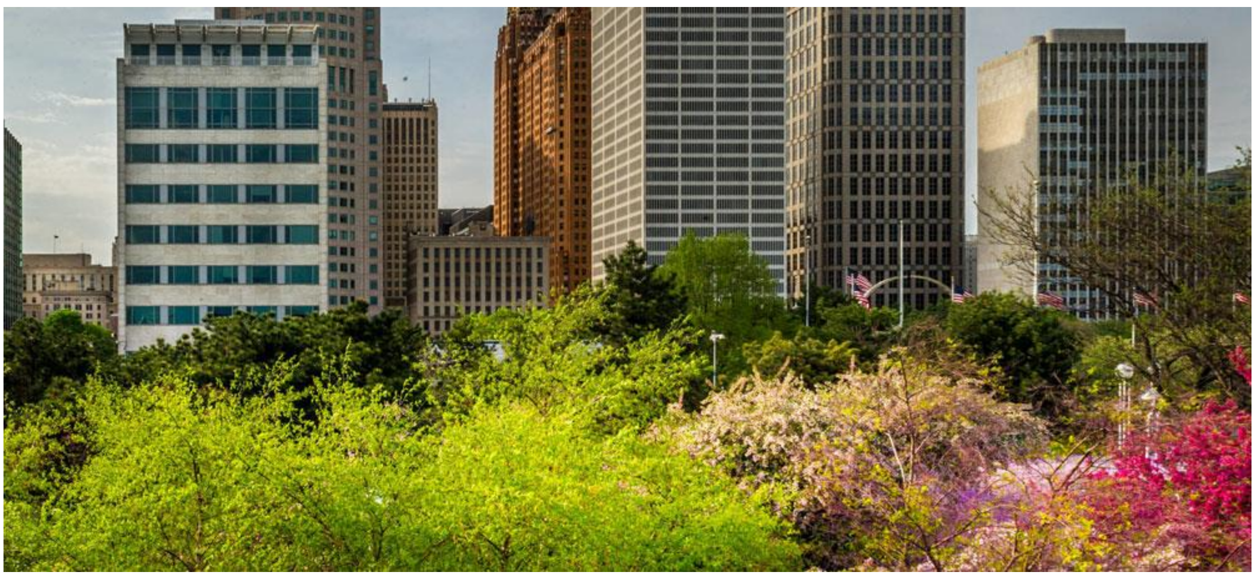
USDA Northern Forests Climate Hub
U.S. DEPARTMENT OF AGRICULTURE

URBAN FOREST VULNERABILITY ASSESSMENT AND SYNTHESIS OF THE DETROIT REGION

A Report from the Urban Forestry Climate Change Response Framework



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Climate Hub Technical Report

ABSTRACT

As the climate changes over the 21st century, Detroit's people, trees, and green spaces will face physical, biological, human health, and indirect impacts. This assessment evaluates the vulnerability of the Detroit region's urban forest. 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 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 aren't 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 Detroit. Major current threats to the region's urban forest include urban heat islands, invasive species and diseases, vacant lands, 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°F to 13°F by the end of the century compared to the 1980-2009 mean. Precipitation in Detroit has been increasing by 0.95 inches per decade since 1960 and spring precipitation is projected to increase, while other 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 heat zone 5 to between 7 and 9, depending on the emissions scenario. Species distribution modeling of native trees projects that suitable habitat will decrease for about a third of the tree species, increase for 13% of species, and remain stable for 13% of species, while 26% of native species evaluated for habitat suitability will be able to gain suitable habitat. In terms of adaptive capacity for planted/developed conditions, 27% of native species evaluated received a high adaptability score, 57% received a medium adapability score, and 16% received a low adaptability score. For natural areas (both native and naturalized), 45% of species received a high adaptability score, 46% received a medium adaptability score, and 9% received a low adaptability score. Under low emissions, the majority of Detroit tree species fell into the low-moderate vulnerability category (51%). However, more species received higher vulnerability ratings under the high emissions scenario. Nearly 14% were categorized as low vulnerability, 21% as low-moderate vulnerability, 20% as moderate vulnerability, 35% as moderate-high vulnerability, and nearly 10% 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.

Cover Photo: Michigan Department of Natural Resources

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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 Urban Forestry Vulnerability Assessment (Brandt et al., 2017) and Vulnerability of Austin's Urban Forest and Natural Areas (Brandt et al., 2020). This project incorporates lessons learned from the Climate Change Response Framework: a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects.

We designed this assessment to be a synthesis of the best available scientific information. Its primary goal is to inform those that work, study, recreate, 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.

Author Contributions and Acknowledgements

Annamarie Rutledge led the writing throughout the vulnerability assessment. Leslie Brandt developed the assessment methodology and report structure, led the analysis of tree species vulnerability and adaptive capacity, and contributed to writing and content. Matthew Peters assembled the climate projections for chapter 2. Fai Foen, Anita Harrington, and Katherine Grantham contributed local information for chapter 1. The Detroit Reforestation team, which included individuals from American Forests, Detroit Future City, SEMCOG, The Greening of Detroit, and the State of Michigan, met monthly to discuss and develop the workshop and report.

We wish to 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 also wish to thank Asia Dowtin (Assistant Professor of Urban and Community Forestry, Department of Forestry, Michigan State University), Robert E. Grese (FASLA, FCELA, Professor Emeritus of Environment and Sustainability, University of Michigan), and Christopher Hoving (Adaptation Specialist, Michigan Department of Natural Resources) for serving as peer reviewers.

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

Key Points

- Detroit is situated in the Southern Great Lakes Forest ecoregion, defined by various forest, prairie, swamp, marsh, and wetland ecosystems.
- Black or African American residents make up the majority of the local population, and its population has been declining since 1950.
- There are three watersheds within the Detroit city boundaries that empty into Lake St. Clair and the Detroit River. The eastern border of the city as well as southwest Detroit are more flood-prone.
- Pre-settlement Detroit 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 diversity of species including oak, birch, beech, hickory, sugar maple, elm, and cottonwood.
- Detroit's urban trees provide approximately $24.3 million in benefits each year, including aesthetic, air quality, net total carbon sequestered and avoided, energy, and stormwater peak flow reductions benefits.
- Stressors and threats to Detroit's urban trees include drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant lands, soil and water contamination, air pollution, and racism and economic inequality.
- Past experiences of Detroit residents have led to resistance to tree planting, which has been linked to mass elm tree removal following the 1967 Detroit Riots in particiular. Heritage narratives can help illuminate these linkages and provide deeper understanding of resident perceptions.
- Detroit's urban forest provides millions of dollars in benefits each year, including aesthetic, air quality, carbon sequestered and avoided, energy, and stormwater peak flow reductions benefits.
- Natural resource managers, nonprofit organizations, and community initiatives in the Detroit region are working to manage Detroit's urban forest to ensure 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 Detroit's urban forest and natural areas.

Key Points

- Detroit has been warming at a rate of about 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 1980-2009 mean.
- Precipitation in Detroit has been increasing by 0.95 inches per decade since 1960. Although precipitation projections vary by season and climate scenario, spring precipitation is generally expected to increase in each.
- Extreme heat and heavy precipitation events are expected to increase in intensity and become more frequent.

- Assuming a drastic reduction in global greenhouse gas (GHG) emissions, the USDA hardiness zones are projected to shift by 1-2 zones and the heat zones are projected to shift 3-5 zones, 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

- A changing climate may shift the timing of leaf-out, flowering, fruit production, and senescence in urban trees, which can cause frost and freeze damage to Michigan's fruit trees.
- Climate change can alter nutrient cycling as well as tree growth, photosynthetic, and transpiration (loss of water vapor) rates. Trees may benefit from longer growing seasons and higher CO_2 concentrations, but can be limited by available moisture and nutrients.
- The abundance and range of pests and pathogens is projected to increase under a changing climate due to increased temperatures and stressed trees, including emerald ash borer, oak borers, Asian longhorned beetle, spotted lanternfly, and oak wilt. Nonnative, invasive species are projected to spread and establish themselves as plants shift their range.
- Species diversity and ecosystem function are expected to change along with climate conditions, causing an increase in species declines and extinctions.
- Fire risk is projected to increase, but behavior is uncertain due to its dependence upon climatic shifts as well as various occurrence factors.

Chapter 4: 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

- Detroit's human population and urban forest 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, associated with health issues such as asthma, diminished lung function, increased hospital visits, and premature deaths. Changing conditions can also shift biogenic volatile organic compound (BVOC) emissions from plants as well as 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, ticks, and emerging infectious diseases (EIDs), which may shift their range, distribution, and abundance under changing conditions.
- Extreme heat is associated with heat-related diseases and mortality and poses a significant threat to Detroit residents, particularly those who are low-income, young, socially isolated, lack air conditioning, or suffer from chronic illness.
- Changes in heavy precipitation events and lake temperatures can increase waterborne diseases, lake closures, and vulnerability to runoff and septic/sewage failures.
- Climate change is expected to cause food shortages and 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 5: Tree Species Vulnerability

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

Key Points

- **Modeling Native Trees:** Species distribution modeling of native species suggests that suitable habitat will decrease for 19 species (31%) and remain stable for eight species (13%). Suitable habitat is expected to increase for eight species (13%), while 16 species (26%) may be able to colonize new, suitable habitats. The rest of the species evaluated had mixed results (17%).
- **Projected Heat and Hardiness Zone Shifts and Species Ranges:** Under a low emissions scenario, the majority of the 187 evaluated species are projected to be in a suitable range (94%), while 6% are not suitable. Under a high emissions scenario, 42% are projected to be in a suitable range, and 58% are not suitable.
- **Adaptive Capacity of Urban Trees:** Adaptive capacity of 187 species was evaluated using scoring systems for planted (187 species) and natural (94 species) environments. For planted/developed conditions, 50 species received a high adaptability score, 30 received a low adaptability score, and the remaining 107 received a medium adaptability score. For natural areas (both native and naturalized), 42 species received a high adaptability score, eight received a low adaptability score, and 43 received a medium adaptability score.
- **Overall Vulnerability of the Detroit Region's Trees:** Under a low emissions scenario, the majority of Detroit tree species fell into the low-moderate vulnerability category (51%). Over 22% were categorized as low vulnerability, nearly 20% as moderate vulnerability, 5% as moderate-high vulnerability, and 1% as high vulnerability. Under a high emissions scenario, more trees were considered vulnerable. Nearly 14% were categorized as low vulnerability, 21% as low-moderate vulnerability, 20% as moderate vulnerability, 35% as moderate-high vulnerability, and nearly 10% as high vulnerability.
    - Common species with moderate-high vulnerability include boxelder, silver maple, sugar maple, common horse chestnut, northern catalpa, white mulberry, callery pear, pin oak, American linden, and winged elm.
    - Uncommon species with low vulnerability include common persimmon, downy serviceberry, fringetree, mockernut hickory, osage-orange, sourwood, southern hackberry, umbrella magnolia, and water locust.

Chapter 6: Neighborhood Resilience and Urban Forest Vulnerability

This chapter focuses on the overall vulnerability of the urban forest in the Detroit region, with attention given to specific districts and neighborhood resilience throughout the city. Vulnerability is the susceptibility of a system to the adverse effects of climate change and is a function of a system's impacts and adaptive capacity.

Key Points

- The urban forest of the Detroit region as a whole is vulnerable to increases in temperature, heavy rain events, and shifts in composition for native and nonnative invasive species, but also has the capacity to adapt through its robust community urban forestry efforts.

- Understanding district-level vulnerabilities can help guide resource allocation and climate adaptation strategies and the relationship between public health and inequality is critical in the planning and implementation process.
- The most vulnerable neighborhoods are located in Southwest Detroit. Vacant lots and impervious surfaces are an issue throughout the city. District 5 and 6 have notable heat islands present, have higher populations without vehicle access, and higher runoff exposure while situated along the Detroit River.
- Species composition is widely distributed across the City of Detroit, contributing to similar patterns of urban tree vulnerability across districts. District 5, south central/downtown, has the most species in a moderate-high to high vulnerability category under the high emissions scenario, but all districts have a siimlar distribution of species vulnerability across low and high emissions scenarios.

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 Detroit's green spaces.
- 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.

INTRODUCTION

Context

This assessment is a fundamental component of the Urban Forestry Climate Change Response Framework project (https://forestadaptation.org/focus/urban-forests). This project builds on lessons learned from the Climate Change Response Framework: a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. Each project interweaves four components: science and management partnerships, vulnerability assessments, adaptation resources, and demonstration projects (Figure X.1). The Detroit assessment uses methods developed in the Chicago Wilderness region pilot (Brandt et al., 2017) and Vulnerability Assessment of Austin's Urban Forest and Natural Areas (Brandt et al., 2020).

Figure X.1. Climate Change Response Framework Components

The overarching goal of all Framework projects is to incorporate climate change considerations into forest management. The overall goal of the Urban project is to ensure that urban forests will continue to provide benefits to the people who live in urban communities as the climate changes. We define the urban forest as all publicly and privately owned trees within an urban area—including individual trees along streets and in backyards, as well as stands of remnant forest. The Urban project works across 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 climates scenarios and to determine the vulnerability of trees and natural and developed landscapes to those changes. In addition, this assessment synthesizes information about the contemporary landscape and projections of physical and biological climate changes used to assess these vulnerabilities. Uncertainties and gaps in information are also discussed throughout the assessment. This assessment covers the City of Detroit and the surrounding the Southeast Michigan Council of Governments (SEMCOG) region (Figure X.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% of which is considered green infrastructure and 56% tree canopy coverage of total green infrastructure.

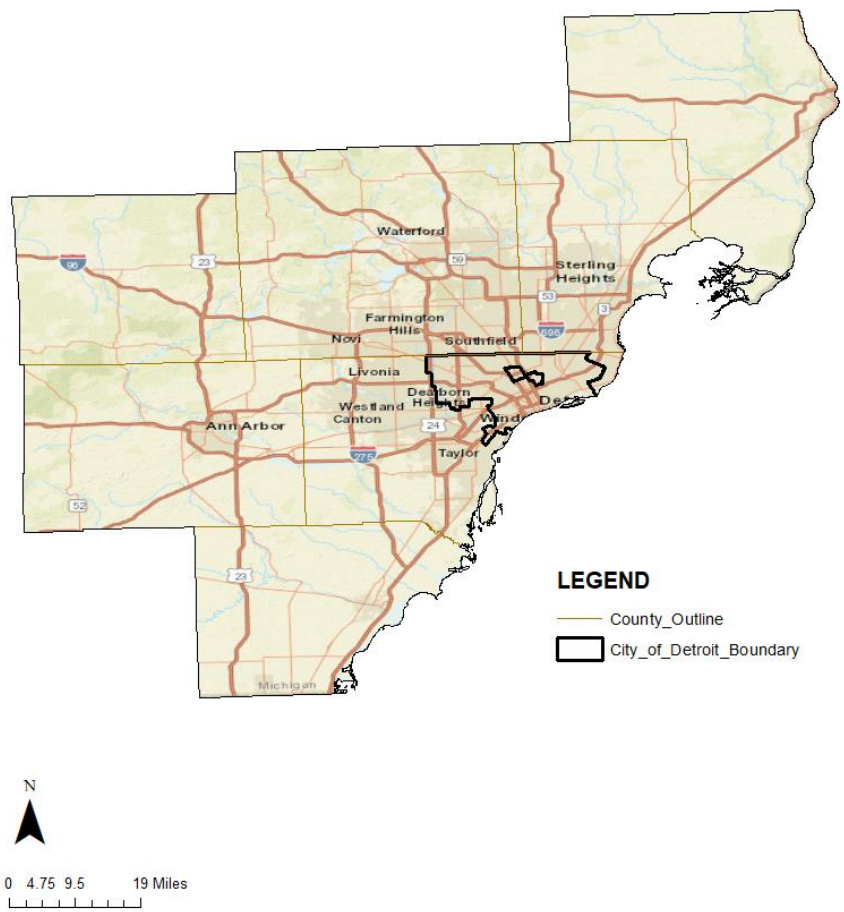

Figure X.2. Assessment Area. The assessment area includes the City of Detroit's boundary as well as the surrounding SEMCOG region.

Assessment Chapters

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

Chapter 2: Climate Trends, Projections, and Physical Impacts
Climate Trends, Projections, and Physical Impacts describes our current understanding of past and projected future changes in climate in the Detroit region, including trends and projections in extreme weather, temperature, and precipitation; effects on soils and hydrology; and shifts in heat and hardiness zones.

Chapter 3: Biological Climate Impacts
Biological Climate Impacts describes phenology shifts, physiological effects, nutrient cycling, pests and pathogens, invasive plant species, species diversity, and fire risk in the Detroit region.

Chapter 4: Human Health Impacts
Human Health Impacts describes climate-related impacts on human health including allergenicity, pests and pathogens, biogenic volatile organic compounds (BVOCs), heat-related illnesses and mortality, flooding and extreme weather events, and increases in food prices, as well as social, mental, and physical impacts.

Chapter 5: Tree Species Vulnerability
Tree Species Vulnerability describes modeled changes in Detroit's habitat suitability as well as adaptive capacity scores in the region.

Chapter 6: Neighborhood Resilience and Urban Forest Vulnerability
Neighborhood Resilience and Urban Forest Vulnerability provides a summary overview of the vulnerability of the Detroit region as well as an overview of key climate impacts and adaptive capacity factors in each of the seven districts in Detroit.

Chapter 7: Management Implications
Management Implications 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.

CHAPTER 1

The Contemporary Landscape

The urban forest is defined as all publicly and privately owned trees within an urban area—including individual trees along streets and in backyards—as well as stands of remnant forest (Nowak et al., 2001). Detroit's natural and glacial history 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 Detroit's urban forest, the forces that shaped it, and current stressors. This information lays the foundation for understanding how shifts in climate contribute to changes in Detroit's trees and urban forests, 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, including Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties (Figure 1.1). 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. It has a population of almost 79% Black or African American residents (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 is also a designated Ramar site. The site has 16 acres of restored wetlands and 25 acres of restored upland buffer habitat, and invasive species have been controlled on 50 acres of upland habitats. Through a partnership with The Greening of Detroit, over 350 trees have been planted on the site.

Although Detroit's population has continued to decline 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 (1985-2015), 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). Over 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.

The City of 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 that threaten both human and environmental health (Gregg et al., 2012).

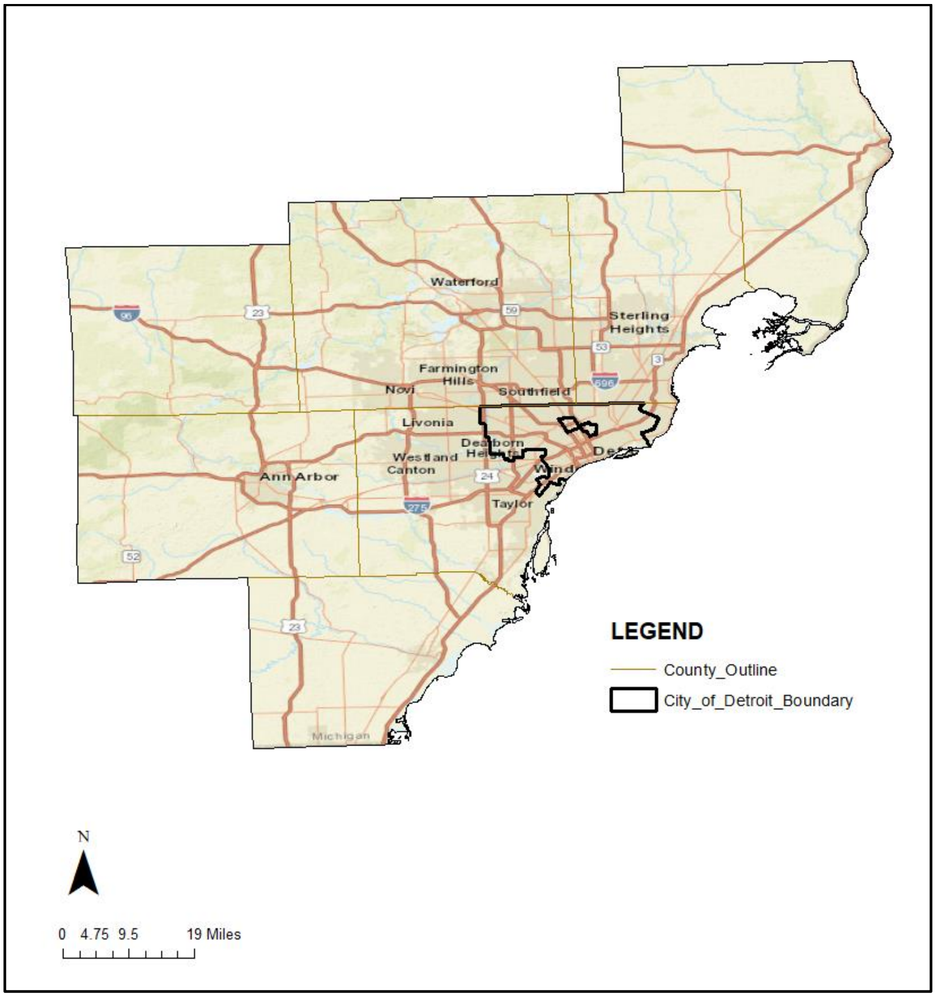

Figure 1.1. Assessment Area. The assessment area includes the City of Detroit's boundary as well as the surrounding SEMCOG region.

More Information on Trees in the Detroit Region

The resources below provide more information regarding the urban forest in the Detroit region:

- Detroit's Tree Management Plan (2016) focuses on short- and long-term maintenance needs for public trees in their inventory. Inventory data paired with analysis provided an understanding of Detroit's conditions and needs of the 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 GIS files that can be downloaded on the scale of county, place, and county subdivision: https://www.nrs.fs.fed.us/data/urban/state/?state=MI

Other resources and plans that influence trees and vegetation in the Detroit area:

- 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 Michigan's plants, animals, invasive species, and natural communities and provides resources, services, programs, projects, and publications related to the state's natural features: 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/government/mayors-office/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 Detroit's Climate Action Plan: https://detroitenvironmentaljustice.org/, https://toolkit.climate.gov/reports/detroit-climate-action-plan#:~:text=The%2077%2Dpage%20report%20contains,and%2080%20percent%20by%202050
- The City of Detroit and Wayne County Forestry Office provide tree services to Detroit communities: https://detroitmi.gov/departments/general-services-department/tree-services, https://www.waynecounty.com/departments/publicservices/roads/forestry-office.aspx
- Michigan's Terrestrial Invasive Species Management Plan outlines terrestrial invasive species in the state, a statewide strategy to reduce environmental and economic impacts, and recommendations for action: http://169.62.82.226/documents/dnr/Terrestrial_invasivesp_plan_618659_7.pdf
- 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 resiliency: https://www.hrwc.org/what-we-do/programs/climate-change/climate-resilient-communities/tree-resilience-toolkit/

Geology, Soils, and Hydrology

Michigan's landscape was shaped primarily during the last ice age. The movement of the last ice sheet—the Wisconsin Glacier—left a significant impact 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. These processes determined many of the landscape characteristics we see today, such as soil types, hydrologic flows, and historic 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 the soil can hold, impacting forest and plant dynamics and stormwater management in the city of Detroit and surrounding areas. Detroit's most common soil types (Figure 1.2) are soils produced from glacial outwash and derived from deposited lake sediments.

