in Detroit, MI, modeled under low and high climate change scenarios for periods 1980 through 2009, 2010 through 2039, 2040 through 2069, and 2070 through 2099. Adapted from Matthews et al. (2018).

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<https://doi.org/10.2737/NRS-RMAP-9/>.

APPENDIX 6: MODELED PROJECTIONS OF HABITAT SUITABILITY

Table 38 provides the current and modeled importance values for the species modeled using the DISTRIB-II species distribution model for trees in the 1-degree by 1-degree latitude/longitude grid cell. This list is limited to species represented in the DISTRIB-II model and may include species that are found in the 1-degree × 1-degree cell but outside of Detroit. Definitions for headings and supporting documentation are in Table 39.

Table 38.—Modeled projections of habitat suitability for tree species in the Detroit region

Common name	Range	MR	percent-Cell	FIA sum	FIAiv	ChngCl45	ChngCl85	Adapt ¹	Abund	Capabil45	Capabil85
American beech	WDH	high	4.5	39.51	7.44	no change	small decrease	medium	rare	fair	poor
American elm	WDH	medium	43.9	409.88	9.66	small increase	small increase	medium	common	very good	very good
American linden (basswood)	WSL	medium	18	140.83	8.39	no change	small decrease	medium	common	good	fair
Ashe juniper	NDH	high	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
bigtooth aspen	NSL	medium	10.1	34.51	5.31	large decrease	large decrease	medium	rare	poor	poor
bitternut hickory	WSL	low	6.8	61.54	7.73	no change	no change	high	common	good	good
black ash	WSH	medium	4.5	59.5	11.21	very large decrease	very large decrease	low	common	lost	lost
black cherry	WDL	medium	34.7	501.19	13.47	no change	small decrease	low	abundant	very good	good
black hickory	NDL	high	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
black locust	NDH	low	1.1	10.25	7.72	small increase	large increase	medium	rare	good	good
black maple	NSH	low	1.1	1.73	1.3	large decrease	large decrease	high	rare	poor	poor
black oak	WDH	high	20.1	402.66	16.34	no change	no change	medium	common	good	good
black walnut	WDH	low	3.4	132.99	33.4	no change	no change	medium	common	good	good
black willow	NSH	low	5.6	75.83	11.43	small decrease	no change	low	common	fair	good
blackgum	WDL	medium	4.5	0.46	1.4	small increase	large increase	high	rare	good	good
blackjack oak	NSL	medium	0	0	0	new habitat	new habitat	high	absent	new habitat	new habitat
bluejack oak	NSL	low	0	0	0	unknown	unknown	medium	absent	unknown	unknown
boxelder	WSH	low	10.7	196.63	22.31	small decrease	small decrease	high	common	fair	fair
bur oak	NDH	medium	19.1	103.74	14.68	no change	no change	high	common	good	good
butternut	NSLX	FIA	1.1	2.06	1.55	unknown	unknown	low	rare	FIA only	FIA only
cedar elm	NDH	medium	0	0	0	new habitat	new habitat	low	absent	new habitat	new habitat

¹ N/A: Not available.

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Table 38 (continued).—Modeled projections of habitat suitability for tree species in the Detroit region