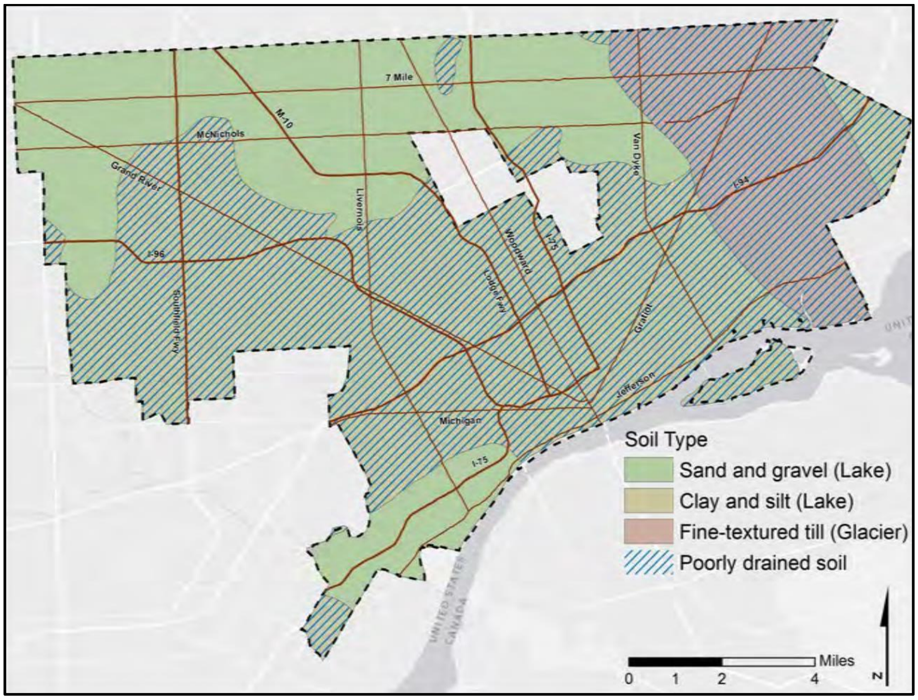

Figure 1.2. Detroit Underlying Soil Types and Drainage. "Lake" refers to soils from deposited lake sediments, while "glacier" refers to soils produced from glacial outwash. Source: Michigan Geographic Data Library, Michigan Quaternary Geology Map. Prepared By: University of Michigan Detroit Climate Capstone.

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 area's watersheds 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 0.002mm in diameter (clay), to 3mm to 75mm 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 strongest types closer to the Detroit River.

Soil types also impact 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) can't 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 the north and northeast of Detroit, which drains more quickly resulting in less runoff.

Michigan's glacial processes have influenced present watersheds in the Detroit area. Detroit is placed within the Great Lakes watershed, moving water through Lake Superior, Lake Michigan, Lake Huron, the St. Clair River, Lake St. Clair, the Detroit River, Lake Erie, Lake Ontario, and to the St. Lawrence River, emptying into the Atlantic Ocean. There are three watersheds within the Detroit boundary, two of which empty into Lake St. Clair (Lake St. Clair and Clinton watersheds) and one that empties into the Detroit River (Rouge watershed) (Figure 1.3). 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.

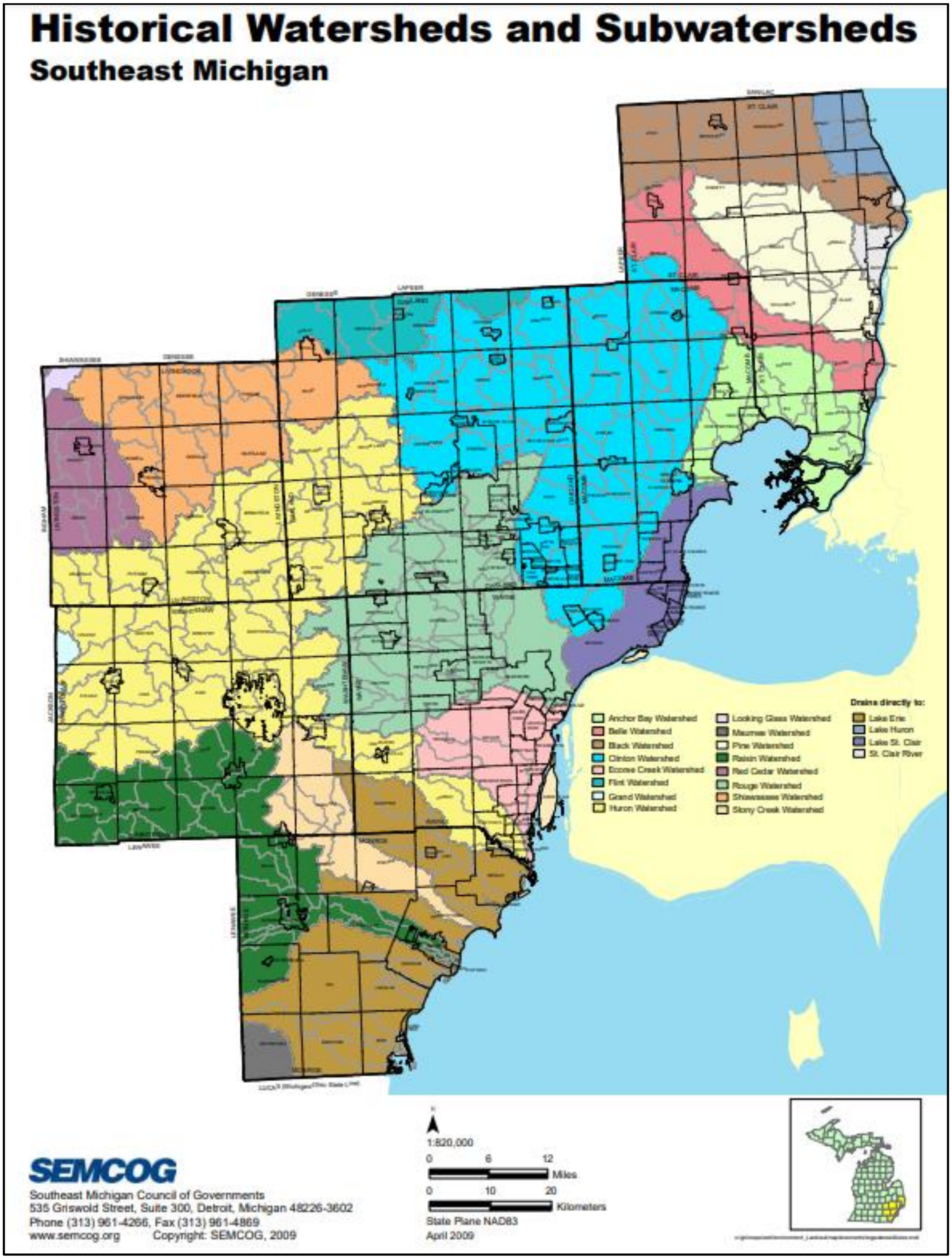

Figure 1.3. Historical Watersheds and Subwatersheds in the SEMCOG Region. Source: SEMCOG.

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

Vegetation

The glacial and soil deposition processes, in addition to more general climate characteristics, have helped determine the region's vegetation composition. Classified as mesic southern forest, pre-settlement Detroit was dominated by beech and sugar maple communities. 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, which favors a combination of beech and blash ash, while oak-hickory was found on drier uplands. The eastern border of the city as well as southwest Detroit remain more prone to flooding compared to other parts of the city, both of which were historically swamp and marsh conditions.

Detroit and its surrounding region are presently located in the Midwest Broadleaf Forest Eco Province. This eco province features flat to hilly terrain associated with glaciation and vegetation including cold-deciduous, hardwood forests (EDC, 2020). Many species are able to tolerate mild, short, and occasional droughts during the late summer season. The USDA Forest Service's Forestry Inventory and Analysis (FIA) program determined that surrounding areas have a diversity of species, predominantly the historic species of oak (*Quercus*), birch (*Betula*), beech (*Fagus*), hickory (*Carya*), and sugar maple (*Acer saccharum*), as well as elm (*Ulmus*) and cottonwood (*Populus*) (Gregg et al., 2012).

<u>Natural Communities</u>

Michigan Natural Features Inventory Community Classification 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.

Historic landcover of the SEMCOG region includes a mixture of upland and lowland forests along with non-forested wetlands. Mesic maple-beech (*Acer-Fagus*) forests were historically more common in the eastern portion of the region, while dry-mesic oak-hickory (*Quercus-Carya*) forests were more in the western portion (Figure 1.4).

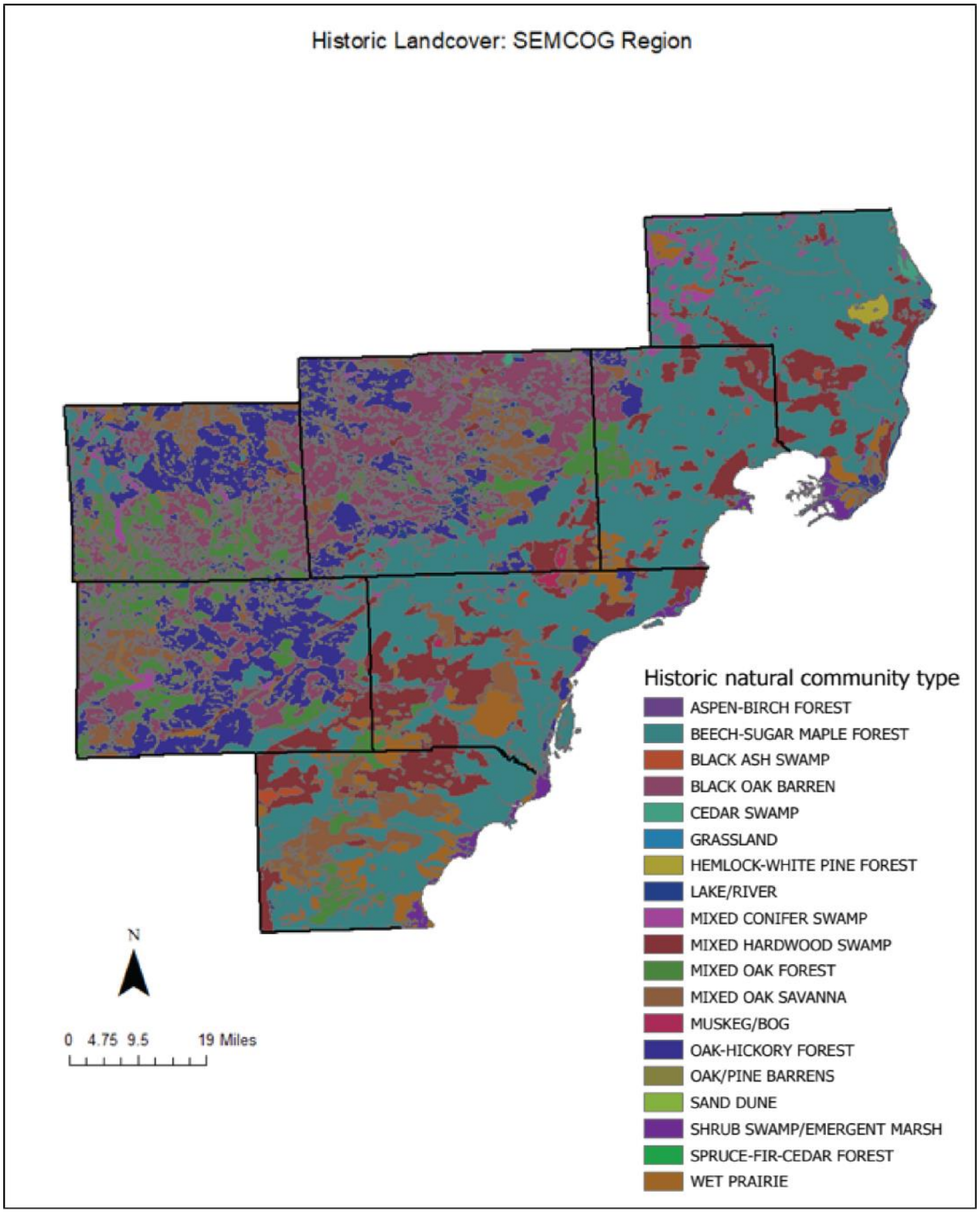

Figure 1.4. Historic Landcover of the SEMCOG Region: Pre-european Settlement of Natural Communities. The scope of the communities list is terrestrial forested ecosystems, focusing on dominant tree species. Source: Michigan Native Landscape.

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.

Floodplain Forest

Floodplain forest is a bottomland, deciduous or deciduous-conifer forest community occupying low-lying areas adjacent to streams and rivers of third order or greater, and subject to periodic over-the-bank flooding and 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. In Detroit, this type of forest can be found in the Rouge River Corridor including the area of the former Rogell Golf Course (Rogell Site Analysis, 2018).

Upland Mesic Forest/Mesic Southern Forest

Mesic southern forest is an American beech (*Fagus grandifolia*)- and sugar maple (*Acer saccharum*)-dominated forest 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 a significant source of intermediate disturbance, thinning the canopy and promoting tree regeneration. Dominant species of the canopy are American beech (*Fagus grandifolia*) and sugar maple (*Acer saccharum*), which account for up to over 80% of the canopy composition (Cohen et al., 2020).

Upland Dry-mesic Forest/Dry-mesic Southern Forest

Dry-mesic southern forest is a fire-dependent, oak (*Quercus*) or oak-hickory (*Quercus*-*Carya*) forest type on generally dry-mesic sites found south of the climatic tension zone in southern Lower Michigan. Frequent fires maintain semi-open 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 (*Quercus alba*) and black oak (*Quercus velutina*), with white oak being the more frequent dominant. Red oak (*Quercus rubra*) can occur as a canopy species under the right conditions. Hickories such as pignut hickory (*Carya glabra*), shagbark hickory (*Carya ovata*), and bitternut hickory (*Carya cordiformis*) 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 (Rogell Site Analysis, 2018). Other examples are found in Palmer and Pitcher Parks (Weatherbee & Klatt, 2004).

Lakeplain Oak Openings

Lakeplain oak openings are a fire-dependent savanna community, dominated by oaks (*Quercus*) and characterized by grass or grass-like ground layer of species associated with both lakeplain prairie and forest communities. 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 (*Quercus velutina*) and white oak (*Quercus alba*). Bur oak (*Quercus macrocarpa*), pin oak (*Quercus palustris*), and swamp white oak (*Quercus bicolor*) are prevalent on flat, poorly drained areas. Ground species include: big bluestem (*Andropogon gerardii*), bluejoint grass (*Calamagrostis canadensis*), Pennsylvania sedge (*Carex pensylvanica*), blazing star (*Liatris spp.*), little bluestem (*Schizachyrium scoparium*), bluejoint grass, tussock sedge (*Carex stricta*), sedge (*C. aquatilis*), twig-rush (*Cladium mariscoides*), switchgrass (*Panicum virgatum*), Virginia mountain mint (*Pycnanthemum virginianum*), cordgrass (*Spartina pectinata*), and Indian grass (*Sorghastrum nutans*). An example of this type of community can be seen as a remnant in the Rouge River-Rogell area of Detroit (Rogell Site Analysis, 2018).

Wet-mesic Flatwoods

Wet-mesic flatwoods is a wet to mesic forest on mineral soils dominated by a highly diverse mixture of upland and lowland hardwoods occurring 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 level. Dominant trees include oaks (*Quercus)*, hickories (*Carya*), maples (*Acer*), ashes (*Fraxinus*), and basswood (*Tilia*). 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 overlay 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.

Wet-mesic flatwoods 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 (*Quercus rubra*), Shumard oak (*Quercus shumardii*, state special concern), white oak (*Quercus alba*), swamp white oak (*Quercus bicolor*), chinquapin oak (*Quercus muhlenbergii*), pin oak (*Quercus palustris*), bur oak (*Quercus macrocarpa*), shagbark hickory (*Carya ovata*), bitternut hickory (*Carya cordiformis*), shellbark hickory (*Carya laciniosa*), American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), black maple (*Acer nigrum*), silver maple (*Acer saccharinum*), red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica*), white ash (*Fraxinus americana*), pumpkin ash (*Fraxinus profunda*, state threatened), and basswood (*Tilia americana*) (Cohen et al., 2020). This type of community can be found on Belle Isle. It has been impacted by altered hydrology due to development on the island, altered soils (fill), and invasive species such as the emerald ash borer (*Agrilus planipennis*), invasive shrubs and grasses, and browse pressure from introduced European fallow deer (removed in 2004). Oak (*Quercus*) 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).

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. 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 (*Acer saccharinum*), red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica*), and black ash (*Fraxinus nigra*). 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 shallowly rooted and prone to frequent blowdown. Windthrow creates a pit and mound microtopography as well as variously sized canopy gaps, which promote regeneration of a diverse overstory. Prior to the introduction and spread of Dutch elm disease, American elm (*Ulmus americana*) was an important canopy constituent, but is now largely relegated to the subcanopy and sapling layers. Typical shrub species include spicebush (*Lindera benzoin*), elderberry (*Sambucus canadensis*), winterberry (*Ilex verticillata*), and buttonbush (*Cephalanthus occidentalis*). 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 and Palmer Parks. Another type of wetland forest community proposed by Weatherbee is the Oak Wetland Forest dominated by oaks (*Quercus*) and found in Detroit at Balduck Park (Weatherbee & Klatt, 2004). Other non-forested 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.

Current Conditions in the Detroit Region

According to the most recent city street tree inventory, most of Detroit's trees are considered to be in fair or better condition (City of Detroit, 2016). Much of Detroit's right-of-way is composed of three species:

Norway maple (*Acer platanoides*, 18%), thornless honeylocust (*Gleditsia triacanthos inermis*, 14%), and silver maple (*Acer saccharinum*, 13%) (City of Detroit, 2016). Maple (*Acer*) species make up 41% of trees on the street right-of-way (City of Detroit, 2016). The city is currently lacking sufficient young trees for an ideal diameter size class distribution.

The City of Detroit has seen an increase in the number of vacant parcels since 2006, and a sizable portion of the General Services Department and Detroit Parks and Recreation Department (DPRD) budget goes toward managing vacant land (City of Detroit, 2017). The General Services Department and DPRD 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). Detroit's parks range from 0.07 acres to 1,181 acres, totaling 4,899 acres of park space (Figure 1.5). Many neighborhoods with low canopy cover are in inner-city areas, which are also high priority planting areas (Figure 1.6).

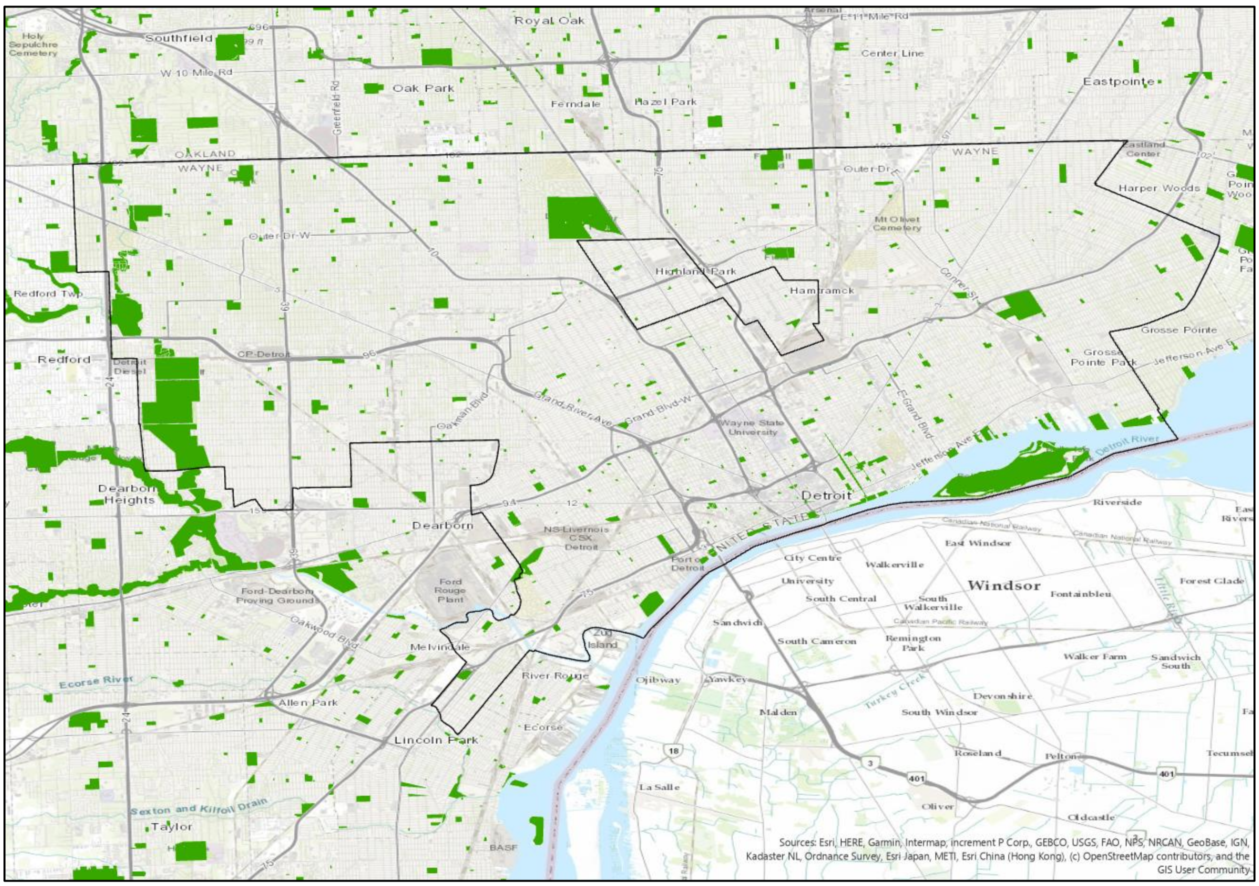

Figure 1.5. Detroit Parks. Source: SEMCOG.

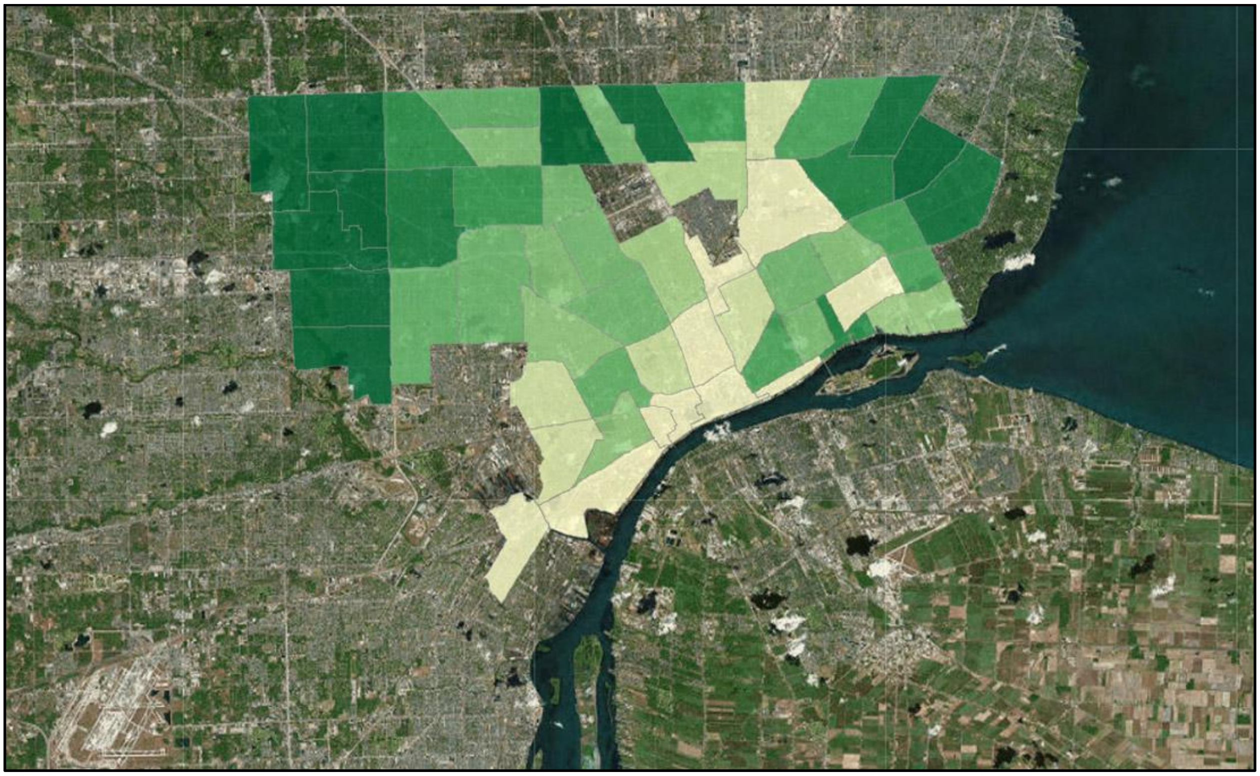

Figure 1.6. Detroit Canopy Cover by Neighborhood. Lighter shades indicate lower canopy percentages. Credit: The University of Vermont.

Detroit's urban trees provide approximately $24.3 million in benefits each year, broken down into aesthetic, air quality, net total carbon sequestered and avoided, energy, and stormwater peak flow reductions benefits (City of Detroit, 2016). Increasing the urban tree canopy can reduce ambient temperatures, control stormwater, provide animal habitat, increase health benefits, reduce crime, and provide aesthetic value and greater social cohesion (USDA Forest Service, 2021). According to ParkScore, Detroit is 73rd in the nation when it comes to park access (70/100), acreage (22/100), amenities (31/100), and investment (41/100) (2020). Although only 6% of Detroit's city land is used for parks and recreation, 80% of residents live within a 10-minute walk to a park (national average is 55%). 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 the community.

Major Stressors and Threats

Detroit's urban forest currently faces a variety of stressors including drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant lands, soil and water contamination, air pollution, as well as racism 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, while the average annual temperature in Ann Arbor increased by 0.2°F throughout the same time period (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. According to the most recent data from the National Land Cover Database, 36.3% of the land is developed, 28.4% is forested, and 30.3% is used for agriculture in the SEMCOG region (Table 1.1). Most of Detroit's land cover is developed (76.5%), which contributes to impervious surfaces (Figure 1.7, Table 1.1). 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 apply 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, otherwise known as the urban heat island (UHI) effect (Figure 1.8).

Table 1.1 Land Cover and Use in the SEMCOG Region. Source: National Land Cover Database, 2016.

	Open Water	**Developed**	**Barren Land**	**Forest**	**Non-forest 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**

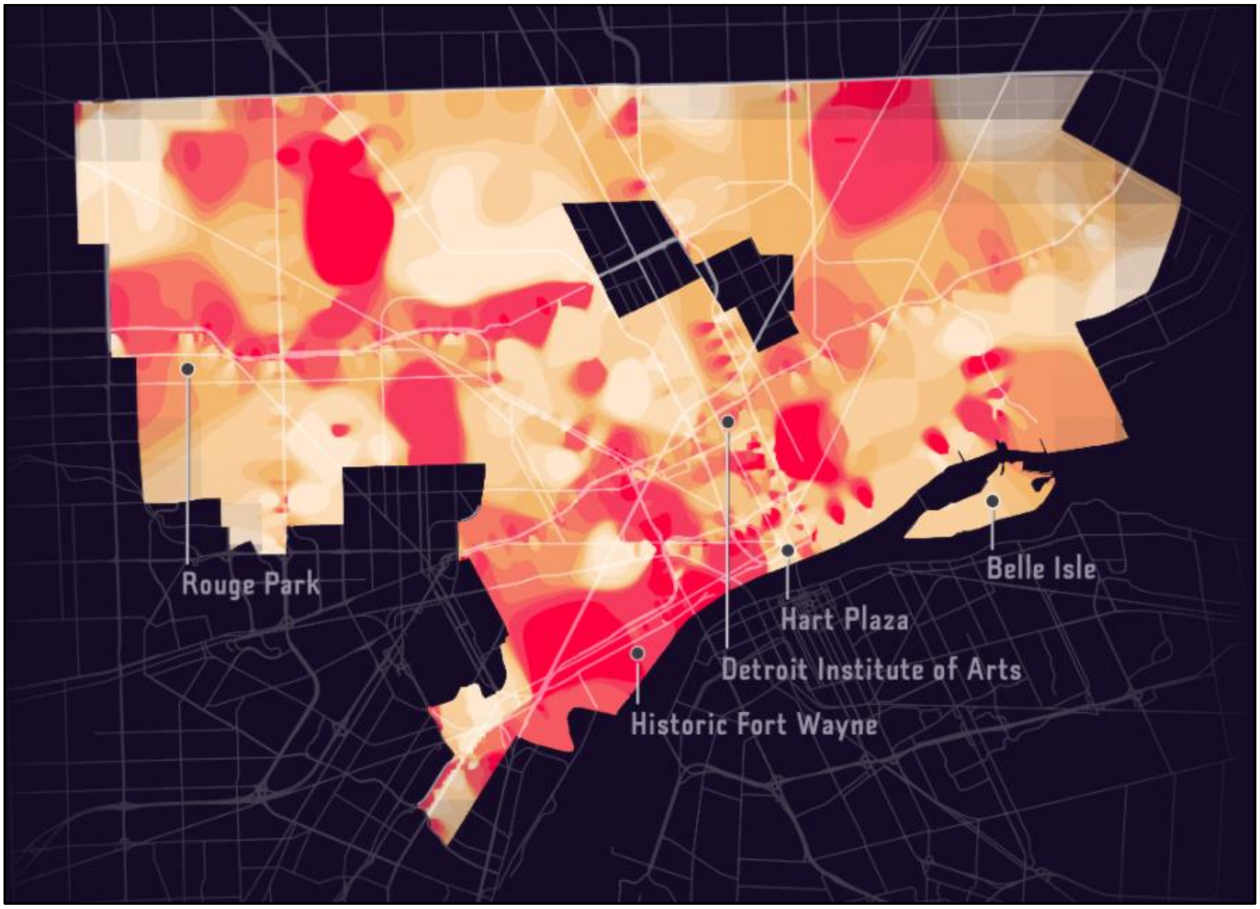

Figure 1.7. Detroit Urban Heat Islands. Maximum urban heat island is represented by red and the minimum is represented by white. Source: Heat in the City, 2020.

The average annual temperatures of UHI areas in Detroit are 1.8°F to 5.4°F warmer than adjacent areas, ranging from 70°F to 85°F (Gregg et al., 2012; Heat in the City, 2020). 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 experience significant UHI effects, and UHI pockets 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 UHI pockets, which are often dependent on the qualities of the land as well as its use.

Invasive Species and Diseases

Detroit has lost significant tree canopy because of invasive species and diseases. 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 CWMA (Cooperative Weed Management Area), Lake St. Clair CISMA, Oakland County CISMA, GiLLS CISMA (Genesee, Lapeer, Livingston, and Shiawasee), and Jackson, Lenawee, and Washtenaw CISMA in the SEMCOG region (State of Michigan, 2021a).

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 (*Ophiostoma ulmi*, *Ophiostoma himal-ulmi, and Ophiostoma novo-ulmi)* and is spread by elm bark beetles—typically by the European elm bark beetle (*Scolytus multistriatus*) and sometimes by the American elm bark beetle (*Hylurgopinus rufipes*). Its hosts include American (*Ulmus americana*), English (*Ulmus procera*), and winged elm (*Ulmus alata*) trees. Many cities had planted elms as fast-growing shade trees in neighborhood streets, including 400,000 trees in Detroit 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 (LaButte, 2020). 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 ginkgos to avoid these risks.

Emerald ash borer (EAB), *Agrilus planipennis*, was discovered in Detroit in 2002. Initial surveys found that EAB population densities and the associated tree mortality were the highest in the greater Detroit area compared to the rest of Michigan (Poland & 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 more urban ports of entry, which is suspected in the case of EAB. The larvae disrupt ash trees' ability to transport water and nutrients by feeding on the inner bark of the tree, while 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, there are over 3,000 dead ash trees scheduled for removal in the city's right-of-ways. According to the Emerald Ash Borer Information Network, EAB has killed more than 30 million ash trees in southeastern Michigan (2018). Although Michigan repealed its EAB internal quarantine in 2018, EAB has future potential to kill additional trees, as ash species (*Fraxinus*) have no immunity to the pest (Emerald Ash Borer Information Network, 2018). To replace this loss in canopy, The Greening of Detroit planted over 65,300 trees since 2002, in addition to hundreds of trees distributed through tree sales and giveaways, with over 50,000 volunteers contributing 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 (*Anoplophora glabripennis*, ALB) also poses notable risk to city trees (City of Detroit, 2016). Although ALB is not currently detected in Detroit, the city currently has over 65,800 maple trees, ALB's favorite host (State of Michigan, 2021b). ALB can also attack and kill additional tree species such as poplar, sycamore, willow, and 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, 2021). Populations in Illinois, New Jersey, and Toronto have been successfully eradicated and early detection is crucial. If populations continue to spread, significant economic and ecological impacts are expected.

Vacant Lands

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 significant 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 a significant 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. According to DLBA's FY 2021 Q1 report, DBLA has an inventory of 85,159 total properties and an economic value of $676,539,916 to Detroit's neighborhoods (2020).

There are 15,855 vacant, DLBA-owned structures that fall into three categories: for sale (2,514), salvage candidates (4,765), and demolition (8,576). 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, 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. Current vacant property registrations are displayed in Figure 1.8.

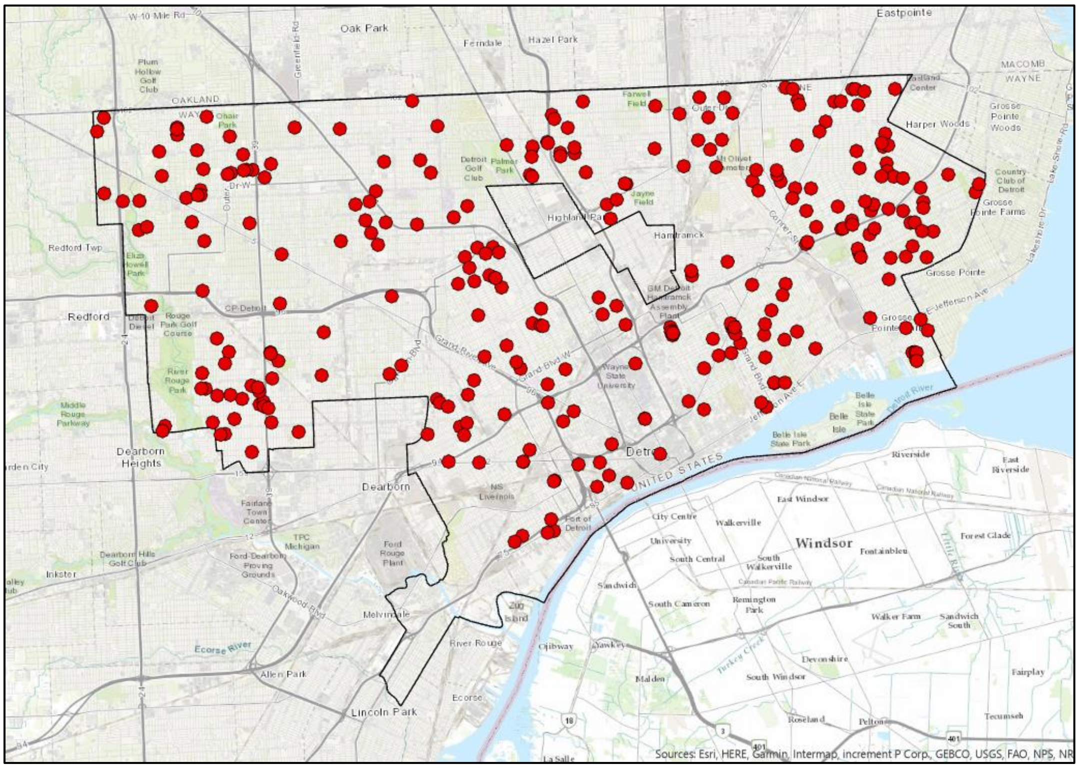

Figure 1.8. Detroit Vacant Property Registrations 2020. Source: City of Detroit, 2021.

Although there continues to be notable vacant land in the city, vacant lots also provide opportunities for community green space development 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 prioritizing vacant land, which can be transformed into gardens, orchards, tree nurseries, pocket parks, and other green spaces and productive landscapes that provide community benefits.

Soil, Water, and Air Pollution

Soil Contamination

Detroit is a post-industrial city with high residential density and historic adjacency to industry, making soil contamination a concern. Lead hazards and contamination are due to lead paint in older housing stock built before 1978, as well as existing pollution from factories, car exhaust, and industrial smelters (CLEARCorps/Detroit, 2004). More than half of Detroit's housing was built prior to 1950, when most homes used lead-based paint. Historic home demolition processes have demolished structures into basements and/or released unabated lead paint onto vacant land. Lead also occurs naturally in soils around concentrations of 10 to 50 mg/kg, but larger concentrations can pose both an environmental and physiological threat. In 2019, the U.S. Department of Housing and Urban Development awarded the City of Detroit with $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 movement into groundwater and other waterways. A newly developing partnership with the USDA Forest Service will collect and analyze soil, tissue, and leaf samples to determine the uptake of contaminants and benefits to local communities. The increase of wet weather could potentially increase soil remediation by this treatment.

There is currently research underway using trees to remediate soil contaminants, specifically 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, in order to apply the existing biomass research within local site conditions. The native and hybrid poplar (*Populus*) and willow (*Salix*) species, chosen for their unique soil remediation abilities, also thrive in saturated soil conditions. Environmental benefits include a reduction in stormwater runoff and blight and an increase in curbside appeal.

Water Contamination

Detroit's source water comes from the Detroit River, within the Lake St. Clair, Clinton River, Detroit River, Ecorse River, and Rouge River watersheds in the U.S., as well as parts of the Thames River, Little River, Turkey Creek, and Sydenham watersheds in Canada (City of Detroit, 2020). The city's drinking water is currently deemed clean and safe to drink, meeting or exceeding all state and federal regulatory standards (City of Detroit, 2019a). 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), and found that all samples were below the EPA's action level. However, lead can contaminate drinking water due to corrosion in service lines as well as household plumbing that contains lead. DWSD customers are provided a corrosion inhibitor to reduce the corrosion of pipe materials into their drinking water.

Additional contaminants that may be present in Detroit's source water include microbial contaminants (viruses and bacteria), inorganic contaminants (salts and metals), organic chemical contaminants (synthetic and volatile organics), pesticides and herbicides, and radioactive contaminants (City of Detroit, 2020). While small amounts of these contaminants may be found in drinking water, the amount is regulated by the EPA.

As the climate changes, storms and extreme flooding events can result in increased stormwater runoff (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 (CSOs) into waterways and a reduction in water quality.

A prominent topic in regard to water quality is stormwater management. Stormwater management is commonly improved by Green Stormwater Infrastructure (GSI), which reduces runoff volume, filters pollutants, and cuts down on flooding. DWSD has built 16 GSI projects in recent years, managing a total of 24.5 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 volatile organic compounds (VOCs), contributing to ozone and carbon monoxide formation. VOC emission rates vary by species and atmosphere. For example, in atmospheres containing low nitrogen oxide concentrations, VOCs have the potential to remove ozone (Nowak, 2002).

While air quality has continued to improve throughout the region over the past 20 years, southeast Michigan is currently designated nonattainment for ozone. This means that the region does not meet the EPA ozone standard of 70 ppb. This standard was lowered from 75 ppb to 70 ppb in 2015. The last average concentration between the 7 monitors was 70 ppb in 2020. The region will be required to obtain the ozone standard in 2021. If the standard is not met, southeast Michigan will be designated marginal nonattainment, which will require the state to develop a State Implementation Plan (SIP), a strategy for how southeast Michigan will achieve the ozone standard. As part of this plan, the Department of Environment, Great Lakes, and Energy (EGLE) is beginning to look into how tree canopy and increasing tree plantings and vegetation can support improved air quality, especially in more vulnerable regions.

Social and Economic Inequality

Social and Political Dynamics

There are notable social and political dynamics in Detroit stemming from issues of racism and economic inequality (Carmichael & McDonough, 2019). There is a spectrum of uncertainty in terms of how much residents blame climate change for health risks, and how much they blame built infrastructure and government management. Historical trauma has caused inevitable 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 a time in Detroit's history following the 1967 Detroit Riot, when large-scale removal of diseased elms occured in resident neighborhoods.

A history of insufficient civic services, investment, and opportunity for native Detroiters has affected their relationship with and perceptions of trees and the urban forest. 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, tree roots clogging sewer systems, raised sidewalks, and increased rodent populations. Many residents feel as though they are left with an enormous burden of the negative externalities associated with the long-term maintenance of trees.

Street Tree Acceptance

Non-profit organizations play a key role in urban and community forestry strategies and approaches, but these efforts can and have been resisted by residents (Carmichael & 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 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, submitted a "no-tree request" (NTR) between 2011 and 2014 (Carmichael &

McDonough, 2018). Street tree acceptance, or lack thereof, imposes a barrier to improving urban tree canopy in the city.

The key reason for resistance to tree-planting may be the power dynamics among stakeholders. Here, the nonprofit was the decision-maker in terms of which trees to plant and where, causing residents to feel as though their values weren't integrated into the program (Carmichael & 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 NTR were aware of the benefits of trees, but their response was ultimately rooted in historical experiences in Detroit, or "heritage narratives" (Carmichael & McDonough, 2018). In addition, residents expressed maintenance concerns and a desire for greater decision-making in species selection. Residents who wanted more decision-making power also assumed they would ultimately be responsible for stewardship, which reflects upon their historical experiences. Negative experiences with trees were often attributed to the lack of city tree maintenance and 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.

In response to the NTRs, nonprofits such as The Greening of Detroit have made changes to their programming, including more material involvement of 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 community, versus Winship, versus Hubbard Farms, versus Morningside can be very different, and it is important to recognize and honor these differences. A community tree planting application continues to be a useful tool to demonstrate the need of a community group for trees. At any one time, hundreds of trees are backlogged due to funding limitations. Targeting larger geographic neighborhood areas anchored by city parks allows for the flexibility of offering street trees with tailored community engagement, without the pressure of having to "convince" residents to accept trees they are not interested in, while servicing those who are ready for trees. Matching tree plantings with a larger scale tree removal schedule is an area ripe for 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's important to provide tree options, 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 trees' public health benefits and pontential for money saving by reducing energy costs. Creative approaches that engage residents of all ages, particularly youth, through multiple channels could be explored further. Multi-year campaigns tied to the city, nonprofits, schools, institutions, public events, partnerships, and social media could increase interest.

Extreme Heat and Precipitation

Detroit is vulnerable to increasing temperatures and experiences disproportionate, compromised health compared to the rest of Michigan. 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 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: 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, all of which 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 dissseminating 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, and/or financially inaccessible.

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 as well as pathways such as the Community Emergency Response Team (CERT). The CERT program provides education on disaster preparedness and trainings 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 increases, Detroit also becomes more vulnerable to precipitation-related health impacts due to stormwater overflow and water pollution (Sampson et al., 2014). Health effects include mold, asthma, respiratory diseases, diseases from raw sewage, and toxins from 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 experience increased temperatures and precipitation events, it's important to understand how we can address climate change impacts and also limit the social, health, and economic disparities residents experience, incorporating the concerns and priorities of community members (Sampson et al., 2014).

Current Management

Community Initiatives

Community planting initiatives have been a significant factor in the reforestation efforts in Detroit. A key figure in this work has been The Greening of Detroit, a nonprofit that has helped combat the effects of Dutch elm disease, emerald ash borer, and the decline of city-funded reforestation. Since its inception, The Greening of Detroit has engaged volunteers to plant over 133,000 trees in Detroit, Hamtramck, and Highland Park. The nonprofit has worked with District Managers and Detroit's General Services, Planning, Office of Sustainability, and Water and Sewage Departments to decide 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 with educating the next generation and implementing green infrastructure, such as the transformation of vacant lots into shrubs, trees, and/or wildflowers.

The efforts of nonprofits, 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 The Greening of Detroit, Southeast Michigan Council of Governments, Michigan Department of Natural Resources, USDA Forest Service, Detroit Water and Sewerage

Department, and Michigan Department of Environmental Quality to inventory and reforest trees in Detroit. By implementing cooperation between various public and private entities, Detroit can strengthen urban-forestry and partnerships between the entities such as SEMCOG, Davey Trees, and The Greening of Detroit.

Many measurements in the forestry realm include quantitative measures such as the number of trees planted, how many trees survived after a period of time, and how many volunteers were engaged. While these are important to document, 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. There is a need for willpower and local leads to pilot big ideas, engage residents in stewardship, and develop policies from inside the community.

Detroit's Climate Action Plan and Sustainability Action Agenda

Detroiters Working for Environmental Justice (DWEJ), an organization working to improve the economic and environmental health of Detroit, established the Detroit Climate Action Collaborative (DCAC) in 2011 (GLISA, 2017). DCAC is composed of universities, state agencies, private organizations, environmental organizations, community-based nonprofits, and the City of Detroit (Gregg et al., 2012). DCAC has provided expert advice to identify short- and long-term actions for greenhouse gas (GHG) emissions reductions and to ready Detroit residents for the impacts of climate change (GLISA, 2017). This led to the development of Detroit's Climate Action Plan.

Detroit's 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). Each of these areas had a workgroup that 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 nonprofits, businesses, academic institutions, and government organizations. DWEJ also commissioned an economic report and three studies examining the impact of the Detroit Climate Action Plan, including a Detroit Vulnerability Study, Detroit Climatology Study, and Greenhouse Gas Inventory.

The City of Detroit's Sustainability Action Agenda is the result of a year-long process incorporating research, community engagement, and interdepartmental collaboration (City of Detroit, 2019b). It was released in summer 2019 as the first sustainability plan for the city, outlining a road map to develop Detroit into a more sustainable city, where residents can thrive. It aims to create a more equitable, green city where Detroiters can access affordable, quality homes; live in clean, more connected neighborhoods, and work together to manage resources.

There are various action items in the Sustainability 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 top 20 census tracts that have vulnerable populations most impacted by pollution as well as heat island effects. Additional action items include enhancing infrastructure and operations to enhance resilience to climate impacts (Action 9), creating neighborhood-scale, distributed green infrastructure projects (Action 34), incorporating green stormwater infrastructure into street redesign and greenway projects (Action 35), and integrating climate change impacts into hazard mitigation planning (Action 36).