Common name	Range	MR	percent-Cell	FIA sum	FIAiv	ChngCl45	ChngCl85	Adapt ¹	Abund	Capabil45	Capabil85
chokecherry	NSLX	FIA	3.4	15.97	4.01	unknown	unknown	medium	rare	FIA only	FIA only
common persimmon	NSL	low	0	0	0	new habitat	new habitat	high	absent	new habitat	new habitat
cucumber tree	NSL	low	0	0	0	unknown	unknown	medium	modeled	unknown	unknown
eastern cottonwood	NSH	low	11.8	110.05	14.28	large increase	large increase	medium	common	very good	very good
eastern hophornbeam (ironwood)	WSL	low	6.8	64.93	8.15	large decrease	large decrease	high	common	fair	fair
eastern red cedar	WDH	medium	2.3	11.75	4.42	large increase	large increase	medium	rare	good	good
eastern redbud	NSL	low	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
eastern white pine	WDH	high	2.3	13.27	5	no change	large decrease	low	rare	fair	poor
flowering dogwood	WDL	medium	1.1	1.55	1.17	small decrease	very large decrease	medium	rare	poor	lost
green ash	WSH	low	37.7	443.44	12.28	no change	no change	medium	common	good	good
hackberry	WDH	medium	5.1	11.36	12.01	small increase	small increase	high	rare	good	good
honeylocust	NSH	low	0	0	0	new habitat	new habitat	high	absent	new habitat	new habitat
live oak	NDH	high	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
mockernut hickory	WDL	medium	0	0	0	new habitat	new habitat	high	absent	new habitat	new habitat
musclewood (American hornbeam)	WSL	low	4.5	12.48	2.35	small decrease	small decrease	medium	rare	poor	poor
northern pin oak	NSH	medium	1.1	40.75	30.7	small decrease	small decrease	high	rare	poor	poor
northern red oak	WDH	medium	25.7	244.01	9.21	no change	no change	high	common	good	good
northern white-cedar	WSH	high	3.4	53.69	13.48	small decrease	small decrease	medium	common	fair	fair
Norway spruce	NSH	FIA	2.3	47.42	17.87	unknown	unknown	N/A	rare	NNIS	NNIS
Osage-orange	NDH	medium	0	0	0	new habitat	new habitat	high	absent	new habitat	new habitat
paper birch	WDH	high	2.3	3.66	1.38	large decrease	large decrease	medium	rare	poor	poor
pawpaw	NSL	low	0	0	0	unknown	unknown	medium	modeled	unknown	unknown
pecan	NSH	low	0	0	0	new habitat	new habitat	low	absent	new habitat	new habitat
pignut hickory	WDL	medium	9	63.4	5.97	no change	no change	medium	common	good	good

¹ N/A: Not available.

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Table 38 (continued).—Modeled projections of habitat suitability for tree species in the Detroit region

Common name	Range	MR	percent-Cell	FIA sum	FIAiv	ChngCl45	ChngCl85	Adapt ¹	Abund	Capabil45	Capabil85
pin oak	NSH	low	0	0	0	new habitat	new habitat	low	absent	new habitat	new habitat
post oak	WDH	high	0	0	0	new habitat	new habitat	high	absent	new habitat	new habitat
quaking aspen	WDH	high	9	82.78	13.82	large decrease	large decrease	medium	common	fair	fair
red maple	WDH	high	37	699.07	20.84	small decrease	small decrease	high	abundant	good	good
red mulberry	NSL	low	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
red pine	NSH	medium	3.4	65.92	16.56	large decrease	large decrease	low	common	fair	fair
sassafras	WSL	low	12.2	114.38	7.69	no change	large decrease	medium	common	good	fair
scarlet oak	WDL	medium	1.1	132.72	100	very large decrease	very large decrease	medium	common	lost	lost
Scots pine	NSH	FIA	7.9	52.04	13.56	unknown	unknown	N/A	common	NNIS	NNIS
serviceberry	NSL	low	2.3	2.39	0.9	very large decrease	very large decrease	medium	rare	lost	lost
shagbark hickory	WSL	medium	20.3	170.84	14.43	small decrease	large decrease	medium	common	fair	fair
Shumard oak	NSL	low	1.1	26.35	19.85	small decrease	small decrease	high	rare	poor	poor
Siberian elm	NDH	FIA	3.4	24.62	6.18	unknown	unknown	N/A	rare	NNIS	NNIS
silver maple	NSH	low	7.9	156.11	16.8	no change	no change	high	common	good	good
slippery elm	WSL	low	1.1	3.45	2.6	no change	small increase	medium	rare	fair	good
southern hackberry (sugarberry)	NDH	medium	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
striped maple	NSL	medium	0	0	0	unknown	unknown	medium	modeled	unknown	unknown
sugar maple	WDH	high	12.4	232.78	22.31	small increase	no change	high	common	very good	good
swamp white oak	NSL	low	11.3	111.55	8.4	small increase	small decrease	medium	common	very good	fair
sweetgum	WDH	high	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
sycamore	NSL	low	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
tamarack (native)	NSH	high	3.4	43.14	10.83	small decrease	small decrease	low	rare	poor	poor
white ash	WDL	medium	20.3	75.45	5.39	large increase	large increase	low	common	very good	very good
white mulberry	NSL	FIA	3.4	11.1	2.79	unknown	unknown	N/A	rare	NNIS	NNIS
white oak	WDH	medium	21.2	269.85	12.86	small increase	no change	high	common	very good	good