Summary

Detroit's urban forest, shaped in part by its natural and glacial history, still cntains various forested communities in the landscape interspersed between developed areas. Current stressors and threats to Detroit's urban forest include drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant lands, soil, water and pollution, air quality, and social inequity. Detroit's Tree Management Plan (2016) was developed to focus on short- and long-term maintenance needs for public trees in their inventory, while Detroit's Climate Action Plan and 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 composed of 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 its population has been declining since 1950.
- There are three watersheds within the Detroit city boundaries that empty into Lake St. Clair and the Detroit River. The eastern border of the city as well as southwest Detroit are more flood-prone.
- Pre-settlement Detroit 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.
- Detroit's urban trees provide approximately $24.3 million in benefits each year, including aesthetic, air quality, net total carbon sequestered and avoided, energy, and stormwater peak flow reductions benefits.
- Stressors and threats to Detroit's urban trees include drought, flooding, strong storms, urban heat islands, invasive species and diseases, vacant lands, soil and water contamination, air pollution, and racism and economic inequality.
- Past experiences of Detroit residents have led to resistance to tree planting, which has been linked to mass elm tree removal following the 1967 Detroit Riots in particiular. Heritage narratives can help illuminate these linkages and provide deeper understanding of resident perceptions.
- Detroit's urban forest provides millions of dollars in benefits each year, including aesthetic, air quality, carbon sequestered and avoided, energy, and stormwater peak flow reductions benefits.
- Natural resource managers, nonprofit organizations, and community initiatives in the Detroit region are working to manage Detroit's urban forest to ensure it continues to provide benefits for the community.

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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 age ended more than 11,000 years ago, the climate in the Detroit region shifted from cool and moist to hot and dry, before eventually becoming the climate we experience today. Detroit's climate is heavily influenced by The Great Lakes and tends to experience cold winters accompanied by moderate snowfall, as well as hot summers with moderate-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 (IPCC, 2018a). 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). Model outputs included annual and seasonal observations and projections of temperature and precipitation as well as extreme events (temperature ≤ 0°F, temperature ≥ 90°F, precipitation ≥ 1 inch, and precipitation ≥ 2 inches). The GRIDMET and MACAv2-METDATA datasets (Abatzoglou, 2012), respectively, were processed using Google Earth Engine (Gorelick et al., 2017) to obtain various indices. A 30-year baseline period of 1980-2009 and three future periods (2010-2039, 2040-2069, 2070-2099) from the HadGEM2-ES (Jones et al., 2011) and IPSL-CM5A-MR (Dufresne et al., 2013) general circulation models under the representative concentration pathways (RCP; Moss et al., 2008) 4.5 and 8.5 represent a range of potential warming and precipitation changes. RCP 4.5 represents a scenario where greenhouse gas emissions are reduced dramatically from current rates, whereas RCP 8.5 is consistent with a business-as-usual greenhouse gas emission scenario. 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 secnario 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 precipitation and temperature from the simulated baseline period to the future periods was used to adjust observed data prior to calculating the climate indices. It's important to note that each model contains uncertainty, with more uncertainty associated with precipitation and timing of conditions.

Historical climate trends were retrieved from the National Oceanic and Atmospheric Administration's (NOAA) Climate at a Glance tool (NOAA, 2020). Climate at a Glance was developed to facilitate near real-time analysis of monthly temperature and precipitation data across the contiguous U.S. and intended for the study of climate variability and change. It is important to note that some of the very recent data (in the last few months) are preliminary, and therefore are subject to change.

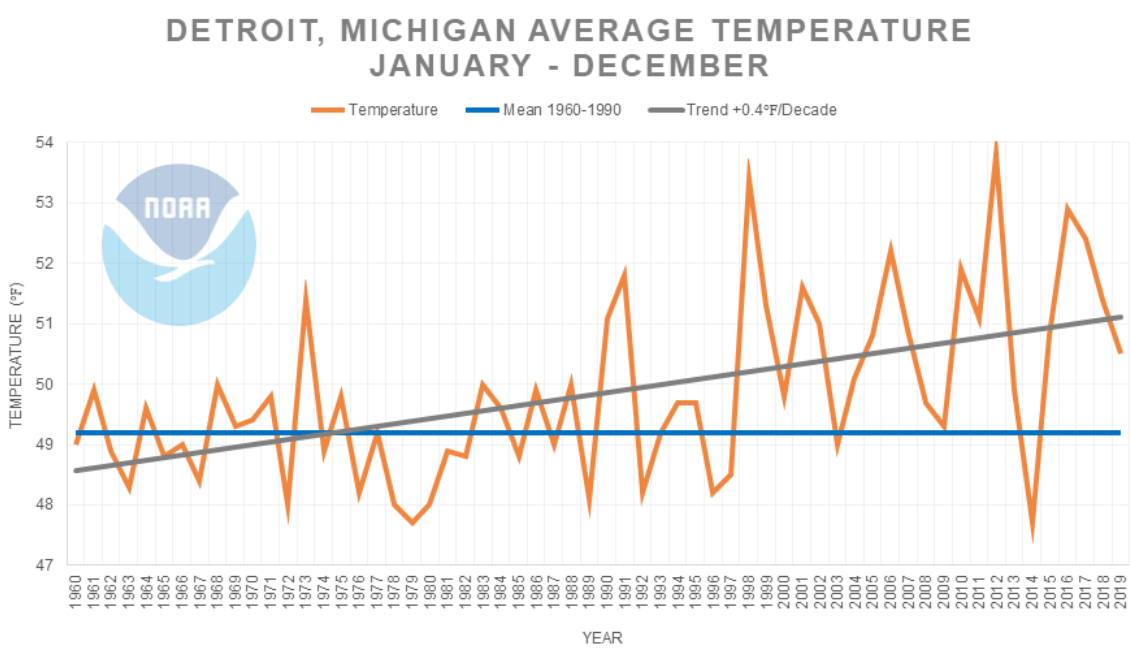
Observed Trends

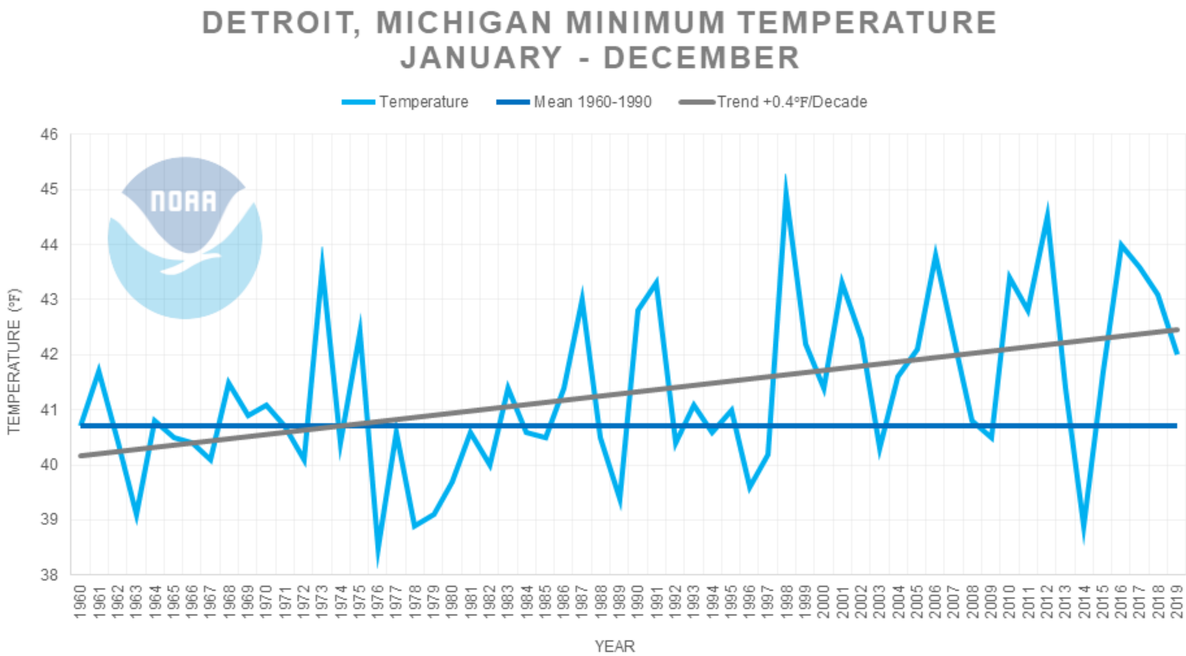
Temperature

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

Comparing 1961-1990 to 1981-2010, the 30-year average annual temperature has increased by 1.4°F (GLISA, 2017). From 1959 to 2011, average overnight temperatures increased by 4.3°F (GLISA, 2017). During that same period, the number of hot, humid summer days increased by 3.5 (172%) and the number of hot, dry summer days increased by 3 (338%) (GLISA, 2017). Contrarily, the number of cool, dry days has decreased by 10.5 (70%) (GLISA, 2017).

The average annual temperature in Detroit has increased from 1960 to 2019 by 0.4°F per decade, and the average annual minimum and maximum temperatures follow a similar trend (Figures 2.1). Examining the average temperature (1960-2019) 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) (Appendix 1). The trend varies by season, increasing the most in December to February (+0.7°F/decade) and the least in September to November (+0.3°F/decade).





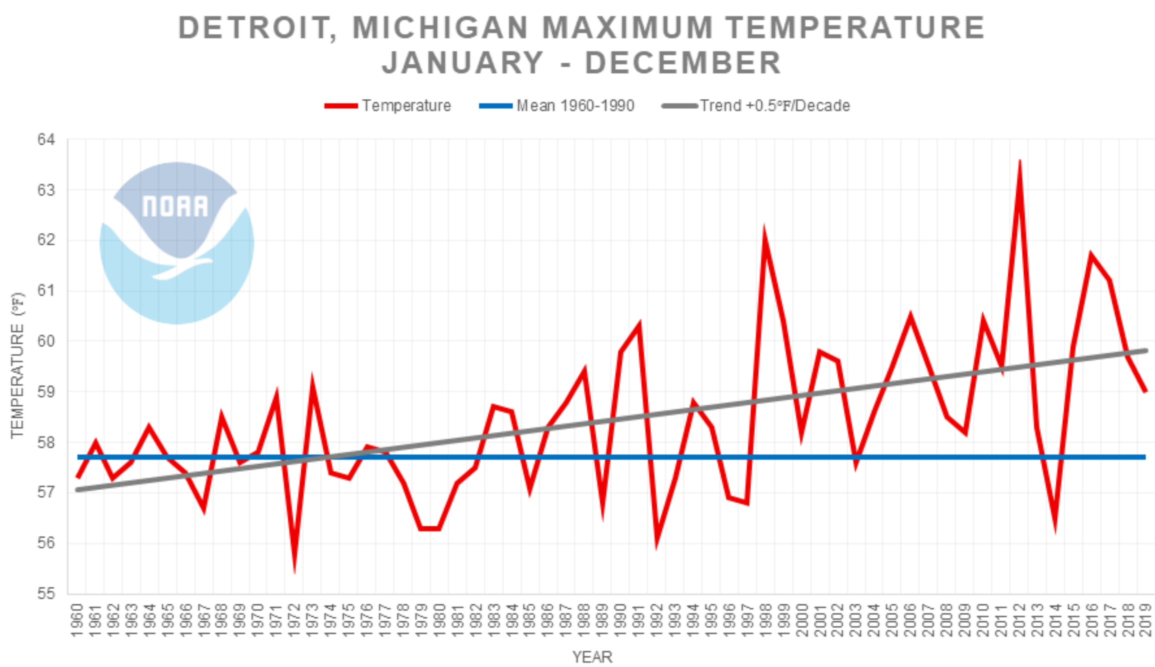


Figure 2.1. Changes in Annual Temperature Over the Observational Record from 1960 to 2019 for Detroit, Michigan Including Average, Minimum, and Maximum Temperatures January - December. The gray line indicates the 1960-1990 average and the blue line shows the trend over the observational record. Source: NOAA, https://www.ncdc.noaa.gov/cag/

Precipitation

Michigan's climate is classified as humid continental, characterized by distinct summer and winter seasons and a relatively equal precipitation distribution throughout the year. June is Detroit's wettest month (average 3.6 inches), and January and February are the driest months, experiencing less than two inches of precipitation (1.95 and 1.78 inches, respectively). Extreme precipitation events have become more frequent and more intense. Comparing the 1961-1990 average to the 1981-2010 average, the total annual precipitation in southeast Michigan increased by 11% (GLISA, 2017). Annual precipitation in Detroit has increased from 1960 to 2019 by 0.95 inches per decade (Figure 2.2). Looking at the seven-county SEMCOG region, precipitation has increased in each season from 1960 to 2019 (Appendix 1). The increasing trend is the greatest in March to May (+0.42 inches/decade) and September to November (+0.43 inches/decade), and the least in June to August (+0.15 inches/decade).

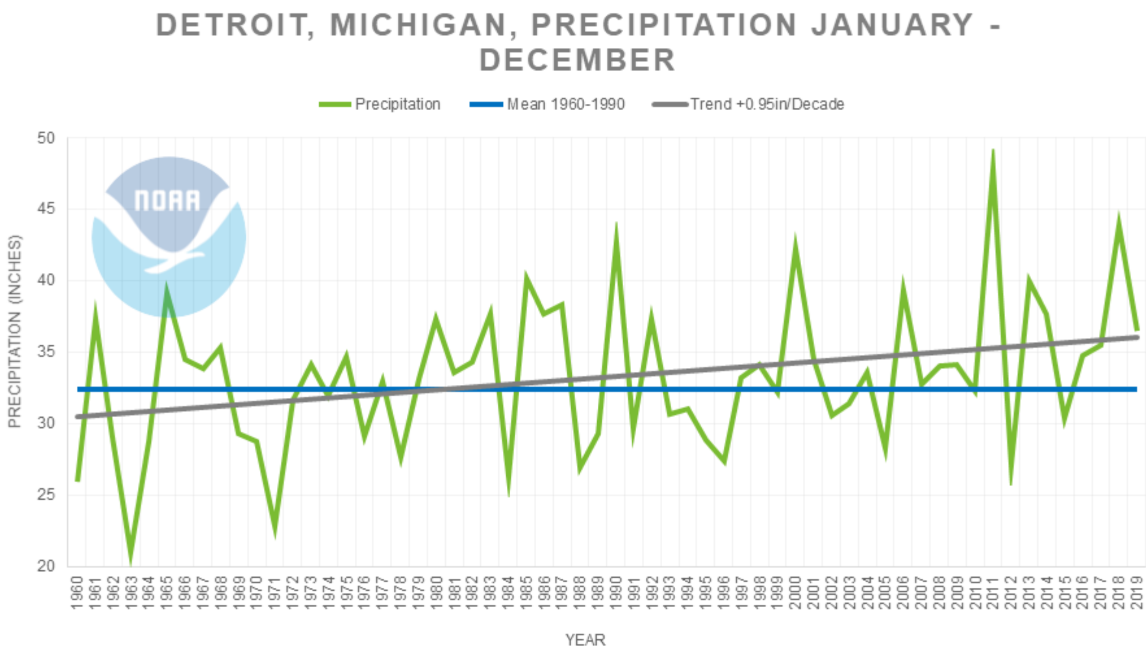


Figure 2.2. Changes in Annual Precipitation Over the Observational Record from 1960 to 2019 for Detroit, Michigan Including Average, Minimum, and Maximum Temperatures January - December. The gray line indicates the 1960-1990 average and the blue line shows the trend over the observational record. Source: NOAA, https://www.ncdc.noaa.gov/cag/

Climate Projections

Temperature

The warming trend is expected to continue, and the extent and intensity will depend on the amount of future greenhouse gas (GHG) emissions. Temperatures are projected to increase across all seasons, GHG scenarios, and models over the rest of the century in the SEMCOG region compared to the 1980-2009 mean (Table 2.1, Appendix 2). The increase in mean annual temperature ranges from 5°F to 13°F for the last 30 years of the century compared to the 1980-2009 mean, depending on the GHG scenario and climate model. The summer season has the greatest projected increase, ranging from over 5°F to over 14°F, and winter and fall seasons have a very similar range. Spring temperature is projected to have the smallest increase, ranging from over 4°F to just over 9°F. Temperature projections by time period and climate scenario are outlined in Table 2.1.

Precipitation

Average 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 mean precipitation in the Detroit and SEMCOG region is expected to increase 16% on average, which is equivalent to about 4.9 inches.

In the SEMCOG region, precipitation projections vary by season and climate scenario (Table 2.1, Appendix 3). Generally, precipitation is expected to increase in the winter and spring, decrease in the summer, and remain relatively steady in the fall.

- Winter precipitation is projected to increase under warm-dry (HAD45) and hot-wet (HAD85) climate scenarios across all three time periods, and under warm-wet (IPSL45) climate scenario in 2070-2099. By the end of the century, winter is projected to experience a decrease in precipitation of over 1 inch or an increase of nearly 4 inches, depending on the climate scenario.
- Spring precipitation is projected to increase in each climate scenario and time period, ranging from 1.5 to 3 inches by the end of the century.
- In the summer when the temperatures are hottest, precipitation is projected to decrease in most models with the exception of the warm-wet (IPSL45) scenario in time periods 2010-2039 and 2070-2099. By the end of the century, summer months could experience a decrease of about 3 inches to an increase of 0.4 inches depending on the climate scenario.
- Fall precipitation is projected to increase under the warm-wet (IPSL45) scenario, remain relatively constant under the warm-dry (HAD45) scenario, and varies for hot-dry (IPSL85) and hot-wet (HAD85) scenarios. By the end of the century, the fall season is projected to stay the same or increase by 0.5 inches, depending on the climate scenario.

Table 2.1. Average Temperature, Precipitation, and Extreme Events Projections Under Warm-wet (IPSL45), Hot-dry (IPSL85). Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties, All Averaged). See Appendix 4 for individual county data.

	Average (1980-2009)	2010-2039				2040-2069				2070-2099			
		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)	Hot-wet (HAD85)
	Temperature (°F)												
Winter	26.7	28.9	28.8	29.7	31.4	30.6	31.6	35.4	35.8	31.1	35.7	36.3	41.0
Spring	47.1	49.9	48.8	49.8	48.5	51.0	52.5	52.2	53.0	51.6	55.7	53.5	56.4
Summer	70.0	72.2	72.4	73.4	73.2	75.0	76.3	76.4	78.1	75.2	81.8	78.9	84.4
Fall	50.8	53.0	54.3	55.0	54.6	54.9	57.3	56.9	59.1	56.4	61.1	59.5	64.6
Annual	48.6	51.0	51.1	51.9	51.8	52.8	54.4	55.2	56.4	53.6	58.5	56.9	61.6
	Precipitation (inches)												
Winter	6.1	5.8	6.0	6.3	6.4	5.7	5.8	7.3	7.5	9.8	4.7	7.0	8.8
Spring	8.3	9.3	9.4	8.5	9.1	8.9	9.5	10.5	9.6	9.8	10.0	10.2	11.3
Summer	9.9	10.0	9.3	8.8	9.6	8.6	8.5	8.0	6.7	10.3	7.7	8.7	7.0
Fall	8.9	9.4	8.8	9.0	10.1	9.0	8.7	9.0	8.3	9.2	9.3	8.9	9.4

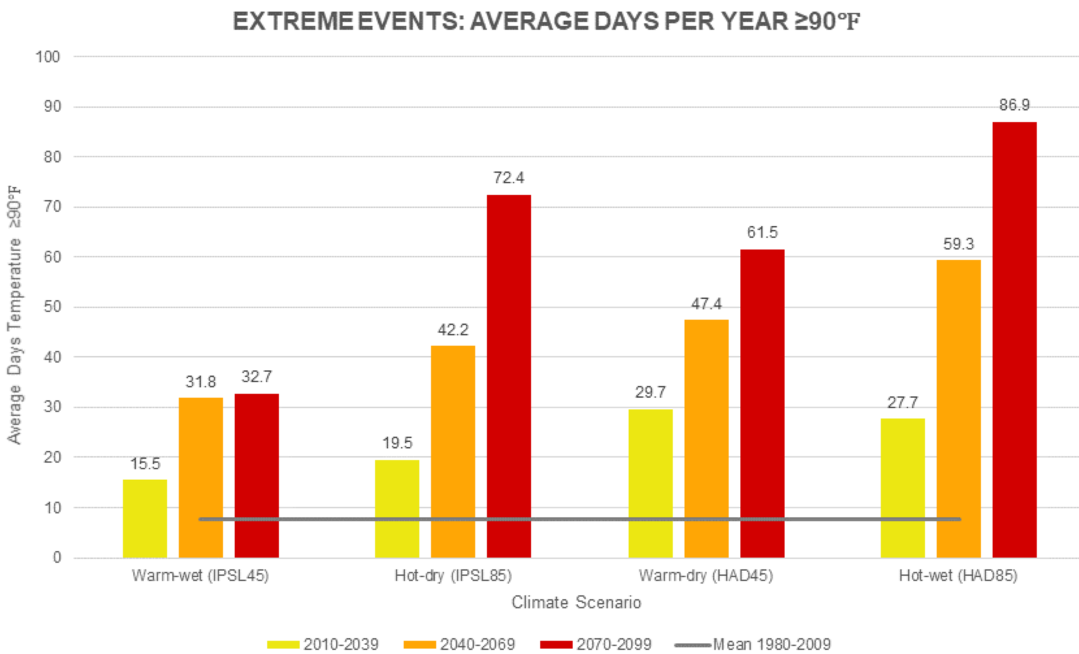
Annual	33.2	34.5	33.4	32.6	35.2	32.2	32.5	34.9	31.9	35.1	31.8	34.8	36.5
	Extreme Events (Average Days/Year)												
Temperature ≤0°F	4.3	1.7	2.3	1.9	1.0	1.5	0.4	0.5	0.5	0.5	0.0	0.4	0.5
Temperature ≥90°F	7.8	15.5	19.5	29.7	27.7	31.8	42.2	47.4	59.3	32.7	72.4	61.5	86.9
Precipitation ≥1”	3.3	3.7	3.7	3.6	3.8	3.1	3.5	4.3	3.5	4.3	4.1	4.3	5.2
Precipitation ≥2”	0.1	0.3	0.3	0.2	0.2	0.2	0.4	0.3	0.3	0.4	0.4	0.4	0.6

Trends and Projections in Extreme Weather

Extreme weather, such as heat and cold waves, heavy precipitation events, tornadoes, thunderstorms, wind storms, 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 1980-2009 mean 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 (Figure 2.3). 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 1980-2009 mean of nearly eight days. Extreme temperature projections by time period and climate scenario are outlined in Table 2.1.



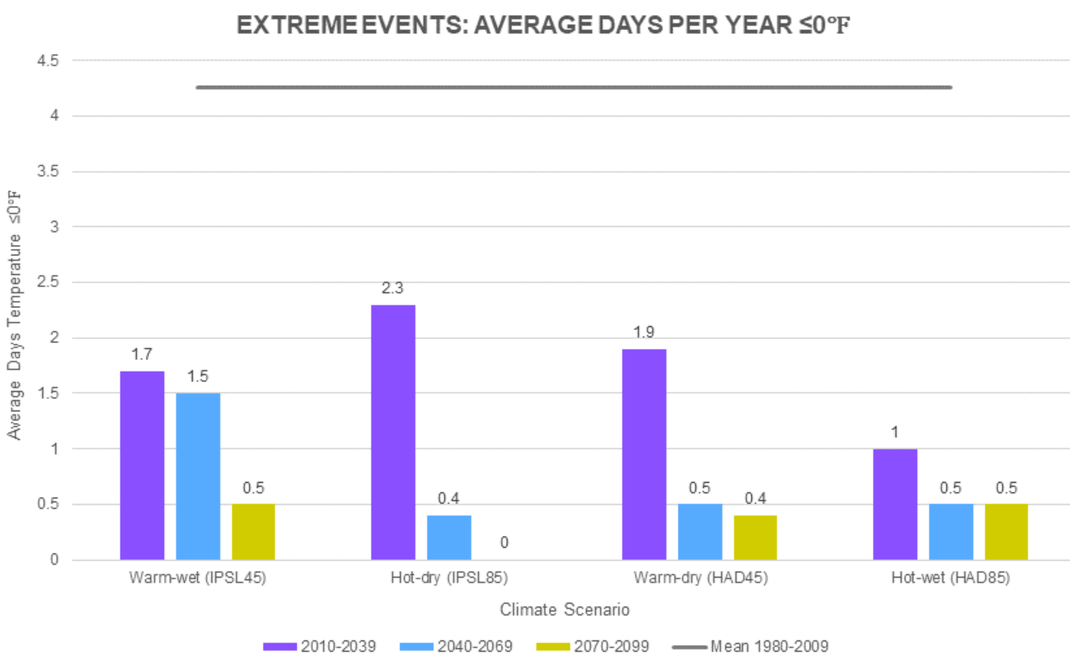


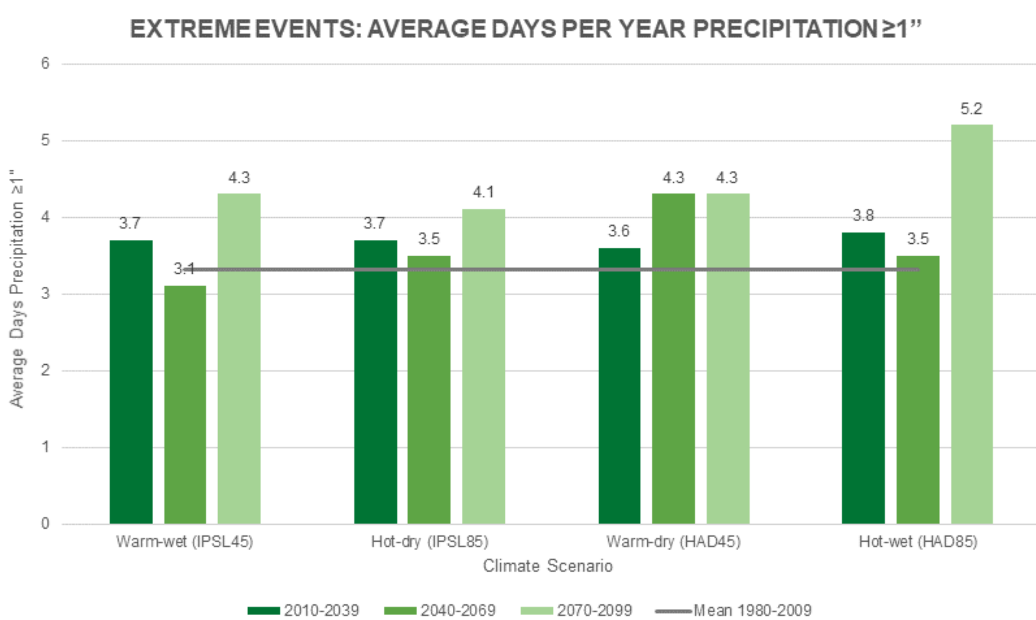
Figure 2.3. Extreme Temperature Projections Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

Heavy Precipitation Events

The scenarios with the highest level of emissions 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 (MDOT, 2015). Inland flooding is predicted to occur more frequently in the Detroit region resulting from increases in extreme storm and precipitation events (GLISA, 2017). Detroit has an estimated 41,691 properties (10% of total properties) that will be at risk in 30 years, an increase of 4.8% from 2020 (First Street Foundation, 2020). Precipitation in the spring and winter seasons are particularly important to flood risk in the Midwest and are expected to increase by up to 30% by 2100 (USGCRP, 2018a). The mesic forest on Belle Isle and other areas have already been experiencing flooding issues; 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).

Urban floods tend to be short-lived, but increased flooding can stress 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 tend to be flood intolerant, such as white oak, Kentucky coffeetree, and bitternut and shagbark hickory (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 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 2040-2069 (Table 2.1, Figure 2.4). 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 2070-2099 and under the hot-wet climate scenario (HAD85).



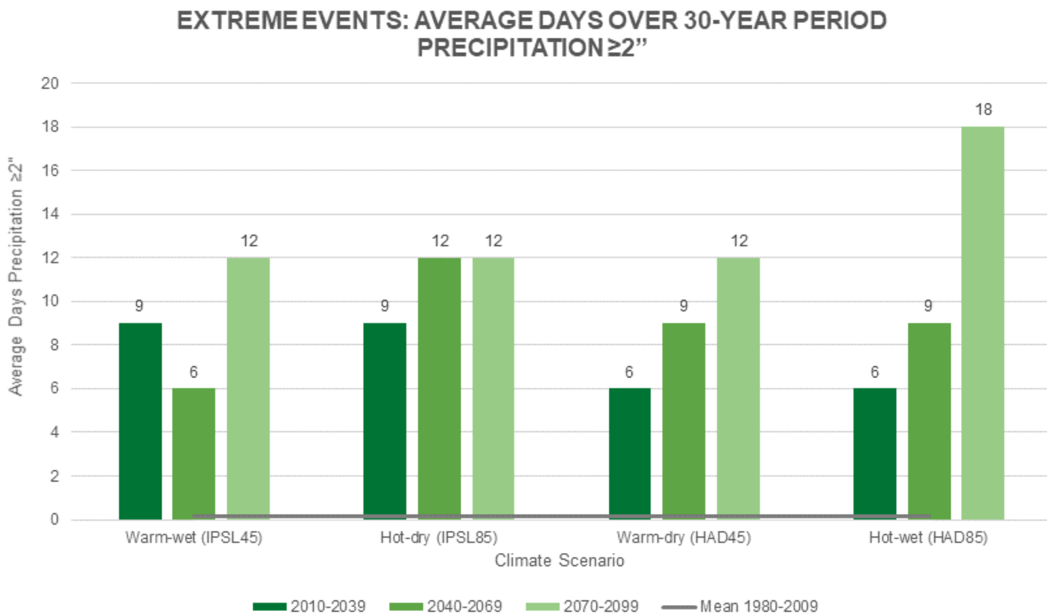


Figure 2.4. Extreme Precipitation Projections Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties). The top graph displays the average days per year ≥1" of precipitation and the bottom graph displays the average days over a 30-year period ≥2" of precipitation

Tornadoes, Thunderstorms, and Wind Storms

Tornadoes, thunderstorms, and wind storms can occur in Detroit, leading to tree damage from strong winds and lightning strikes. In the past 30 years, tornado alley has shifted 500 miles east (Jones, 2018). However, future tornado activity is difficult to predict. 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 (Diffenbaugh et al., 2008; Kunkel et al., 2008).

Michigan is located on the northeast edge of the Midwest's tornado belt. It is difficult to project whether tornadoes will increase in the coming decades. Although some studies project an increase in severe thunderstorms, only about 20% of supercell thunderstorms create tornadoes and the formation of tornadoes is still not fully understood (National Geographic, 2019). In addition, tornado records date back to just the 1950s, and there are issues with collecting reliable wind data to determine trends. The number of severe tornadoes has decreased in the past century, but severity is determined by the level of structural damage as opposed to wind speed (Diffenbaugh et al., 2008). Building construction has changed over time, and thus we may not be able to determine if storms are weaker or if there is less damage due to improved construction.

There is no strong evidence of changes in the severity or frequency of thunderstorms in the United States over the past century (Kunkel et al., 2008). Researchers have taken a variety of approaches because of limitations in observational records for past trends, making it difficult to establish a baseline for future projections to be interpreted (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. Tornadoes spawn as a result of wind shear and convective available potential energy (CAPE). For a tornado to form, it requires spin and lift. Shear, which describes a change in wind speed and/or direction with height, is required for tornadoes to rotate. Lift is defined by CAPE, a quantity calculated by understanding the degree to which a pocket of air density will allow it to rise. Climate models predict increases in CAPE and potential decreases in wind shear (Diffenbaugh et al., 2008, 2013). The balance of these forces paired with the potential for seasonal and geographic shifts within this balance results in uncertainty. One study suggests that the timing of wind shear decrease may be offset from the days with increased CAPE, making the conditions for tornadoes and other severe storms more favorable (Diffenbaugh et al., 2013).

Thunderstorms in a changing climate have become a rapidly growing research area. Another study modeling changes in CAPE and wind shear found that severe thunderstorms will increase by a wide spatial range under RCP4.5 (30 to 150%) and RCP8.5 (50 to 180%) (Seeley & Romps, 2015). Although this study contributed to a growing understanding that there may be an increase in severe thunderstorms in a changing climate, there are remaining sources of uncertainty in these models due to assumptions 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 wind speed 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 may 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. Winters are expected to be shorter, and more precipitation is projected to be in the form of rain instead of snow (GLISA, 2017). However, when these extreme winter storms do occur, they may be more severe.

Winter storms and cold snaps are a major concern among local practitioners. In 2019, quick freezing temperatures led to an increase of winter injury to Detroit's tree planting projects. Winter injury can include limb-breaking ice buildup, frost cracks, sunscald, and the freezing of buds, all of which stress newly established trees.

> *Acclimation to temperatures much below freezing results from exposure to slowly falling temperatures and other factors. Plants that are dormant but not fully acclimated can be stressed or injured by a sudden, hard freeze. Rapid or extensive drops in temperature following mild autumn weather cause injury to woody plants. Extended periods of mild winter weather can de-acclimate plants, again making them vulnerable to injury from rapid temperature drops. (Morton Arboretum, 2020)*

There is scientific debate over whether extreme cold events will increase, decrease, or stay the same in the face of a changing climate. Some research suggests that deep cold weather events are related, but there is no strong consensus. For example, polar vortexes are often perceived to be associated with climate change. However, polar vortexes are a regular atmospheric feature and there is significant variability regarding which regions will get hit with extreme cold and snow (L'Heureux, 2021). According to Paul Ullrich, associate professor of regional climate modeling at UC-Davis, polar vortexes are becoming more extreme with climate change (University of California, Davis, 2021). Ullrich also expects climate change to weaken the polar jet stream, which would increase extreme weather events. Another study published in *Nature Climate Change* states that it remains unclear whether the link between reduced ice cover and cold mid-latitude winters are causal (Blackport et al., 2019). More research will illucidate whether we can expect more extreme cold events in the future.

Effects on Soils and Hydrology

The hydrologic behavior of urban areas is quite complex. Due to the increasing frequency of heavy rain events, Detroit is expected to experience more soil erosion and nutrient runoff (USGCRP, 2018a). A combination of increased precipitation and soil moisture can lead to loss of soil carbon and surface water quality, and waterlogged soils will also lead to a reduction in planting season work days (USGCRP, 2018a). 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 has the ability to kill thin roots, decrease in plant productivity, and alter nutrient and water cycling (Notaro et al., 2014; Rustad et al., 2012).

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 (Hopton et al., 2015; Carlson & White, 2017). 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, 2017). 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. This will be strongest in the summers, when temperatures are high and groundwater recharge will decrease, leading to an increase in low-flow periods.

Shifts in Heat and Hardiness Zones

Heat and hardiness zones are geographic areas that define which a species or cultivars are considered suitable to planting and survival. These zones are critical for understanding tree species selection under a changing climate. Defined by the U.S. Department of Agriculture, climate hardiness zones help arborists, gardeners, farmers, and others interested in tree and plant growth compare their local climate to that where a specific tree or plant is known to grow well. Each hardiness zone is 10°F warmer (or colder) than the adjacent zone to its north (or south). It is significant, therefore, that hardiness zones have migrated north by one-half, to one full level since 1990 (USDA Forest Service, 2020). Southeastern Michigan was in zone 5 in 1990; in 2015 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). See Appendix 5 for more background on heat and hardiness zones.

The Detroit region is in hardiness zone 6 (-23.3 to -17.8). Future hardiness and heat zones were obtained from Matthews et al. (2018). Under the RCP 4.5 scenario, which assumes a reduction in global emissions of greenhouse gases, the hardiness zone is projected to begin shifting to zone 7 (-17.7 to -12.2) in parts of the SEMCOG region by 2039 and the entire region by 2040-2069. Under the "business as usual" scenario, RCP 8.5, the hardiness zone is projected to shift to zone 7 by 2039, shift to zone 8 (-12.1 to -6.7) in parts of the region by 2040-2069, and entirely to zone 8 across the region by by 2070-2099.

The American Horticultural Society has established heat zones for determining the upper temperature limits trees are able to tolerate. The average number of days greater than 86°F (30°C) determines heat zones. Detroit and the SEMCOG region are in heat zones 4 and 5 (>14-30 and >30-45 days exceeding 86°F). Under the RCP 4.5 scenario, which assumes a reduction in global emissions of greenhouse gases, the heat zone is projected to shift to zone 6 (>46-90 days exceeding 86°F) by 2039 and zone 7 (>61-90 days exceeding 86°F) by 2040-2069 (Table 2.2). Under the "business as usual" scenario, RCP 8.5, the heat zone is projected to shift to zone 7 by 2039, zone 8 (>91-120 days exceeding 86°F) by 2040-2069, and zone 9 (>21-150 days exceeding 86°F) by 2070-2099.

Table 2.2. Hardiness and Heat Zone Shifts by Climate Scenario (RCP4.5 and RCP8.5) and Time Period (2010-2039, 2040-2069, and 2070-2099) Compared to the 1980-2010 Ranges.

Time Period	Hardiness Zone Range		Heat Zone Range	
1980-2010	Zone 6		Zone 5	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2010-2039	Zone 7	Zone 7	Zone 6	Zone 7
2040-2069	Zone 7	Zone 8	Zone 7	Zone 8
2070-2099	Zone 7	Zone 8	Zone 7	Zone 9

As the climate warms, the composition of forests changes. Many tree species are moving northward, resulting in more southerly varieties replacing them (Groffman et al., 2014). Following this trend, many iconic tree species are expected to lose their advantage and be replaced within the next century (Groffman et al., 2014). When significantly warmer temperatures occur over a period of time long enough to cause a change in hardiness zone classification, trees' vulnerability to mortality from insect infestations, temperature, soil moisture levels, and disease will increase. How climate change impacts the future diversity and vitality of trees in Detroit still depends, in part, on land-use and tree planting decisions residents, businesses, and city government make today.

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 experience more stress due to effects on soils and hydrology, such as loss of soil carbon and waterlogged soils. Hardiness and heat zones are projected to shift, which could create both new opportunities and challenges for species selection.

Key Points

- Detroit has been warming at a rate of about 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 1980-2009 mean.
- Precipitation in Detroit has been increasing by 0.95 inches per decade since 1960. Although precipitation projections vary by season and climate scenario, spring precipitation is generally expected to increase in each.
- Extreme heat and heavy precipitation events are expected to increase in intensity and become more frequent.
- Assuming a drastic reduction in global greenhouse gas (GHG) emissions, the USDA hardiness zones are projected to shift by 1-2 zones and the heat zones are projected to shift 3-5 zones, depending on the climate scenario.

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CHAPTER 3

Biological Climate Impacts

A changing climate has the potential to affect biological stressors to Detroit's urban forest. 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 potential impacts a changing climate will have on urban forests in the Detroit region, including phenology shifts, physiological effects, nutrient cycling, pests and pathogens, invasive plant species, species diversity, and fire risk.

Shifts in Phenology

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 trigger transitions. 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 when plants grow or bloom, which would lead to a significant change to the foundation of the food web, affecting food sources to pollinators and other wildlife that depend on trees (Hall, 2012). Projecting the changes in timing and possible mismatches of phenological shifts is very uncertain as patterns in phenology vary in time and space (Hall, 2012).

Freeze damage depends on the development 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 can often survive low temperatures in the teens without harm (Longstroth, 2012). When the buds open up, they can be harmed by temperatures in the low 20s. Fruit tree species that bloom 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 also bring additional pests, such as plum curculio (*Conotrachelus nenuphar*), to feed on and lay eggs in exposed fruit. As temperatures increase, fruit trees will grow more quickly and temperatures may be just below freezing at the time of bloom (Longstroth, 2012), making them more vulnerable to freeze injury.

Physiological Effects on Trees

Shifts in tree size and growth rates have been observed across the Midwest (USGCRP, 2018a). Growth rates and productivity can benefit from longer growing seasons and higher CO_2 concentrations, but only if sufficient moisture and nutrients are available. As temperatures rise, frequency of drought stress paired with changing precipitation patterns is expected to reduce tree growth and increase mortality (USGCRP, 2018a). In addition, climate change impacts the photosynthesis and transpiration rates of trees. Photosynthetic rates can increase in the presence of increasing CO_2 concentrations (Kirschbaum, 2004). However, as CO_2 concentrations increase, trees and other plants may not be able to remove CO_2 from the atmosphere quickly enough (Lombardozzi et al., 2018). Plants use carbon to create sugars for energy, but are unable to do so indefinitely. Many plants have the ability to adapt to changing photosynthetic rates impacted by increased temperatures, but water and nutrient limitations will define how plants respond to climate stressors (Kirschbaum, 2004; Dusenge et al., 2019).

Optimum temperatures differ among species and growth conditions, and are higher under elevated CO_2 concentrations. Increased temperatures generally result in increased air vapor pressure deficits and an increase in the transpiration rate of canopies (Kirschbaum, 2004). Higher temperatures will likely stimulate soil organic matter decomposition rates, allowing nutrients to be more readily mineralized and available (Kirschbaum, 2004). This 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 their stomata, small pores located under the leaves that assist with regulating plants' temperature and allow for a critical part of photosynthesis—the exchange of CO_2 and oxygen (Rudolph, 2017). Examining long-term growth in Detroit' Lafayette Park and in the St. Aubin Avenue median, researchers found elm trees and some oaks performed well in terms of growth in response to increased temperatures (Rudolph, 2017).

Nutrient Cycling and Mycorrhizae

Climate change is altering primary production and nutrient cycling in forests (USGCRP, 2018a). The combination of increased CO_2 and temperature levels may increase nutrient cycling rates by affecting soil enzyme activity (Lukac et al., 2010). Warming temperatures, shifts in precipitation patterns, soil frost, soil pH, soil moisture, and changes in growing season can alter the way nutrients are cycled between soils, plants, and the atmosphere (Campbell et al., 2009). This can have significant implications for 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 influenced 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 & Matzner, 2009). As a result, episodic precipitation (like that projected for the Detroit region) may lead to a reduction in tree nutrient availability.

Drought has been found to consistently reduce plant growth. Arbuscular mycorrhizal fungi (AMF) 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. With sufficient water, AMF can benefit plant growth and flower production when compared to non-mycorrhizal plants (Pischl & Barber, 2016). The intensity of plant root colonization by AMF is strongly related to frost periods, warm-season temperature, and soil carbon-to-nitrogen ratio (Soudzilovskaia et al., 2015). AMF can help mitigate the impact of temperature stress on trees and other plants by increasing growth and the amount of nutrients (Pischl & Barber, 2016).

Pests and Pathogens

Climate change is expected to make some already existing pests more problematic. The emerald ash borer (EAB) was first discovered in the state of Michigan near Detroit in 2002 and has killed tens of millions of ash trees in forests and neighborhoods (State of Michigan, 2019a). Milder winters can be beneficial for the species, raising the costs of EAB damage in addition to increased tree mortality and human health impacts such as cardiovascular and lower-respiratory-tract illnesses from a loss of tree canopy (Kovacs et al., 2010; Donovan et al., 2013). The European oak borer (EOB) is another beetle species found in Michigan in 2003. In several studies, EOB was found to attack weakened or recently dead oak species, posing a risk to trees under climate stress (Petrice & Haack, 2014).

Oak wilt, a high-mortality oak disease caused by the fungal pathogen *Bretziella fagacearum*, is a prominent concern to Detroit's 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. Climate suitability for oak wilt remains relatively high in each of four climate models (Earth System Models (ESMs): CanESM2, CESM1CAM5, HadGEM2-ES, and MIROC-ESM) for time periods 2011-2040 and 2041-2070 under a moderate greenhouse gas emissions scenario, RCP4.5 (Pedlar et al., 2020). Oak wilt suitability is projected to move northward, eventually covering much of the oak range in eastern Canada (Pedlar et al., 2020). Although climate suitability is projected to decrease slightly in the Detroit region by 2070, it remains a primary concern.

Climate change may make Detroit's urban forest more vulnerable to new pests. The Asian longhorned beetle's (ALB) favorite host is the maple tree, which is abundant in Detroit, and can also cause tree mortality in other species such as willow, poplar, sycamore, and horse chestnut (State of Michigan, 2019b). While not currently detected in Michigan, ALB poses a significant risk to Detroit's urban forest. A study modeling ALB's phenology found the species to adapt well to ambient environmental conditions (Keena, 2009). Warming temperatures pose an ALB infestation threat to the Detroit region (Keena, 2009). The spotted lanternfly prefers fruit and tree hosts such as oak, maple, willow, and sycamore, posing another prominent concern for infestation (State of Michigan, 2019c). Populations have been detected in states such as Pennsylvania and are rapidly growing. Drought stress can make tree species more vulnerable to potential attacks by these invasive insect pests.

Invasive Plant Species

Invasive plant species can out-compete native trees in urban natural areas. Many invasive species have spread from horticultural plantings, including trees planted as street trees (Reichard et al., 2001). As nonnative, invasive plants shift their range, 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., 2020b). This indicates that there are mutual benefits shared between management of invasive species and conservation of native biodiversity.

Monitoring invasive species is expensive, and therefore range-shifting invasive species are often considered the highest priority for monitoring (Rockwell-Postel et al., 2020). In a survey of natural resource managers across the country, most were concerned about how climate change will impact invasive species management, but lack of funding, personnel, and information limits their ability to manage invasive species and incorporate climate change in their decision-making (Beaury et al., 2020a). 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.

Researchers have mapped the future distribution of invasive species common in the United States in the Early Detection and Distribution Mapping System (EDDMapS, 2020). Under a range of future models, the following is projected 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 retract in all counties with the exception of St. Clair County, where it is projected to be unsuitable.
- 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, expand in Livingston and Washtenaw counties, and be unsuitable in Macomb, Monroe, St. Clair, and Wayne counties.

Species Diversity

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 stress 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, and bird species (USGCRP, 2018a).

Changing climate factors are expected to cause an accelerated rate of species declines and extinctions (USGCRP, 2018a). As native trees are already experiencing declines from pests and pathogens such as oak wilt and EAB, overall declines in native tree species diversity are expected. The Great Lakes are facing many stressors and species loss may have the potential to reduce or remove ecosystem services that trees rely on, such as flood control and water purification (USGCRP, 2018a). Wildlife diversity may also be affected: some wildlife species will be driven northward and others westward, but individual species will respond differently (Wuebbles et al., 2019).