¹ N/A: Not available.

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Table 38 (continued).—Modeled projections of habitat suitability for tree species in the Detroit region

Common name	Range	MR	percent-Cell	FIA sum	FIAiv	ChngCl45	ChngCl85	Adapt ¹	Abund	Capabil45	Capabil85
white spruce	NSL	medium	3.4	49.33	12.39	large decrease	large decrease	medium	rare	poor	poor
winged elm	WDL	medium	0	0	0	new habitat	new habitat	medium	absent	new habitat	new habitat
yellow birch	NDL	high	2.3	29.2	11	large decrease	large decrease	medium	rare	poor	poor
yellow-poplar	WDH	high	1.1	3.72	2.8	large increase	large increase	high	rare	good	good

¹ N/A: Not available.

Table 39.—Definitions of headings and supporting documentation for Table 38

Heading	Heading definition
Species common name	Species common name used by the Forest Service, Forest Inventory and Analysis (FIA) program.
Range	Code for species distribution characteristics throughout the eastern United States. Codes for distribution: wide (W) or narrow (N), first letter; codes for commonness: dense (D) or sparse (S), second letter; and codes for importance value: high (H) or low (L). If there is an “X” in the fourth position of the code, the species was so rare as to be unreliably modeled. Distribution was based on the percentage of the eastern United States occupied by the species (wide ≥ 10 percent occupied, narrow < 10 percent). Commonness was based on the percentage of 10-km $\times$ 10-km cells with the species detected by FIA (dense ≥ 40 percent, sparse < 40 percent). Importance was based on the mean importance value where present (high ≥ 5, low < 5). This code thus gives a quick evaluation of the nature of the species distribution throughout the eastern United States (Iverson et al. 2008).
MR	The model reliability of the model predicting current and future suitable habitat (high, medium, low) for the species. A code of “FIA” indicates that the model is unacceptable for predicting into the future; thus the change classes and capability classes are unknown (Iverson et al. 2008).
percentCell	The percentage of cells within the 1-degree $\times$ 1-degree of latitude/longitude (or other area) zone which has FIA records for the species according to the 10-km $\times$ 10-km or 20-km $\times$ 20-km cells. It does not mean the species actually covers that amount of ground within the sample area. If the percentCell is less than 5 percent for any species, it is recorded as Abund = Rare regardless of the FIASum (Peters et al. 2019).
FIAsum	The area-weighted sum of the importance values (IVs) per 100 square kilometers (sq. km), so it is based on both abundance and area occupied within the zone, calibrated to 10,000 sq. km, the approximate area of a 1-degree $\times$ 1-degree zone at 35 degrees latitude. This is the primary variable to sort on for ranked abundance of species within the region. These values have been corrected for partial 1-degree $\times$ 1-degree zones (to 10,000 sq. km), and for varying sizes north to south (curvature of Earth makes zones narrower toward the poles), or partial coastal grids, according to their proportion of a full 1-degree $\times$ 1-degree zone at mid-latitudes (35 degrees) (Iverson et al. 2017, Peters et al. 2019).
FIAiv	The average IV according to FIA records for the species. This provides an indication of abundance of the species where it is found, not including where it is absent.
ChngCl45	Class of potential change in habitat suitability by 2100 according to the ratios of future (2070 through 2099) suitable habitat for an average of three general circulation models (GCMs) to current (1981 through 2010) modeled habitat at RCP 4.5 (Iverson et al. 2011).
ChngCl85	Class of potential change in habitat suitability by 2100 according to the ratios of future (2070 through 2099) suitable habitat for an average of three GCMs to current (1981 through 2010) modeled habitat at RCP 8.5 (Iverson et al. 2011).
Adapt	Adaptability score for the species, according to a literature review of 12 disturbance and 9 biological characteristics, or Modification Factors. Scores have been classified as high (> 4.5), medium (3.5 to 4.5), and low (< 3.5) (Brandt et al. 2017).
Abund	The abundance of the species based on the last FIA inventory cycle; it is simply a classification of FIASum into abundant (FIAsum > 500), common (FIAsum 50 through 500), rare (FIAsum > 0 and < 50), modeled (only in modeled output), and absent (FIAsum = 0). If the percentCell is less than 5 percent for any species, it is recorded as Abund = rare regardless of the FIASum.
Capabil45	Capability at RCP 4.5; it is an estimate of capability for the species to cope with the changing climate, at RCP 4.5, within the assessment area based on its current abundance (Abund) within the zone, change class (ChngCl45), and adaptability (Adapt). Ranks are coded very good, good, fair, poor, very poor, FIA only (no model, no capability assigned), NNIS (no model, nonnative invasive species), unknown (insufficient data to model), and new habitat (potential to migrate into the zone) (Iverson et al. 2019, Peters et al. 2015, Prasad et al. 2016).
Capabil85	Capability at RCP 8.5; it is an estimate of capability for the species to cope with the changing climate, at RCP 8.5, within the assessment area based on its current abundance (Abund) within the zone, change class (ChngCl85), and adaptability (Adapt). Ranks are coded very good, good, fair, poor, very poor, FIA only (no model, no capability assigned), NNIS (no model, nonnative invasive species), unknown (insufficient data to model), and new habitat (potential to migrate into the zone) (Iverson et al. 2019, Peters et al. 2015, Prasad et al. 2016).

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APPENDIX 7: MODIFICATION FACTORS FOR ASSESSING ADAPTIVE CAPACITY OF TREE SPECIES IN URBAN AREAS

Modification Factor scores, based on Matthews et al. (2011), were developed for 187 tree species that either are already present or have the potential to gain habitat in the Detroit region. The purpose of these scores is to provide managers and policymakers with regional information about individual species which will allow potential suitable habitat distribution models to be considered in a local context based on specific variables within their jurisdiction. This approach will assist interpretation of modeled outputs as published on the Climate Change Tree Atlas (Peters et al. 2020) and other species distribution models.

Scoring System

Each species was given individual scores for each Modification Factor; these scores were then weighted and converted into an overall Disturbance, Biological, and Adaptability score.

Following are the definitions for the scoring system.

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

ModFactor—A Modification Factor that is considered to affect the establishment, growth, mortality rate, and regeneration of a species and that could reduce or increase the habitat suitability or future abundance for that species. See the next 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), that relates to the potential influence a ModFactor has on the species throughout its range at the present.

Uncert—A default score (multiplier to Score) reflecting the level of uncertainty about the influence of the ModFactor on the distribution of the species. Scores are 0.5 = highly uncertain, 0.75 = somewhat uncertain, and 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 ($\text{Score} \times \text{Uncert} \times \text{FutureRelevance}$) for the species throughout its range.

Average disturbance score—The average of all the weighted disturbance factor scores; it relates to 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 the 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 Converted Bio score. Values can range from 0 to 8.5.

Adapt class—Categories assigned based on Adapt score. Low: less than 3.5. Medium: 3.5 to 4.5. High: more than 4.5.