Loss of native tree species could also have implications for the wildlife that rely on them. Trees play a significant 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 larvae (moths and butterflies), 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, native properties supported a significantly greater population of caterpillars and caterpillar species, as well as significantly greater bird biomass, diversity, abundance, species richness, and breeding pairs (Burghardt et al., 2009). Thus, as native trees are lost from pests and disease or direct changes in climate, there may be negative implications for species that depend upon them.

Fire

Fire is driven in part by hot, dry conditions, which may become more prevalent during the summer months in the Detroit region. Fires can decrease forest productivity and be a catalyst for change in vegetation (Handler et al., 2014). There are also benefits of low severity fires for native ecosystems such as prairies and savannas, which help maintain the health and vigor of these ecosystems. Wildfire risk is expected to increase in the Midwest, but fire behavior will be dependent upon climatic shifts over the 21st century (Handler et al., 2014). Occurrence will vary over time and space, which is determined by climate in addition to topography, efforts to suppress and prevent fires, and fuel accumulation affected by plant growth and disturbance frequency (USGCRP, 2018a). Fuel loads due to blowdown events or pest-induced mortality can increase fire risk, but the interactions between these factors can be complicated (Hicke, 2012).

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 human lives and property. In the Detroit region, wildland growth exists in suburbs and beyond, expanding into the countryside. However, land use and management are primary factors in determining whether an increase in fire risk is associated with an increase in wildfire activity (Handler et al., 2014). Future policy regarding wildfire suppression and prescribed burns are key sources of uncertainty.

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, invasive plant species, species diversity, and potentially catastrophic wildfire risk. Changing climate conditions has 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, photosynthetic, and transpiration rates. The range of pests, pathogens, and invasive species may also increase under a changing climate, posing a risk to already stressed trees. Many of these risks and processes are uncertain due to limiting factors such as nutrient and water availability.

Key Points

- A changing climate may shift the timing of leaf-out, flowering, fruit production, and senescence in urban trees, which can cause frost and freeze damage to Michigan's fruit trees.
- Climate change can alter nutrient cycling as well as tree growth, photosynthetic, and transpiration (loss of water vapor) rates. Trees may benefit from longer growing seasons and higher CO_2 concentrations, but can be limited by available moisture and nutrients.
- The abundance and range of pests and pathogens is projected to increase under a changing climate due to increased temperatures and stressed trees, including emerald ash borer, oak borers, Asian longhorned beetle, spotted lanternfly, and oak wilt. Nonnative, invasive species are projected to spread and establish themselves as plants shift their range.
- Species diversity and ecosystem function are expected to change along with climate conditions, causing an increase in species declines and extinctions.
- Fire risk is projected to increase, but behavior is uncertain due to its dependence upon climatic shifts as well as various occurrence factors.

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CHAPTER 4

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 UV light, storing carbon, and reducing air pollution. USDA 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 (USDA Forest Service, 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 volatile organic compounds (BVOCs), and pests and pathogens are projected to be altered by climate stressors, in addition to heat-related illnesses and mortality, flooding and extreme weather events, increases in food prices, and social, mental, and physical impacts. 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 (Great Lakes Integrated Sciences + Assessments) identified five priority climate-related health effects for Michigan including respiratory diseases, heat-related illnesses, waterborne and vector-borne diseases, and injuries, particularly carbon monoxide (CO poisoning) (Briley 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 (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. Southwest Detroit's concentration of vehicles and factories 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-trafficked highways, as well as a six-lane bridge (IQAir, 2021). These sources combine to produce dangerous emissions leading to unhealthly concentrations of particulate matter. As the climate continues to warm, premature deaths related to ozone and particle pollution are projected to increase (CDC, 2020).

Allergenicity

Climate change impacts the presence of airborne allergens (aeroallergens such as tree, grass, and weed pollen) by shifting the production, allergenicity, distribution, and timing (USGCRP, 2018b). 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 predominately vulnerable to aeroallergens, which have the ability to cause allergic rhinitis and enhance asthma and sinusitis (USGCRP, 2018a). 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.

There is a range of variability in pollen production among tree species, resulting in health considerations regarding climate impacts on the timing and production of allergens. Oak pollen in particular is expected to cause an increase in asthma-related emergency room visits (USGCRP, 2018a). 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 two to four weeks earlier (USGCRP, 2018b). Common ragweed, the most common aeroallergen in the U.S., is expected to continue its longer pollen season in central North America (Ziska et al., 2011). Increases in CO_2 and temperature have been found to cause earlier flowering and higher floral numbers and pollen production, as well as increased allergenicity in ragweed (USGCRP, 2018b). However, not all pollen seasons will be extended; as some areas become drier, there is potential for pollen seasons to shorten due to plant stress (USGCRP, 2018b). Allergenicity is an important factor to consider when determining which tree species to plant in the Detroit region, and allergen levels (mild, moderate, severe, or no allergy reported) are provided in the table below (Table 4.1).

Table 4.1. Allergenicity of Detroit Tree Species Considered Suitable for Planting.

Scientific Name	Common Name	Estimated Trees in Detroit
Mild Allergen		
Aesculus x carnea	red horse chestnut	
Ailanthus altissima	tree of heaven	984
Albizia julibrissin	Persian silk tree	
Amelanchier arborea	downy serviceberry	8
Asimina triloba	pawpaw	6
Castanea dentata	American chestnut	4
Castanea mollissima	Chinese chestnut	1
Catalpa speciosa	northern catalpa	1,238
Cercis canadensis	eastern redbud	416
Cornus alternifolia	pagoda dogwood	6
Cornus florida	flowering dogwood	99
Cornus mas	cornelian cherry dogwood	31
Cornus racemosa	gray dogwood	4
Crataegus crusgalli	cockspur thorn	27
Crataegus viridis 'Winter King'	green hawthorn 'Winter King'	1
Diospyros virginiana	common persimmon	1
Elaeagnus angustifolia	Russian olive	11
Fagus grandifolia	American beech	37
Fagus sylvatica	European beech	21

Ginkgo biloba	ginkgo	1,220
Gleditsia triacanthos	honeylocust	187
Gleditsia triacanthos inermis	honeylocust (thornless)	22,971
Gymnocladus dioicus	Kentucky coffeetree	12
Halesia tetraptera	mountain silverbell	2
Hibiscus syriacus	rose of Sharon	
Liquidambar styraciflua	sweetgum	632
Liriodendron tulipifera	tulip tree	509
Maackia amurensis	amur maackia	2
Magnolia grandiflora	southern magnolia	1
Magnolia stellata	star magnolia	34
Magnolia tripetala	umbrella magnolia	1
Magnolia virginiana	sweetbay magnolia	18
Magnolia x soulangiana	saucer magnolia	
Malus pumila	paradise apple	64
Malus spp.	apple	
Metasequoia glyptostroboides	dawn redwood	108
Nyssa sylvatica	black gum	42
Oxydendrum arboreum	sourwood	1
Prunus avium	sweet cherry	
Prunus cerasifera	cherry plum	12
Prunus persica	peach	5
Prunus sargentii	sargent cherry	4
Prunus serotina	black cherry	31
Prunus serrulata	Japanese cherry	29
Prunus subhirtella	higan cherry	3
Prunus virginiana	chokecherry	12
Prunus x yedoensis	yoshino cherry	6
Pyrus calleryana	callery pear	2,936
Pyrus communis	European pear	

Rhamnus cathartica	European buckthom	19
Rhamnus frangula	glossy buckthorn	
Rhus typhina	staghorn sumac	1
Robinia pseudoacacia	black locust	324
Salix matsudana	Chinese willow	
Sassafras albidum	sassafras	31
Sorbus americana	American mountain ash	
Sorbus aucuparia	European mountain ash	26
Styphnolobium japonicum	Japanese pagoda tree	18
Tilia x euchlora	Crimean linden	6
Tilia x europaea	common lime	
Moderate Allergen		
Acer buergerianum	trident maple	7
Acer campestre	hedge maple	304
Acer griseum	paperbark maple	5
Acer miyabei	miyabei maple	17
Acer nigrum	black maple	67
Acer palmatum	Japanese maple	235
Acer platanoides	Norway maple	30,157
Acer pseudoplatanus	sycamore maple	58
Acer rubrum	red maple	7,287
Acer saccharinum	silver maple	20,476
Acer saccharum	sugar maple	5,240
Acer tataricum	tatarian maple	
Acer x freemanii	freeman maple	873
Alnus glutinosa	black alder	
Alnus rugosa	grey alder	1
Betula alleghaniensis	yellow birch	
Betula nigra	river birch	202
Betula papyrifera	paper birch	130

Betula pendula	silver birch	24
Betula platyphylla	Japanese white birch	
Betula populifolia	gray birch	40
Carpinus betulus	European Hornbeam	171
Carpinus caroliniana	musclewood or American hornbeam	200
Celtis laevigata	southern hackberry/sugarberry	
Celtis occidentalis	common hackberry	2,270
Cercidiphyllum japonicum	katsura tree	49
Cornus kousa	kousa dogwood	71
Corylus colurna	Turkish hazel or Turkish filbert	11
Maclura pomifera	osage-orange	6
Ostrya virginiana	Eastern hophornbeam/Ironwood	95
Pinus bungeana	lacebark pine	3
Pinus parviflora	Japanese white pine	
Platanus occidentalis	American sycamore	5,771
Platanus x acerifolia	London planetree	6,971
Populus alba	white poplar	52
Populus balsamifera	balsam poplar	
Populus deltoides	eastern cottonwood	885
Populus grandidentata	bigtooth aspen	2
Populus nigra	black poplar	
Populus tremuloides	quaking aspen	20
Thuja occidentalis	northern white cedar	594
Tilia americana	American linden or basswood	2,482
Tilia cordata	littleleaf linden	5,396
Tilia tomentosa	silver linden	198
Ulmus Accolade	accolade elm	
Ulmus alata	winged elm	
Ulmus americana	American elm	2,509

Ulmus crassifolia	cedar elm	
Ulmus parvifolia	lacebark elm	136
Ulmus pumila	Siberian elm	4,897
Ulmus rubra	slippery elm	729
Zelkova serrata	Japanese zelkova	528
Severe Allergen		
Acer negundo	boxelder	1,002
Carya cordiformis	bitternut hickory	26
Carya glabra	pignut hickory	9
Carya illinoinensis	hardy pecan	7
Carya laciniosa	shellbark hickory	1
Carya ovata	shagbark hickory	70
Carya texana	black hickory	
Carya tomentosa	mockernut hickory	3
Fraxinus americana	white ash	855
Fraxinus excelsior	European ash	
Fraxinus nigra	black ash	
Fraxinus pennsylvanica	green ash	5,705
Juglans nigra	black walnut	181
Juglans regia	English walnut	
Juniperus chinensis	Chinese juniper	10
Juniperus virginiana	eastern red-cedar	107
Morus alba	white mulberry	2,308
Morus rubra	red mulberry	41
Quercus acutissima	sawtooth oak	4
Quercus alba	white oak	232
Quercus bicolor	swamp white oak	858
Quercus cerris	turkey oak	
Quercus coccinea	scarlet oak	38
Quercus ellipsoidalis	northern pin oak	

Quercus imbricaria	shingle oak	181
Quercus lyrata	overcup oak	
Quercus macrocarpa	bur oak	595
Quercus macrocarpa x robur	heritage oak	
Quercus marilandica	blackjack oak	
Quercus muehlenbergii	chinkapin oak	6
Quercus palustris	pin oak	2,033
Quercus phellos	willow oak	3
Quercus prinus	chestnut oak	8
Quercus robur	common oak	530
Quercus rubra	northern red oak	2,234
Quercus shumardii	Shumard oak	34
Quercus stellata	post oak	
Quercus velutina	black oak	20
Salix babylonica	weeping willow	93
Salix discolor	pussy willow	15
Salix nigra	black willow	13
No Allergy Reported		
Abies balsamea	balsam fir	13
Abies concolor	white fir	2
Acer tataricum ginnala	amur maple	107
Aesculus glabra	Ohio buckeye	31
Aesculus hippocastanum	common horse chestnut	1,180
Amelanchier x grandiflora	apple serviceberry	
Chionanthus virginicus	fringetree	
Cladrastis kentukea	yellowwood	79
Cotinus coggygria	smoketree	29
Eucommia ulmoides	hardy rubber tree	

Gleditsia aquatica	water locust	
Koelreuteria paniculata	goldenrain tree	48
Larix decidua	European larch	2
Larix laricina	tamarack	
Parrotia persica	Persian parrotia	4
Paulownia tomentosa	princess tree	14
Phellodendron amurense	amur corktree	9
Picea abies	Norway spruce	90
Picea glauca	white spruce	82
Picea pungens	Colorado spruce	450
Picea rubens	red spruce	3
Pinus banksiana	jack pine	5
Pinus mugo	mugo pine	
Pinus nigra	Austrian pine	535
Pinus resinosa	red pine	11
Pinus strobus	eastern white pine	106
Pinus sylvestris	Scots pine	
Pinus virginiana	Virginia pine	10
Pseudotsuga menziesii	douglas fir	26
Syringa reticulata	Japanese tree lilac	556
Syringa vulgaris	common lilac	16
Taxodium distichum	bald cypress	36
Tsuga canadensis	eastern hemlock	5
Viburnum lentago	nannyberry	1

Source: http://www.pollenlibrary.com/

Biogenic Volatile Organic Compounds

BVOCs can have notable effects on the physical characteristics and chemical composition of the atmosphere (Laothawornkitkul et al., 2009). This relationship can be altered by anthropogenic change, leading to adverse and uncertain consequences for the Earth's system (Laothawornkitkul et al., 2009). These emissions release fine particulate matter (PM2.5) as well as ground-level ozone pollution, both of which can harm human health (Ren et al., 2017).

BVOC emissions are particularly prominent in urban green spaces, where the urban core has been found as the hotspot of regional emission intensity (Ren et al., 2017). Urban green spaces play an important role in human health compared to rural areas, accounting for 62% of total health damage caused by BVOC emissions (Ren et al., 2017). 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 have no to low emission rates, such as apple, elm, ash, hawthorn, serviceberry, and basswood, while others have quite high emission rates, such as sweetgum, oak, black locust, sycamore, poplar, and willow (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, vectors of significant disease-causing agents, are projected to spread their geographic region, seasonal distribution, and abundance under a changing climate (Sonenshine, 2018). This will expose more people and wildlife to diseases carried by ticks, such as Lyme disease. Similarly, West Nile virus and its mosquito vector will favor the projected warmer winters, earlier springs, and warmer summers in Detroit (Briley 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 and associated loss of trees increases the risk of mortality related to cardiovascular and lower-respiratory tract illnesses (Donovan et al., 2013).

Emerging infectious diseases (EIDs) are another concern. EIDs 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 wellbeing via economic and agricultural loss (Anderson et al., 2004). Emerging plant EIDs are primarily driven by anthropogenic environmental change, including severe weather events and shifts in the abundance and distribution of arthropod vectors—both related to climate change (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 an increased survival of plant pathogens, enabling plants and pathogens to survive outside their typical ranges (Harvell et al., 2002).

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. People who are older, less educated, have a lower income, and are without vehicle access are considered to be the most vulnerable (USGCRP, 2018a; GLISA, 2017). 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. Over 39% of Detroit residents live below the poverty level, making it the lowest-income major city in the country (GLISA, 2017). Extreme heat is also dangerous for those who are very young, are socially isolated, lack air conditioning, or who suffer from chronic physical or mental illness (Gregg et al., 2012). High electricity demand for air conditioning, which is common during extreme heat events, has the potential to increase brown outs and power outages. In addition, increased demand for air conditioining results in increased emissions, leading to greater air pollution and a compound impact on human health.

Tree canopy tends to be lower in urban heat islands. A vulnerability index of Detroit was created combining the exposure assessment (using land cover variables: impervious surfaces and tree canopy) and sensitivity assessment (using demographic variables: residents 65 and older, lower educational attainment, poverty, and household access to a vehicle). This index identified areas of higher heat risk for residents in census block groups (Figure 4.1). Here, heat vulnerability is distributed relatively randomly. Many vulnerable groups are concentrated downtown, with noticeably lower risk in northwest Detroit where this is higher tree canopy and more parkland.

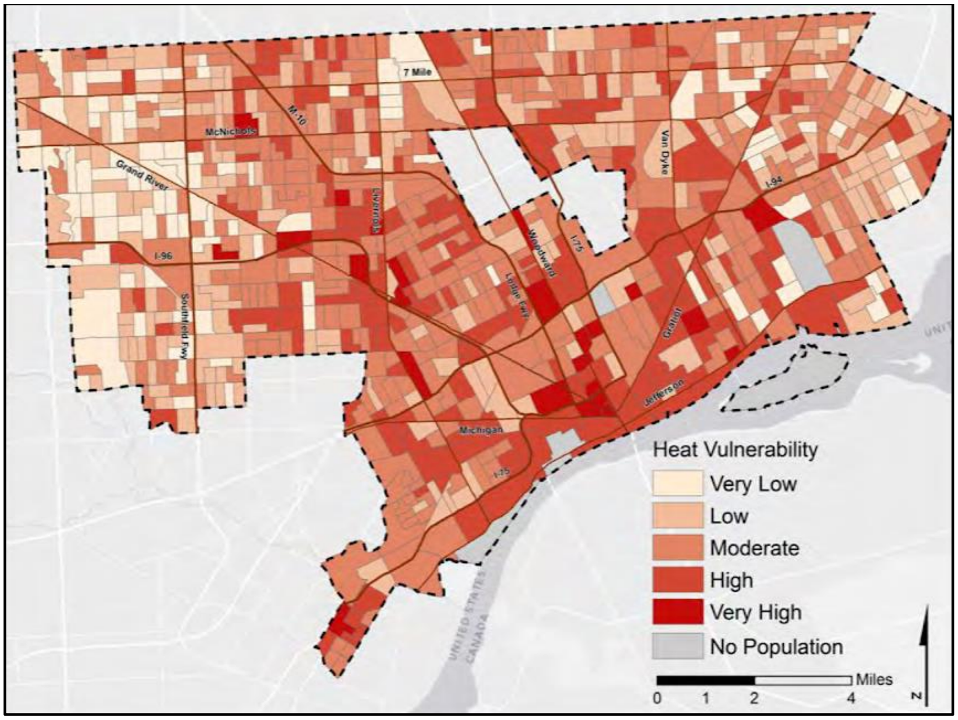

Figure 4.1. Heat Vulnerability Index of Detroit, Michigan. The darkest red shade indicates the greatest heat vulnerability, while the lightest shade indicates minimal heat vulnerability. Source: USGS GloVis LandSat 7 ETM+; American Community Survey; US Census 2010. Map Prepared By: University of Michigan Detroit Climate Capstone.

A study examining mortality rates in three climate scenarios (warming 2.7°F, 3.6°F, and 5.4°F) found that the city of Detroit is projected to endure more heat-related deaths compared to cities such as Atlanta, Houston, and Phoenix (Lo et al., 2019). The Union of Concerned Scientists estimates 732 deaths per 1-in-30-year extreme heat event at 2.7 degrees of warming, 910 deaths at 3.6 degrees of warming, and 1,372 deaths at 5.4 degrees of warming. The increased levels of warming in Detroit are associated with urban heat islands in the region and a lack of access to air conditioning. Areas with higher tree canopy cover tend to be cooler and present less of a risk. Enhancing tree canopy cover along with other measures such as improved heat-related health care, increased availability of cooling centers and air conditioning, and increased awareness of heat-related illnesses and mortality can help mitigate these risks.

Water Quality

In the Great Lakes region, waterborne diseases and beach closures are projected to increase because of changes in heavy precipitation events and lake temperatures. Areas in Detroit vulnerable to runoff and septic/sewage failures will be more at-risk for algal blooms and waterborne diseases (CDC, 2020; Briley et al., 2015). In addition to indicators such as the capacity of water treatment systems, combined sewer outflow release, and water-borne illnesses, water quality can also be measured by the coverage of absorptive vegetation. 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 (USDA Forest Service, 2015). As temperatures increase, there can be negative impacts on vegetation, increasing vulnerability in that region. Riparian forests can help maintain and enhance water quality, however. 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.

Food Security

A changing climate is expected to result in food shortages and insecurity by threatening global food production in addition to 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 nutrients like iron, zinc, calcium, vitamins, and sugars.

Increases in food prices—the result of declining food production and other factors—will 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 issues from obesity to micronutrient malnutrition (CDC, 2020). These issues are further exacerbated within neighborhoods classified as food deserts, a term that describes an urban area lacking accessibility to quality, nutritious, and affordable food. According to the Detroit Food Policy Council's 2019 Food Metrics Report, 39% of Detroit households are food insecure, an increase of 6% from 2018, and 40% of households are using the Supplemental Nutrition Assistance Program (SNAP) while 18% of eligible households are not enrolled (Hill, 2020). There are also notable grocery square footage gaps within the city, notably in Districts 2 and 3 (Figure 4.2). As a result, some Detroit residents with a lack of reliable transportation walk miles to find affordable food.

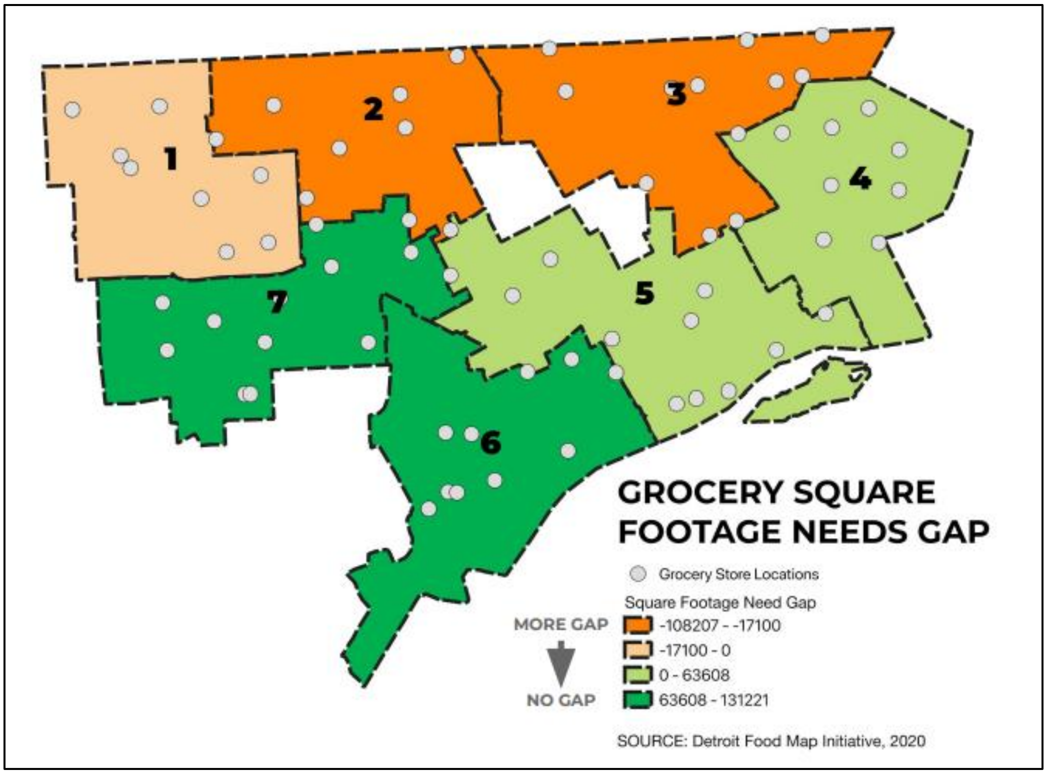

Figure 4.2. Grocery Square Footage Needs Gap in Detroit, Michigan. Source: Hill, Alex B. Detroit Food Metrics Report 2019. Detroit Food Policy Council (2020).