Factors for Trees in Natural and Other Undeveloped Areas

These scores were developed for native, naturalized, and invasive species in the Detroit region for use in natural areas and other areas where trees naturally regenerate. Scores for native species were primarily based on those developed by Matthews et al. (2011), with most information derived from Burns and Honkala (1990). For invasive species, information was gleaned from various sources, including the USDA PLANTS Database (USDA Natural Resources Conservation Service 2023) and invasive species fact sheets developed by Federal and State agencies. Additional information for windstorm 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 pest and disease influences such as oak wilt and Biscogniauxia (Hypoxylon) canker. Factors that received a weighted score of less than -4.5 or greater than 4.5 were listed as contributing negatively or positively, respectively, to the overall adaptability score of the species in tables. Weighted scores between these two values were not listed.

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: Score = -1, Uncert = 0.75, and FutureRelevance = 2.

Insect pests—Accounts for the number and severity of insects that may attack the 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: Score = -1, 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: Score = -2 (+1 if promoted by browsing), Uncert = 0.75, and FutureRelevance = 1.

Invasive plants—The effects of invasive plants on the 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: 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: Score = -1, Uncert = 0.75, and FutureRelevance = 5.

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 flooding exposure under climate change. Defaults for all species: Score = -1, Uncert = 0.75, and FutureRelevance = 4.

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

Wind—The damaging effects of windstorms and uprooting potential (and top breakage) of a species: Score = -1, Uncert = 0.75, and FutureRelevance = 2. If a species is susceptible to windthrow, the standard default is Score = -2; if the species is generally resistant to windthrow, Score = +1.

Salt—The sensitivity of a species to road salt and salt spray; includes tolerance of any alternative ice control substances (assuming that information is available). Defaults for all species: 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.

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 fire exposure 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: Score = -1, Uncert = 0.75, and FutureRelevance = 2.

Harvest—If the species is harvested 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: 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 diverse 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: Score = 1, Uncert = 0.75, and FutureRelevance = 2.

Air pollution—Airborne pollutants that affect, mostly negatively, the growth, health, and distribution of the species. This category includes acid deposition and ozone. Defaults for all species: 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 the species. Defaults for all species: Score = -1, Uncert = 0.5, and FutureRelevance = 1.

Biological Factors

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

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 wide 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: Score = 0, Uncert = 0.75, and FutureRelevance = 2.

Environmental habitat specificity—Considers the range of nonedaphic 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: 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: 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: 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 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: Score = 1, Uncert = 0.75, and FutureRelevance = 2.

Fire regeneration—The capability of 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 vegetation reproduction. Defaults are: Score = 0, Uncert = 0.75, and FutureRelevance = 2.

An example score for naturally regenerating boxelder is given in Table 40.

Table 40.—Example of natural Modification Factor scores generated for the species boxelder

FactorType	ModFactor	Score	Uncert	Future Relevance	Weighted
disturbance	disease	-1	0.75	4	-3.00
disturbance	insect pests	-1	0.5	4	-2.00
disturbance	browse	-1	0.75	1	-0.75
disturbance	invasive plants	-1	0.5	4	-2.00
disturbance	drought	3	0.75	4	9.00
disturbance	flood	2	0.75	3	4.50
disturbance	ice	-2	0.5	1	-1.00
disturbance	wind	-2	0.75	2	-3.00
disturbance	salt	1	0.50	1	0.50
disturbance	fire topkill	-2	0.75	2	-3.00
disturbance	harvest	0	0.5	2	0.00
disturbance	temperature gradients	3	0.75	2	4.50
disturbance	air pollution	-2	0.75	3	-4.50
disturbance	soil and water pollution	-1	0.5	1	-0.50
biological	competition-light	2	0.75	3	4.50
biological	edaphic specificity	2	0.75	2	3.00
biological	environmental habitat specificity	1	0.75	3	2.25
biological	dispersal	3	1	3	9.00
biological	seedling establishment	3	0.75	4	9.00
biological	vegetative reproduction	2	0.75	2	3.00
biological	fire regeneration	1	0.75	2	1.50
Average disturbance score					-0.09
Average biological score					-0.13
Converted Dist score					2.62
Converted Bio score					5.00
Adapt score					5.64
Adapt class					high

Factors for Planted Trees in Developed Areas

We created separate scores for trees planted in developed areas. Factors, scores, and weighting were modified from naturally occurring trees to account for the different growing conditions associated with areas of urban development. Many biological factors were also altered to account for the fact that dispersal and natural reproduction are not typically factors for planted trees. Most information for native species was derived from Burns and Honkala (1990) with supplementary material relevant to cultivated environments from Gilman and Watson (1993). Most information for cultivars and nonnative species was taken from Gilman and Watson (1993). Additional information for windstorm and ice storm susceptibility was obtained 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 as contributing negatively or positively, respectively, to the species overall adaptability score in tables. Weighted scores between these two values were not listed.

Disturbance Factors

Disease—Same as for natural scores.

Insect pests—Same as for natural scores.

Browse—Same as for natural scores, but default is -1 because it is assumed that herbivory would be lower in planted environments (primarily because larger trees are planted).

Invasive plants—Same as for natural scores, but default is 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 5 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.

Salt—Same as for natural scores, but defaults 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.

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

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

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

Biological Factors

Competition-light—Same as for natural scores.

Edaphic specificity—Same as for natural scores.

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

Restricted rooting conditions and soil compaction—The ability of the species to grow and survive in narrow boulevards and other constrained spaces. Defaults for all species: 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 the species is. FutureRelevance is high for this factor because it will largely determine the extent to which the species is widely propagated and planted. 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 to establish. Defaults for all species: Score = 1, Uncert = 0.75, and FutureRelevance = 2. If species is not easily established, Score = -1.

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

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

An example planted score for boxelder is given in Table 41.

Table 41.—Example of planted Modification Factor scores generated for the species boxelder

Factor Type	ModFactor	Score	Uncert	Future Relevance	Weighted
disturbance	disease	-1	0.75	2	-1.50
disturbance	insect pests	-3	0.5	5	-7.50
disturbance	browse	-1	0.75	1	-0.75
disturbance	invasive plants	0	0.5	2	0.00
disturbance	drought	3	0.75	3	6.75
disturbance	flood	2	0.75	3	4.50
disturbance	ice	-1	0.5	2	-1.00
disturbance	wind	-1	0.75	2	-1.50
disturbance	salt	1	0.50	1	0.50
disturbance	temperature gradients	3	0.75	3	6.75
disturbance	air pollution	-2	0.75	3	-4.50
disturbance	soil and water pollution	-2	0.5	1	-1.00
biological	competition-light	2	0.5	1	1.00
biological	edaphic specificity	2	0.75	2	3.00
biological	land-use and planting site specificity	1	0.75	3	2.25
biological	restricted rooting conditions and soil compaction	1	0.75	3	2.25
biological	nursery production potential	-1	0.75	4	-3.00
biological	planting establishment	2	0.75	2	3.00
biological	maintenance required	-1	0.75	2	-1.50
biological	invasive potential	-3	0.75	3	-6.75
Average disturbance score					0.02
Average biological score					0.03
Converted Dist score					2.83
Converted Bio score					3.38
Adapt score					4.41
Adapt class					medium

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APPENDIX 8: CLASSIFICATION OF DETROIT TREE SPECIES BY ALLERGEN INTENSITY (ALLERGENICITY)

Table 42.—Allergen intensity (allergenicity) of Detroit tree species considered suitable for planting (IMS Health 2022)