Urban agriculture and food forests can play a significant 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). Societal inequities can be exacerbated while planning for urban agriculture. For example, urban agriculture can benefit those with greater access to land as well as the propertied class and organizations that are better resourced, which can 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 investments in urban farms and gardens to benefit disadvantaged communities can help to implement equitable urban agriculture (Horst et al., 2017).

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

Linking the Urban Forest with 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/or communities. This can have secondary negative effects, 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, access to a vehicle, and overall quality of life. While 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 (USDA Forest Service, 2015). There are also health benefits 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 employees’ workdays, perceived stress and health complaints decreased (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 & Sullivan, 2016).

Urban trees can provide benefits when it comes to safety and crime. Studies have shown that the presence of trees and grass surrounding residences corresponds with decreased crime compared to more barren areas (Vibrant Cities Lab, 2020). When green spaces are well cared for, it shows that the community cares about its space and is more likely to be active in it as well. Green spaces can also lower aggression and increase perceived personal safety. In a study of tree canopy and crime in New Haven, CT, tree canopy coverage was inversely related to crime rates, supporting 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 greater mental health, are more physically active, and are expected to have a greater life span (USDA Forest Service, 2018). Trees help shade humans from UV 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 looking to outdoor green spaces as a way to promote healthy living, reduce obesity, improve stress, and combat chronic diseases (Vibrant Cities Lab, 2020). 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. 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 aren’t maintained over the long-term. Integrating both human health and climate perspectives into green infrastructure can help address these concerns and ensure that strategies are implemented equitably (Vibrant Cities Lab, 2020).

Summary

A changing climate has the potential to worsen existing health issues and create new issues, such as increases in food prices, flooding and extreme weather events, heat-related illnesses and mortality, and the presence and intensity of allergens, biogenic volatile organic compounds (BVOCs), and pests and pathogens. Urban forests have the potential to help oversome 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

- Detroit's human population and urban forest 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, associated with health issues such as asthma, diminished lung function, increased hospital visits, and premature deaths. Changing conditions can also shift biogenic volatile organic compound (BVOC) emissions from plants as well as 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, ticks, and emerging infectious diseases (EIDs), which may shift their range, distribution, and abundance under changing conditions.
- Extreme heat is associated with heat-related diseases and mortality and poses a significant threat to Detroit residents, particularly those who are low-income, young, socially isolated, lack air conditioning, or suffer from chronic illness.
- Changes in heavy precipitation events and lake temperatures can increase waterborne diseases, lake closures, and vulnerability to runoff and septic/sewage failures.
- Climate change is expected to cause food shortages and 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.

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CHAPTER 5

Tree Species Vulnerability

Changes in climate have the potential to profoundly affect Detroit's trees in both developed and natural areas. Some tree species that are currently present may experience declines in habitat suitability 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 changing insect pests, pathogens, and nonnative invasive species, as well as 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 Detroit's developed and natural areas.

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). SDMs 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 a species' realized niche instead of its fundamental niche. The realized niche is the actual habitat a species occupies given predation, disease, and competition with other species. A species' fundamental niche, in contrast, is the habitat it could potentially occupy in the absence of competitors, diseases, or predators. Given that a species' fundamental niche can be greater than its realized niche, SDMs may underestimate current niche size and future suitable habitat. In addition, species distributions in the future might be constrained by competition, disease, and predation in ways that do not currently occur. If so, SDMs could overestimate the amount of suitable habitat in the future. 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 part of the Tree Atlas toolset (Iverson et al., 2019; Iverson et al., 2008; Peters et al., 2019; Peters et al., 2014). DISTRIB-II measures relative size and abundance, referred to as importance values, for 125 eastern tree species (note that only 61 of these were of interest to the Detroit region because they are currently present or expected to gain habitat in the area). Inputs include tree species distribution data from the USDA Forest Service Forest Inventory and Analysis (FIA) program and environmental variables (pertaining to climate, soil properties, elevation, land use, and fragmentation), which are used to statistically model 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-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 (4.5 and 8.5). Note that this model does not account for projected changes in human population, land use, or the urban heat island effect.

Table 5.1 shows the projected change in potential suitable habitat for 61 species within an approximately 9000 km^2 buffer zone around the Detroit Metropolitan Statistical Area. The table includes species that 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 upon whether the results from the two climate-RCP scenarios projected an increase, decrease, or no change in suitable habitat compared to current conditions; if the model results were mixed; or if they 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 of them was projected to decline under both high and low scenarios. Native species expected to decline include 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, model results were slightly unclear regarding the direction of change. There was a small projected increase for sugar maple, white oak, swamp white oak, and black willow under a low-emissions scenario, and a small increase for slippery elm under a high-emissions scenario. On the other hand, under a high-emissions 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. With the exception of swamp white oak, the alternate scenario suggested no change in habitat suitability for each of the species.

Suitable habitat for eight species was projected to remain relatively stable under both scenarios. Species in Detroit that fell under this category include silver maple, bitternut hickory, pignut hickory, green ash, black walnut, bur oak, northern red oak, and black oak. Eight species were projected to experience a gain in suitable habitat, including common hackberry, white ash, eastern red cedar, tulip tree, black gum, eastern cottonwood, black locust, and American elm. Sixteen species would be able to colonize new, suitable habitats under low- and high-emissions scenarios, including hardy pecan, black hickory, mocknut 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 only available for native species and are based on data collected from phase II plots every 6,000 acres in natural areas through the USDA Forest Service 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).

Table 5.1 Projected Changes in Habitat Suitability for Trees Native to the 1-by-1-degree Latitude/Longitude Area around the Detroit Region based on the DISTRIB-II Model.

Scientific Name	**Common Name**	**Model Reliability**	**Change Class-Low Emissions (RCP 4.5)**	**Change Class-High Emissions (RCP 8.5)**
DECREASE UNDER BOTH SCENARIOS				
Acer negundo	boxelder	Low	Small decrease	Small decrease
Acer nigrum	black maple	Low	Large decrease	Large decrease
Acer rubrum	red maple	High	Small decrease	Small decrease
Betula alleghaniensis	yellow birch	High	Large decrease	Large decrease

Betula papyrifera	paper birch	High	Large decrease	Large decrease
Carpinus caroliniana	musclewood/American hornbeam	Low	Small decrease	Small decrease
Carya ovata	shagbark hickory	Medium	Small decrease	Large decrease
Cornus florida	flowering dogwood	Medium	Small decrease	Very large decrease
Fraxinus nigra	black ash	Medium	Very large decrease	Very large decrease
Larix laricina	tamarack	High	Small decrease	Small decrease
Ostrya virginiana	Eastern hophornbeam/Ironwood	Low	Large decrease	Large decrease
Picea glauca	white spruce	Medium	Large decrease	Large decrease
Pinus resinosa	red pine	Medium	Large decrease	Large decrease
Populus grandidentata	bigtooth aspen	Medium	Large decrease	Large decrease
Populus tremuloides	quaking aspen	High	Large decrease	Large decrease
Quercus coccinea	scarlet oak	Medium	Very large decrease	Very large decrease
Quercus ellipsoidalis	northern pin oak	Medium	Small decrease	Small decrease
Quercus shumardii	Shumard oak	Low	Small decrease	Small decrease
Thuja occidentalis	northern white cedar	High	Small decrease	Small decrease
Scientific Name	**Common Name**	**Model Reliability**	**Change Class-Low Emissions (RCP 4.5)**	**Change Class-High Emissions (RCP 8.5)**
MIXED RESULTS				
Acer saccharum	sugar maple	High	Small increase	No change
Fagus grandifolia	American beech	High	No change	Small decrease
Pinus strobus	eastern white pine	High	No change	Large decrease
Prunus serotina	black cherry	Medium	No change	Small decrease
Quercus alba	white oak	Medium	Small increase	No change
Quercus bicolor	swamp white oak	Low	Small increase	Small decrease
Salix nigra	black willow	Low	Small decrease	No change
Sassafras albidum	sassafras	Low	No change	Large decrease
Tilia americana	American linden or basswood	Medium	No change	Small decrease
Ulmus rubra	slippery elm	Low	No change	Small increase
Scientific Name	**Common Name**	**Model Reliability**	**Change Class-Low Emissions (RCP 4.5)**	**Change Class-High Emissions (RCP 8.5)**
NO CHANGE				
Acer saccharinum	silver maple	Low	No change	No change
Carya cordiformis	bitternut hickory	Low	No change	No change
Carya glabra	pignut hickory	Medium	No change	No change
Fraxinus pennsylvanica	green ash	Low	No change	No change
Juglans nigra	black walnut	Low	No change	No change
Quercus macrocarpa	bur oak	Medium	No change	No change
Quercus rubra	northern red oak	Medium	No change	No change
Quercus velutina	black oak	High	No change	No change
Scientific Name	**Common Name**	**Model Reliability**	**Change Class-Low Emissions (RCP 4.5)**	**Change Class-High Emissions (RCP 8.5)**
INCREASE				
Celtis occidentalis	common hackberry	Medium	Small increase	Small increase
Fraxinus americana	white ash	Medium	Large increase	Large increase
Juniperus virginiana	eastern red cedar	Medium	Large increase	Large increase
Liriodendron tulipifera	tulip tree	High	Large increase	Large increase
Nyssa sylvatica	black gum	Medium	Small increase	Large increase
Populus deltoides	eastern cottonwood	Low	Large increase	Large increase
Robinia pseudoacacia	black locust	Low	Small increase	Large increase
Ulmus americana	American elm	Medium	Small increase	Small increase

Scientific Name	Common Name	Model Reliability	Change Class-Low Emissions (RCP 4.5)	Change Class-High Emissions (RCP 8.5)
NEW HABITAT				
Carya illinoinensis	hardy pecan	Low	New Habitat	New Habitat
Carya texana	black hickory	High	New Habitat	New Habitat
Carya tomentosa	mockernut hickory	Medium	New Habitat	New Habitat
Celtis laevigata	southern hackberry/sugarberry	Medium	New Habitat	New Habitat
Cercis canadensis	eastern redbud	Low	New Habitat	New Habitat
Diospyros virginiana	common persimmon	Low	New Habitat	New Habitat
Gleditsia triacanthos	honeylocust	Low	New Habitat	New Habitat
Liquidambar styraciflua	sweetgum	High	New Habitat	New Habitat
Maclura pomifera	osage-orange	Medium	New Habitat	New Habitat
Morus rubra	red mulberry	Low	New Habitat	New Habitat
Platanus occidentalis	American sycamore	Low	New Habitat	New Habitat
Quercus marilandica	blackjack oak	Medium	New Habitat	New Habitat
Quercus palustris	pin oak	Low	New Habitat	New Habitat
Quercus stellata	post oak	High	New Habitat	New Habitat
Ulmus alata	winged elm	Medium	New Habitat	New Habitat
Ulmus crassifolia	cedar elm	Medium	New Habitat	New Habitat

Projected Suitability from Heat and Hardiness Zone Shifts

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. These species are usually either too rare in the region to be modeled reliably, have a range that extends outside of the U.S., 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.

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

A species' hardiness and heat zone ranges are the areas in which the species is considered suitable for planting. The species was considered to be suitable under the low emissions scenarios if its minimum hardiness zone was 6 or lower and maximum hardiness and heat zone was 7 or greater (Table 5.2). The species was considered suitable under the high emissions scenario if it had a minimum hardiness zone of 6, its maximum hardiness was 8 or greater, and the maximum heat zone was 9 or greater. These minima and maxima were determined by the current and projected heat and hardiness 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 minima and maxima were determined by hardiness alone.

Table 5.2 Hardiness and Heat Zone (Where Available) Suitability Under Low (RCP 4.5) and High (RCP 8.5) Emissions Scenarios for Species That Are Currently Found in the Detroit Region or Are Being Considered for Planting in the Area. N/A= not available.

Scientific Name	Common Name	Hardiness Zone	Heat Zone	Zone Suitability - Low	Zone Suitability - High
Abies balsamea	balsam fir	3 to 6	6 to 1	Not Suitable	Not Suitable
Abies concolor	white fir	3 to 7	7 to 1	Suitable	Not Suitable
Acer buergerianum	trident maple	5 to 9	9 to 5	Suitable	Suitable
Acer campestre	hedge maple	5 to 8	8 to 4	Suitable	Not Suitable
Acer griseum	paperbark maple	5 to 8	8 to 1	Suitable	Not Suitable
Acer miyabei	miyabei maple	4 to 8	8 to 1	Suitable	Not Suitable
Acer negundo	boxelder	2 to 10	8 to 3	Suitable	Not Suitable
Acer nigrum	black maple	4 to 8	8 to 3	Suitable	Not Suitable
Acer palmatum	Japanese maple	5 to 8	8 to 2	Suitable	Not Suitable
Acer platanoides	Norway maple	4 to 7	7 to 1	Suitable	Not Suitable
Acer pseudoplatanus	sycamore maple	4 to 7	8 to 1	Suitable	Not Suitable
Acer rubrum	red maple	3 to 9	9 to 1	Suitable	Suitable
Acer saccharinum	silver maple	3 to 9	8 to 1	Suitable	Not Suitable
Acer saccharum	sugar maple	3 to 8	8 to 1	Suitable	Not Suitable
Acer tataricum	tatarian maple	3 to 8	7 to 1	Suitable	Not Suitable
Acer tataricum ginnala	amur maple	3 to 8	7 to 1	Suitable	Not Suitable
Acer x freemanii	freeman maple	3 to 8	8 to 1	Suitable	Not Suitable
Aesculus glabra	Ohio buckeye	3 to 7	7 to 1	Suitable	Not Suitable
Aesculus hippocastanum	common horse chestnut	3 to 8	8 to 1	Suitable	Not Suitable
Aesculus x carnea	red horse chestnut	5 to 9	8 to 6	Suitable	Not Suitable
Ailanthus altissima	tree of heaven	4 to 8	8 to 1	Suitable	Not Suitable
Albizia julibrissin	Persian silk tree	6 to 9	9 to 6	Suitable	Suitable
Alnus glutinosa	black alder	4 to 7	7 to 1	Suitable	Not Suitable
Alnus rugosa	grey alder	2 to 6	7 to 1	Suitable	Not Suitable
Amelanchier arborea	downy serviceberry	4 to 9	9 to 1	Suitable	Suitable
Amelanchier x grandiflora	apple serviceberry	4 to 9	7 to 1	Suitable	Not Suitable
Asimina triloba	pawpaw	6 to 9	8 to 6	Suitable	Not Suitable
Betula alleghaniensis	yellow birch	3 to 7	7 to 1	Suitable	Not Suitable
Betula nigra	river birch	4 to 9	9 to 1	Suitable	Suitable
Betula papyrifera	paper birch	2 to 6	7 to 1	Suitable	Not Suitable
Betula pendula	silver birch	2 to 7	7 to 1	Suitable	Not Suitable
Betula platyphylla	Japanese white birch	5 to 7	7 to 5	Suitable	Not Suitable
Betula populifolia	gray birch	3 to 6	6 to 1	Not Suitable	Not Suitable
Carpinus betulus	European Hornbeam	4 to 9	8 to 1	Suitable	Not Suitable
Carpinus caroliniana	musclewood/American hornbeam	3 to 9	9 to 1	Suitable	Suitable
Carya cordiformis	bitternut hickory	4 to 9	9 to 1	Suitable	Suitable
Carya glabra	pignut hickory	4 to 9	8 to 1	Suitable	Not Suitable

Scientific Name	Common Name	Hardiness Zone	Heat Zone	Zone Suitability - Low	Zone Suitability - High
Carya illinoinensis	hardy pecan	5 to 9	9 to 1	Suitable	Suitable
Carya laciniosa	shellbark hickory	4 to 9	8 to 1	Suitable	Not Suitable
Carya ovata	shagbark hickory	4 to 8	8 to 1	Suitable	Not Suitable
Carya texana	black hickory	5 to 9	N/A	Suitable	Suitable
Carya tomentosa	mockernut hickory	4 to 9	9 to 1	Suitable	Suitable
Castanea dentata	American chestnut	5 to 8	8 to 1	Suitable	Not Suitable
Castanea mollissima	Chinese chestnut	4 to 8	8 to 1	Suitable	Not Suitable
Catalpa speciosa	northern catalpa	4 to 8	8 to 1	Suitable	Not Suitable
Celtis laevigata	southern hackberry/sugarberry	5 to 9	N/A	Suitable	Suitable
Celtis occidentalis	common hackberry	2 to 9	9 to 1	Suitable	Suitable
Cercidiphyllum japonicum	katsura tree	4 to 8	8 to 1	Suitable	Not Suitable
Cercis canadensis	eastern redbud	4 to 8	9 to 6	Suitable	Suitable
Chionanthus virginicus	fringetree	4 to 9	9 to 1	Suitable	Suitable
Cladrastis kentukea	yellowwood	4 to 8	9 to 1	Suitable	Suitable
Cornus alternifolia	pagoda dogwood	4 to 8	8 to 1	Suitable	Not Suitable
Cornus florida	flowering dogwood	5 to 9	9 to 3	Suitable	Suitable
Cornus kousa	kousa dogwood	5 to 8	8 to 5	Suitable	Not Suitable
Cornus mas	Cornelian cherry dogwood	4 to 8	8 to 5	Suitable	Not Suitable
Cornus racemosa	gray dogwood	3 to 8	8 to 3	Suitable	Not Suitable
Corylus colurna	Turkish hazel or Turkish filbert	4 to 7	7 to 4	Suitable	Not Suitable
Cotinus coggygria	smoketree	4 to 8	9 to 3	Suitable	Suitable
Crataegus crusgalli	cockspur thorn	3 to 7	7 to 1	Suitable	Not Suitable
Crataegus viridis 'Winter King'	green hawthorn 'Winter King'	4 to 8	7 to 5	Suitable	Not Suitable
Diospyros virginiana	common persimmon	4 to 9	9 to 1	Suitable	Suitable
Elaeagnus angustifolia	Russian olive	3 to 7	8 to 1	Suitable	Not Suitable
Eucommia ulmoides	hardy rubber tree	4 to 7	7 to 1	Suitable	Not Suitable
Fagus grandifolia	American beech	4 to 9	9 to 1	Suitable	Suitable
Fagus sylvatica	European beech	5 to 8	8 to 1	Suitable	Not Suitable
Fraxinus americana	white ash	4 to 9	10 to 1	Suitable	Suitable
Fraxinus excelsior	European ash	5 to 7	8 to 3	Suitable	Not Suitable
Fraxinus nigra	black ash	2 to 5	7 to 1	Suitable	Not Suitable
Fraxinus pennsylvanica	green ash	3 to 9	9 to 1	Suitable	Suitable
Ginkgo biloba	ginkgo	4 to 8	9 to 3	Suitable	Suitable
Gleditsia aquatica	water locust	5 to 9	9 to 1	Suitable	Suitable
Gleditsia triacanthos	honeylocust	4 to 8	9 to 1	Suitable	Suitable
Gleditsia triacanthos inermis	honeylocust (thornless)	4 to 8	9 to 1	Suitable	Suitable

Scientific Name	Common Name	Hardiness Zone	Heat Zone	Zone Suitability - Low	Zone Suitability - High
Gymnocladus dioicus	Kentucky coffeetree	4 to 8	9 to 2	Suitable	Suitable
Halesia tetraptera	mountain silverbell	5 to 8	8 to 4	Suitable	Not Suitable
Hibiscus syriacus	rose of Sharon	5 to 8	9 to 1	Suitable	Suitable
Juglans nigra	black walnut	4 to 9	9 to 3	Suitable	Suitable
Juglans regia	English walnut	4 to 8	7 to 1	Suitable	Not Suitable
Juniperus chinensis	Chinese juniper	4 to 9	9 to 1	Suitable	Suitable
Juniperus virginiana	eastern red cedar	3 to 9	9 to 1	Suitable	Suitable
Koelreuteria paniculata	goldenrain tree	5 to 9	9 to 1	Suitable	Suitable
Larix decidua	European larch	3 to 6	6 to 1	Not Suitable	Not Suitable
Larix laricina	tamarack	2 to 5	5 to 1	Not Suitable	Not Suitable
Liquidambar styraciflua	sweetgum	5 to 9	10 to 1	Suitable	Suitable
Liriodendron tulipifera	tulip tree	5 to 7	9 to 2	Suitable	Suitable
Maackia amurensis	amur maackia	3 to 7	7 to 4	Suitable	Not Suitable
Maclura pomifera	osage-orange	4 to 9	10 to 1	Suitable	Suitable
Magnolia grandiflora	southern magnolia	7 to 10	11 to 1	Not Suitable	Not Suitable
Magnolia stellata	star magnolia	4 to 9	9 to 5	Suitable	Suitable
Magnolia tripetala	umbrella magnolia	5 to 8	N/A	Suitable	Suitable
Magnolia virginiana	sweetbay magnolia	5 to 9	9 to 6	Suitable	Suitable
Magnolia x soulangiana	saucer magnolia	4 to 9	9 to 5	Suitable	Suitable
Malus pumila	paradise apple	4 to 7	10 to 1	Suitable	Suitable
Malus spp.	apple	3 to 8	10 to 1	Suitable	Suitable
Metasequoia glyptostroboides	dawn redwood	4 to 8	10 to 5	Suitable	Suitable
Morus alba	white mulberry	4 to 8	8 to 1	Suitable	Not Suitable
Morus rubra	red mulberry	4 to 9	N/A	Suitable	Suitable
Nyssa sylvatica	black gum	6 to 9	9 to 7	Suitable	Suitable
Ostrya virginiana	Eastern hophornbeam/Ironwood	3 to 9	9 to 5	Suitable	Suitable
Oxydendrum arboreum	sourwood	5 to 9	9 to 3	Suitable	Suitable
Parrotia persica	Persian parrotia	5 to 8	8 to 1	Suitable	Not Suitable
Paulownia tomentosa	princess tree	5 to 9	8 to 4	Suitable	Not Suitable
Phellodendron amurense	amur corktree	3 to 7	8 to 1	Suitable	Not Suitable
Picea abies	Norway spruce	3 to 7	8 to 1	Suitable	Not Suitable
Picea glauca	white spruce	2 to 6	7 to 1	Suitable	Not Suitable
Picea pungens	Colorado spruce	2 to 7	8 to 1	Suitable	Not Suitable
Picea rubens	red spruce	2 to 5	N/A	Not Suitable	Not Suitable
Pinus banksiana	jack pine	2 to 6	6 to 1	Not Suitable	Not Suitable
Pinus bungeana	lacebark pine	4 to 7	7 to 1	Suitable	Not Suitable
Pinus mugo	mugo pine	3 to 7	7 to 1	Suitable	Not Suitable