Allergenicity	Species common name	Estimated number of trees in Detroit
mild allergen	American beech	37
mild allergen	American chestnut	4
mild allergen	American mountain ash	--
mild allergen	Amur maackia	2
mild allergen	apple	--
mild allergen	black cherry	31
mild allergen	black locust	324
mild allergen	blackgum	42
mild allergen	Callery pear	2,936
mild allergen	cherry plum	12
mild allergen	Chinese chestnut	1
mild allergen	Chinese willow	--
mild allergen	chokecherry	12
mild allergen	cockspur thorn	27
mild allergen	common lime	--
mild allergen	common persimmon	1
mild allergen	cornelian cherry dogwood	31
mild allergen	Crimean linden	6
mild allergen	dawn redwood	108
mild allergen	downy serviceberry	8
mild allergen	eastern redbud	416
mild allergen	European beech	21
mild allergen	European buckthorn	19
mild allergen	European mountain ash	26
mild allergen	European pear	--
mild allergen	flowering dogwood	99
mild allergen	ginkgo	1,220
mild allergen	glossy buckthorn	--
mild allergen	gray dogwood	4
mild allergen	green hawthorn 'Winter King'	1
mild allergen	Higan cherry	3

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Table 42 (continued).—Allergen intensity (allergenicity) of Detroit tree species considered suitable for planting (IMS Health 2022)

Allergenicity	Species common name	Estimated number of trees in Detroit
mild allergen	honeylocust	187
mild allergen	honeylocust (thornless)	22,971
mild allergen	Japanese cherry	29
mild allergen	Japanese pagoda tree	18
mild allergen	Kentucky coffeetree	12
mild allergen	mountain silverbell	2
mild allergen	northern catalpa	1,238
mild allergen	pagoda dogwood	6
mild allergen	paradise apple	64
mild allergen	pawpaw	6
mild allergen	peach	5
mild allergen	Persian silk tree	--
mild allergen	red horse chestnut	--
mild allergen	rose of Sharon	--
mild allergen	Russian olive	11
mild allergen	Sargent cherry	4
mild allergen	sassafras	31
mild allergen	saucer magnolia	--
mild allergen	sourwood	1
mild allergen	southern magnolia	1
mild allergen	staghorn sumac	1
mild allergen	star magnolia	34
mild allergen	sweet cherry	--
mild allergen	sweetbay magnolia	18
mild allergen	sweetgum	632
mild allergen	tree of heaven	984
mild allergen	tulip tree	509
mild allergen	umbrella magnolia	1
mild allergen	Yoshino cherry	6
moderate allergen	Accolade™ elm	--
moderate allergen	American elm	2,509
moderate allergen	American linden (basswood)	2,482
moderate allergen	American sycamore	5,771
moderate allergen	balsam poplar	--
moderate allergen	bigtooth aspen	2

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Table 42 (continued).—Allergen intensity (allergenicity) of Detroit tree species considered suitable for planting (IMS Health 2022)

Allergenicity	Species common name	Estimated number of trees in Detroit
moderate allergen	black alder	--
moderate allergen	black maple	67
moderate allergen	black poplar	--
moderate allergen	cedar elm	--
moderate allergen	common hackberry	2,270
moderate allergen	eastern cottonwood	885
moderate allergen	eastern hophornbeam (ironwood)	95
moderate allergen	European hornbeam	171
moderate allergen	Freeman maple	873
moderate allergen	gray alder	1
moderate allergen	gray birch	40
moderate allergen	hedge maple	304
moderate allergen	Japanese maple	235
moderate allergen	Japanese white birch	--
moderate allergen	Japanese white pine	--
moderate allergen	Japanese zelkova	528
moderate allergen	katsura tree	49
moderate allergen	kousa dogwood	71
moderate allergen	lacebark elm	136
moderate allergen	lacebark pine	3
moderate allergen	littleleaf linden	5,396
moderate allergen	London planetree	6,971
moderate allergen	Miyabe maple	17
moderate allergen	musclewood (American hornbeam)	200
moderate allergen	northern white-cedar	594
moderate allergen	Norway maple	30,157
moderate allergen	Osage-orange	6
moderate allergen	paper birch	130
moderate allergen	paperbark maple	5
moderate allergen	quaking aspen	20
moderate allergen	red maple	7,287
moderate allergen	river birch	202
moderate allergen	Siberian elm	4,897
moderate allergen	silver birch	24
moderate allergen	silver linden	198

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Table 42 (continued).—Allergen intensity (allergenicity) of Detroit tree species considered suitable for planting (IMS Health 2022)

Allergenicity	Species common name	Estimated number of trees in Detroit
moderate allergen	silver maple	20,476
moderate allergen	slippery elm	729
moderate allergen	southern hackberry (sugarberry)	--
moderate allergen	sugar maple	5,240
moderate allergen	sycamore maple	58
moderate allergen	Tatarian maple	--
moderate allergen	trident maple	7
moderate allergen	Turkish hazel (Turkish filbert)	11
moderate allergen	white poplar	52
moderate allergen	winged elm	--
moderate allergen	yellow birch	--
severe allergen	boxelder	1,002
severe allergen	bitternut hickory	26
severe allergen	black ash	--
severe allergen	black hickory	--
severe allergen	black oak	20
severe allergen	black walnut	181
severe allergen	black willow	13
severe allergen	blackjack oak	--
severe allergen	bur oak	595
severe allergen	chestnut oak	8
severe allergen	Chinese juniper	10
severe allergen	chinkapin oak	6
severe allergen	common oak	530
severe allergen	eastern redcedar	107
severe allergen	English walnut	--
severe allergen	European ash	--
severe allergen	green ash	5,705
severe allergen	hardy pecan	7
severe allergen	Heritage® oak	--
severe allergen	mockernut hickory	3
severe allergen	northern pin oak	--
severe allergen	northern red oak	2,234
severe allergen	overcup oak	--
severe allergen	pignut hickory	9

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Table 42 (continued).—Allergen intensity (allergenicity) of Detroit tree species considered suitable for planting (IMS Health 2022)

Allergenicity	Species common name	Estimated number of trees in Detroit
severe allergen	pin oak	2,033
severe allergen	post oak	--
severe allergen	pussy willow	15
severe allergen	red mulberry	41
severe allergen	sawtooth oak	4
severe allergen	scarlet oak	38
severe allergen	shagbark hickory	70
severe allergen	shellbark hickory	1
severe allergen	shingle oak	181
severe allergen	Shumard oak	34
severe allergen	swamp white oak	858
severe allergen	turkey oak	--
severe allergen	weeping willow	93
severe allergen	white ash	855
severe allergen	white mulberry	2,308
severe allergen	white oak	232
severe allergen	willow oak	3
no allergen reported	Amur corktree	9
no allergen reported	Amur maple	107
no allergen reported	apple serviceberry	--
no allergen reported	Austrian pine	535
no allergen reported	bald cypress	36
no allergen reported	balsam fir	13
no allergen reported	Colorado spruce	450
no allergen reported	common horse chestnut	1,180
no allergen reported	common lilac	16
no allergen reported	Douglas-fir	26
no allergen reported	eastern hemlock	5
no allergen reported	eastern white pine	106
no allergen reported	European larch	2
no allergen reported	fringetree	--
no allergen reported	goldenrain tree	48
no allergen reported	hardy rubber tree	--
no allergen reported	jack pine	5
no allergen reported	Japanese tree lilac	556

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Table 42 (continued).—Allergen intensity (allergenicity) of Detroit tree species considered suitable for planting (IMS Health 2022)

Allergenicity	Species common name	Estimated number of trees in Detroit
no allergen reported	mugo pine	--
no allergen reported	nannyberry	1
no allergen reported	Norway spruce	90
no allergen reported	Ohio buckeye	31
no allergen reported	Persian parrotia	4
no allergen reported	princess tree	14
no allergen reported	red pine	11
no allergen reported	red spruce	3
no allergen reported	Scots pine	--
no allergen reported	smoketree	29
no allergen reported	tamarack	--
no allergen reported	Virginia pine	10
no allergen reported	water locust	--
no allergen reported	white fir	2
no allergen reported	white spruce	82
no allergen reported	yellowwood	79

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