Scientific Name	Common Name	Hardiness Zone	Heat Zone	Zone Suitability - Low	Zone Suitability - High
Pinus nigra	Austrian pine	4 to 7	8 to 1	Suitable	Not Suitable
Pinus parviflora	Japanese white pine	6 to 9	9 to 1	Suitable	Suitable
Pinus resinosa	red pine	2 to 5	7 to 1	Suitable	Not Suitable
Pinus strobus	eastern white pine	3 to 8	7 to 1	Suitable	Not Suitable
Pinus sylvestris	Scots pine	3 to 7	7 to 1	Suitable	Not Suitable
Pinus virginiana	Virginia pine	5 to 8	8 to 1	Suitable	Not Suitable
Platanus occidentalis	American sycamore	4 to 9	9 to 3	Suitable	Suitable
Platanus x acerifolia	London planetree	5 to 8	9 to 5	Suitable	Suitable
Populus alba	white poplar	4 to 9	9 to 1	Suitable	Suitable
Populus balsamifera	balsam poplar	5 to 9	N/A	Suitable	Suitable
Populus deltoides	eastern cottonwood	3 to 9	9 to 1	Suitable	Suitable
Populus grandidentata	bigtooth aspen	2 to 5	N/A	Not Suitable	Not Suitable
Populus nigra	black poplar	3 to 9	9 to 1	Suitable	Suitable
Populus tremuloides	quaking aspen	2 to 6	8 to 1	Suitable	Not Suitable
Prunus avium	sweet cherry	3 to 8	8 to 1	Suitable	Not Suitable
Prunus cerasifera	cherry plum	4 to 9	9 to 1	Suitable	Suitable
Prunus persica	peach	5 to 9	9 to 1	Suitable	Suitable
Prunus sargentii	sargent cherry	5 to 8	9 to 4	Suitable	Suitable
Prunus serotina	black cherry	3 to 9	9 to 1	Suitable	Suitable
Prunus serrulata	Japanese cherry	5 to 6	9 to 4	Not Suitable	Not Suitable
Prunus subhirtella	higan cherry	5 to 8	8 to 6	Suitable	Not Suitable
Prunus virginiana	chokecherry	2 to 7	8 to 1	Suitable	Not Suitable
Prunus x yedoensis	yoshino cherry	5 to 6	8 to 3	Suitable	Not Suitable
Pseudotsuga menziesii	douglas fir	4 to 6	7 to 1	Suitable	Not Suitable
Pyrus calleryana	callery pear	5 to 9	8 to 3	Suitable	Not Suitable
Pyrus communis	European pear	5 to 9	9 to 5	Suitable	Suitable
Quercus acutissima	sawtooth oak	5 to 9	8 to 3	Suitable	Not Suitable
Quercus alba	white oak	3 to 9	8 to 1	Suitable	Not Suitable
Quercus bicolor	swamp white oak	4 to 8	8 to 1	Suitable	Not Suitable
Quercus cerris	turkey oak	7 to 9	8 to 1	Suitable	Not Suitable
Quercus coccinea	scarlet oak	4 to 9	9 to 4	Suitable	Suitable
Quercus ellipsoidalis	northern pin oak	4 to 7	7 to 1	Suitable	Not Suitable
Quercus imbricaria	shingle oak	4 to 8	8 to 4	Suitable	Not Suitable
Quercus lyrata	overcup oak	6 to 9	8 to 4	Suitable	Not Suitable
Quercus macrocarpa	bur oak	3 to 8	9 to 1	Suitable	Suitable
Quercus macrocarpa x robur	heritage oak	4 to 9	N/A	Suitable	Suitable
Quercus marilandica	blackjack oak	5 to 9	9 to 3	Suitable	Suitable
Quercus muehlenbergii	chinkapin oak	4 to 7	8 to 2	Suitable	Not Suitable

Scientific Name	Common Name	Hardiness Zone	Heat Zone	Zone Suitability - Low	Zone Suitability - High
Quercus palustris	pin oak	4 to 8	7 to 3	Suitable	Not Suitable
Quercus phellos	willow oak	6 to 9	9 to 3	Suitable	Suitable
Quercus prinus	chestnut oak	4 to 8	8 to 1	Suitable	Not Suitable
Quercus robur	common oak	3 to 8	8 to 3	Suitable	Not Suitable
Quercus rubra	northern red oak	4 to 8	9 to 5	Suitable	Suitable
Quercus shumardii	Shumard oak	5 to 9	9 to 1	Suitable	Suitable
Quercus stellata	post oak	5 to 9	9 to 4	Suitable	Suitable
Quercus velutina	black oak	3 to 9	8 to 1	Suitable	Not Suitable
Rhamnus cathartica	European buckthorn	3 to 8	N/A	Suitable	Suitable
Rhamnus frangula	glossy buckthorn	3 to 7	N/A	Suitable	Not Suitable
Rhus typhina	staghorn sumac	4 to 8	8 to 1	Suitable	Not Suitable
Robinia pseudoacacia	black locust	4 to 8	9 to 3	Suitable	Suitable
Salix babylonica	weeping willow	6 to 9	9 to 1	Suitable	Suitable
Salix discolor	pussy willow	2 to 7	8 to 2	Suitable	Not Suitable
Salix matsudana	Chinese willow	5 to 9	N/A	Suitable	Suitable
Salix nigra	black willow	4 to 9	N/A	Suitable	Suitable
Sassafras albidum	sassafras	3 to 9	10 to 1	Suitable	Suitable
Sorbus americana	American mountain ash	2 to 6	6 to 1	Not Suitable	Not Suitable
Sorbus aucuparia	European mountain ash	3 to 6	7 to 1	Suitable	Not Suitable
Styphnolobium japonicum	Japanese pagoda tree	5 to 8	9 to 5	Suitable	Suitable
Syringa reticulata	Japanese tree lilac	3 to 7	7 to 1	Suitable	Not Suitable
Syringa vulgaris	common lilac	4 to 8	8 to 1	Suitable	Not Suitable
Taxodium distichum	bald cypress	4 to 11	12 to 2	Suitable	Suitable
Thuja occidentalis	northern white cedar	2 to 7	7 to 1	Suitable	Not Suitable
Tilia americana	American linden or basswood	3 to 8	8 to 1	Suitable	Not Suitable
Tilia cordata	littleleaf linden	3 to 7	8 to 1	Suitable	Not Suitable
Tilia tomentosa	silver linden	4 to 7	9 to 1	Suitable	Suitable
Tilia x euchlora	Crimean linden	3 to 7	7 to 1	Suitable	Not Suitable
Tilia x europaea	common lime	3 to 7	8 to 1	Suitable	Not Suitable
Tsuga canadensis	eastern hemlock	3 to 7	8 to 1	Suitable	Not Suitable
Ulmus Accolade	accolade elm	4 to 9	8 to 1	Suitable	Not Suitable
Ulmus alata	winged elm	6 to 7	N/A	Suitable	Not Suitable
Ulmus americana	American elm	3 to 9	9 to 1	Suitable	Suitable
Ulmus crassifolia	cedar elm	7 to 9	9 to 6	Not Suitable	Not Suitable
Ulmus parvifolia	lacebark elm	5 to 9	9 to 1	Suitable	Suitable
Ulmus pumila	Siberian elm	4 to 9	9 to 1	Suitable	Suitable
Ulmus rubra	slippery elm	3 to 9	10 to 3	Suitable	Suitable
Viburnum lentago	nannyberry	2 to 8	8 to 1	Suitable	Not Suitable

Scientific Name	Common Name	Hardiness Zone	Heat Zone	Zone Suitability - Low	Zone Suitability - High
Zelkova serrata	Japanese zelkova	5 to 8	9 to 5	Suitable	Suitable

Adaptive Capacity of Urban Trees

The results presented above 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 et al. 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 include fire or drought tolerance, dispersal ability, shade tolerance, site specificity, and susceptibility to insect pests and diseases (Table 5.3). 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 a large number of positive modification factors would have a high adaptive capacity, and a species with a large number of negative modification factors would have a low adaptive capacity.

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

For natural areas (both native and naturalized), 42 species received a high adaptability score, eight received a low adaptability score, and 43 received a medium adaptability score (Table 5.4). 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) include boxelder, Norway maple, red maple, silver maple, and tulip tree. It's worth noting that 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.

For planted/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 5.5). Common species in Detroit with high adaptability scores (≥5) 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/salt spray).

Species that received low adaptability ratings included 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 were 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 5.3. Trait Codes for Adaptability Tables. Traits are listed if they were among the main contributors to the overall adaptability score. N=applies to naturally occurring trees; P=applies to planted trees. See Appendix 7 for more information.

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

Table 5.4. Adaptability Scores for Trees in Natural Areas. Native trees are considered those historically native to Michigan growing in natural populations using the USDA's plant search (https://plants.usda.gov/). See Table 5.3 for trait codes. See Appendix 7 for description of Adapt scoring system. Adapt scores are all positive. A score below 3.5 is low, above 4.5 is high, and between 3.5 and 4.5 is a medium adapt class.

Scientific Name	Common Name	Native?	Natural Adapt Score	Natural Adapt Class	Natural Positive Factors	Natural Negative Factors
Acer negundo	boxelder	Yes	5.64	High	DRO FLO TEM COL DIS PLE	-
Acer nigrum	black maple	Yes	4.76	High	COL	INS INPL
Acer platanoides	Norway maple	Yes	5.98	High	DRO FLO COL ESP PLE	INS
Acer rubrum	red maple	Yes	5.52	High	FLO COL EHS PLE VEGR	INS INPL DRO
Acer saccharinum	silver maple	Yes	5.18	High	FLO DISP PLE COL	INS INPL
Acer saccharum	sugar maple	Yes	4.78	High	COL EHS	INS INPL
Aesculus glabra	Ohio buckeye	Yes	3.09	Low	COL	INPL PLE
Ailanthus altissima	tree of heaven	No	6.58	High	INS INPL DRO AIP EHS ESP DISP PLE VEGR FIRE	-
Albizia julibrissin	Persian silk tree	No	4.99	High	DRO FLO ESP EHS PLE	INPL
Alnus rugosa	grey alder	Yes	4.22	Medium	FLO	INPL DRO
Amelanchier arborea	downy serviceberry	Yes	5.76	High	TEM COL EHS PLE FIRE	INPL
Betula alleghaniensis	yellow birch	Yes	5.17	High	COL PLE VEGR	INPL
Betula nigra	river birch	Yes	4.06	Medium	-	INPL DRO COL
Betula pendula	silver birch	No	4.16	Medium	EHS	INS INPL COL
Betula populifolia	gray birch	Yes	4.16	Medium	-	INS INPL COL
Carya cordiformis	bitternut hickory	Yes	4.06	Medium	DRO	INPL
Carya glabra	pignut hickory	Yes	4.72	High	EHS	INPL
Carya illinoinensis	hardy pecan	No	3.12	Low	-	INPL
Carya laciniosa	shellbark hickory	Yes	3.99	Medium	COL	INPL DRO
Carya ovata	shagbark hickory	Yes	4.66	Medium	-	INPL
Carya texana	black hickory	No	3.52	Medium	DRO EHS PLE	INPL FLO
Carya tomentosa	mockernut hickory	Yes	3.68	Medium	TEM	AIP
Castanea dentata	American chestnut	Yes	3.1	Low	-	RRC NUP
Catalpa speciosa	northern catalpa	Yes	3.44	Low	-	INPL COL
Celtis laevigata	southern hackberry/sugarberry	No	5.74	High	DRO COL ESP EHS DISP PLE	INPL
Celtis occidentalis	common hackberry	Yes	4.9	Medium	DRO	INPL
Cercis canadensis	eastern redbud	Yes	4.98	Medium	FLO	INPL
Cornus alternifolia	pagoda dogwood	Yes	4.46	Medium	-	INPL
Cornus florida	flowering dogwood	Yes	4.86	High	COL	INPL DRO
Cornus racemosa	gray dogwood	Yes	4.96	High	COL PLE	INPL
Fagus grandifolia	American beech	Yes	4.25	Medium	COL	INPL FLO

Scientific Name	Common Name	Native?	Natural Adapt Score	Natural Adapt Class	Natural Positive Factors	Natural Negative Factors
Fraxinus americana	white ash	Yes	4.12	Medium	-	INS INPL
Fraxinus nigra	black ash	Yes	2.89	Low	FLO	INS DRO COL PLE
Fraxinus pennsylvanica	green ash	Yes	4.46	Medium	FLO	INS INPL
Gleditsia triacanthos	honeylocust	Yes	4.72	High	DRO EHS	INPL
Gymnocladus dioicus	Kentucky coffeetree	Yes	4.26	Medium	DRO	INPL
Juglans nigra	black walnut	Yes	3.85	Medium	PLE	INPL COL
Juniperus virginiana	eastern red cedar	Yes	4.03	Medium	DRO	INPL
Koelreuteria paniculata	goldenrain tree	No	4.7	High	DRO DISP PLE	INPL COL
Liquidambar styraciflua	sweetgum	No	4.63	High	FLO EHS VEGR	INS INPL DRO COL
Liriodendron tulipifera	tulip tree	Yes	5.39	High	EHS PLE FIRE	INPL DRO
Maclura pomifera	osage-orange	Yes	4.94	High	DRO ESP EHS	INPL
Magnolia grandiflora	southern magnolia	No	4.29	Medium	COL PLE	INPL DRO
Magnolia tripetala	umbrella magnolia	No	4.29	Medium	-	-
Magnolia virginiana	sweetbay magnolia	No	4.29	Medium	-	-
Morus alba	white mulberry	No	4.98	High	DISP PLE	-
Morus rubra	red mulberry	Yes	4.44	Medium	COL	INPL
Nyssa sylvatica	black gum	Yes	5.31	High	COL	INPL
Ostrya virginiana	Eastern hophornbeam/Ironwood	Yes	4.88	High	FLO COL PLE	INPL DRO
Oxydendrum arboreum	sourwood	No	5.32	High	COL EHS	INPL
Phellodendron amurense	amur corktree	No	5.11	High	PLE	-
Picea rubens	red spruce	Yes	3.5	Medium	EHS	DRO PLE INPL
Pinus strobus	eastern white pine	Yes	3.75	Medium	-	INS INPL DRO
Pinus virginiana	Virginia pine	No	3.83	Medium	-	INPL AIP COL
Platanus occidentalis	American sycamore	Yes	3.49	Low	FLO	INPL DRO
Populus balsamifera	balsam poplar	Yes	4.16	Medium	FLO VEGR FIRE	INPL DRO COL
Populus deltoides	eastern cottonwood	Yes	3.15	Low	TEM NUP	INS AIP
Populus grandidentata	bigtooth aspen	Yes	4.67	High	VEGR FIRR	INPL DRO AIP COL
Populus tremuloides	quaking aspen	Yes	4.41	Medium	TEM EHS VEGR	INS INPL DRO COL
Prunus cerasifera	cherry plum	No	3.82	Medium	TEM NUP	INS AIP
Prunus serotina	black cherry	Yes	3.61	Medium	DISP PLE	INPL EHS
Prunus virginiana	chokecherry	Yes	3.93	Medium	-	INPL COL

Scientific Name	Common Name	Native?	Natural Adapt Score	Natural Adapt Class	Natural Positive Factors	Natural Negative Factors
Pyrus communis	European pear	No	3.47	Medium	TEM NUP	AIP
Quercus bicolor	swamp white oak	Yes	4.36	Medium	-	INPL
Quercus coccinea	scarlet oak	Yes	5.02	High	ESP EHS VEGR	INPL
Quercus ellipsoidalis	northern pin oak	Yes	4.22	Medium	DRO FIRT	INPL COL
Quercus imbricaria	shingle oak	Yes	4.33	Medium	DRO EHS	INPL COL
Quercus macrocarpa	bur oak	Yes	4.76	High	DRO AIP	INPL
Quercus marilandica	blackjack oak	No	4.67	High	DRO PLE VEGR FIR	INPL FLO COL
Quercus muehlenbergii	chinkapin oak	Yes	4.99	High	DRO TEM	INPL
Quercus palustris	pin oak	Yes	3.65	Medium	FLO	INPL COL
Quercus prinus	chestnut oak	No	5.498	High	DRO EHS PLE VEGR	INPL
Quercus rubra	northern red oak	Yes	4.88	High	-	INPL
Quercus shumardii	Shumard oak	Yes	4.04	Medium	DRO FLO TEM	INPL COL
Quercus stellata	post oak	No	4.17	Medium	DRO TEM	INPL FLO COL
Quercus velutina	black oak	Yes	4.61	High	DRO	INPL
Rhamnus cathartica	European buckthorn	No	6.74	High	INPL DRO TEM AIP COL ESP DISP PLE VEGR	
Rhamnus frangula	glossy buckthorn	No	6.74	High	INPL FLO TEM AIP COL ESP EHS DISP PLE VEGR	-
Rhus typhina	staghorn sumac	Yes	4.77	High	DRO PLE VEGR FIRE	INPL COL
Robinia pseudoacacia	black locust	Yes	4.66	Medium	DRO	INPL
Salix discolor	pussy willow	Yes	4.24	Medium	INS DISP PLE FIRE	DRO COL
Salix nigra	black willow	Yes	3.26	Low	FLO	INPL DRO COL
Syringa vulgaris	common lilac	No	3.88	Medium	RRC NUP	AIP
Taxodium distichum	bald cypress	Yes	3.81	Medium	FLO	INPL DRO
Thuja occidentalis	northern white cedar	Yes	4.38	Medium	COL	INPL DRO
Tilia americana	American linden or basswood	Yes	4.18	Medium	FLO COL	INPL PLE
Ulmus americana	American elm	Yes	4.64	High	EHS	DISE INS DRO
Ulmus crassifolia	cedar elm	No	5.57	High	DRO FLO AIP ESP DISP PLE FIR	INPL
Ulmus parvifolia	lacebark elm	No	5.44	High	DRO ESP EHS PLE	INPL
Ulmus pumila	Siberian elm	No	4.83	High	INS DRO EHS PLE	-
Ulmus rubra	slippery elm	Yes	4.5	High	DRO COL	INPL
Viburnum lentago	nannyberry	Yes	4.73	High	COL	INPL

Table 5.5. Adaptability Scores for Trees in Planted Areas. Native trees are considered those historically native to Michigan growing in natural populations using the USDA's plant search (https://plants.usda.gov/). See Table 5.3 for Trait Codes.

Scientific Name	Common Name	Native ?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Abies balsamea	balsam fir	Yes	4.22	Medium	NUP	DRO TEM AIP
Abies concolor	white fir	No	3.87	Medium	-	FLO AIP
Acer buergerianum	trident maple	No	4.21	Medium	RRC	FLO LPS
Acer campestre	hedge maple	No	4.47	Medium	NUP	INS LPS
Acer griseum	paperbark maple	No	3.28	Low	-	DRO TEM AIP NUP
Acer miyabei	miyabei maple	No	5.10	High	SAL	AIP
Acer negundo	boxelder	Yes	4.30	Medium	DRO FLO TEM	INS AIP INPO ICE
Acer nigrum	black maple	Yes	3.69	Medium	TEM	INS AIP SAL NUP
Acer palmatum	Japanese maple	No	3.92	Medium	NUP	DRO AIP LPS
Acer platanoides	Norway maple	Yes	5.10	High	DRO FLO ESP LPS RRC NUP	INS INPO
Acer pseudoplatanus	sycamore maple	No	4.25	Medium	NUP	INS, AIP
Acer rubrum	red maple	Yes	4.70	High	FLO TEM NUP COL LPS	INS DRO AIP
Acer saccharinum	silver maple	Yes	3.80	Medium	FLO TEM NUP	INS RRC MAR
Acer saccharum	sugar maple	Yes	4.40	Medium	NUP MAR COL	INS FLO AIP RRC SAL
Acer tataricum	tatarian maple	No	3.92	Medium	DRO	AIP INPO
Acer tataricum ginnala	amur maple	No	4.50	Medium	TEM LPS DRO	INPO
Acer x freemanii	freeman maple	Yes	4.46	Medium	LPS NUP	INS WIN MAR
Aesculus glabra	Ohio buckeye	Yes	3.69	Medium	-	AIP DRO ESP
Aesculus hippocastanum	common horse chestnut	No	4.20	Medium	TEM	
Aesculus x carnea	red horse chestnut	No	3.91	Medium	-	-
Ailanthus altissima	tree of heaven	No	4.94	High	DRO TEM AIP ESP LPS RRC	LPS NUP INPO ESP
Albizia julibrissin	Persian silk tree	No	2.88	Low	DRO FLO TEM ESP	AIP LPS INPO
Alnus glutinosa	black alder	No	4.25	Medium	FLO	INS AIP INPO
Alnus rugosa	grey alder	Yes	4.17	Medium	FLO	AIP
Amelanchier arborea	downy serviceberry	Yes	5.00	High	TEM NUP	AIP
Amelanchier x grandiflora	apple serviceberry	No	4.01	Medium	LPS RRC NUP	DRO FLO AIP
Asimina triloba	pawpaw	Yes	4.30	Medium	-	NUP
Betula alleghaniensis	yellow birch	Yes	4.58	High	NUP	TEM DRO BRO INS
Betula nigra	river birch	Yes	3.65	Medium	TEM LPS NUP	DISE DRO PLE
Betula papyrifera	paper birch	Yes	3.65	Medium	NUP	DISE INS DRO TEM AIP
Betula pendula	silver birch	No	3.22	Low	-	INS AIP
Betula platyphylla	Japanese white birch	No	3.85	Medium	-	-
Betula populifolia	gray birch	No	3.22	Low	-	DISE INS AIP LPS

Scientific Name	Common Name	Native ?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Carpinus betulus	European Hornbeam	No	4.42	Medium		SAL
Carpinus caroliniana	musclewood/American hornbeam	Yes	4.75	High	FLO TEM NUP COL	DRO AIP
Carya cordiformis	bitternut hickory	Yes	3.83	Medium	DRO	AIP
Carya glabra	pignut hickory	Yes	3.91	Medium	TEM	NUR
Carya illinoinensis	hardy pecan	No	3.15	Low	NUP	-
Carya laciniosa	shellbark hickory	Yes	3.26	Low	-	AIP
Carya ovata	shagbark hickory	Yes	3.16	Low	TEM	AIP PLE NUP
Carya texana	black hickory	No	2.92	Low	-	FLO NUP
Carya tomentosa	mockernut hickory	Yes	3.51	Medium	TEM	AIP NUP
Castanea dentata	American chestnut	Yes	3.10	Low	-	RRC NUP
Castanea mollissima	Chinese chestnut	No	3.59	Medium	TEM	-
Catalpa speciosa	northern catalpa	Yes	4.26	Medium	DISE LPS INS PLE	AIP RRC
Celtis laevigata	southern hackberry/sugarberry	No	3.66	Medium	DRO FLO TEMP	AIP NUP
Celtis occidentalis	common hackberry	Yes	4.55	High	DRO TEM LPS NUP ESP	MAR WIN
Cercidiphyllum japonicum	katsura tree	No	3.31	Low	DISE NUP	DRO WIN AIP RRC
Cercis canadensis	eastern redbud	Yes	3.90	Medium	FLO TEM NUP	AIP LPS
Chionanthus virginicus	fringetree	No	4.92	High	DRO TEM LPS RRC NUP	
Cladrastis kentukea	yellowwood	No	4.33	Medium	TEM RRC	AIP DRO
Cornus alternifolia	pagoda dogwood	Yes	4.30	Medium	NUP	AIP
Cornus florida	flowering dogwood	Yes	3.84	Medium	TEM NUP	DRO FLO AIP RRC LPS
Cornus kousa	kousa dogwood	No	4.63	High	NUP	DRO AIP
Cornus mas	Cornelian cherry dogwood	No	4.06	Medium	TEM	AIP
Cornus racemosa	gray dogwood	Yes	4.48	Medium	-	-
Corylus colurna	Turkish hazel or Turkish filbert	No	4.27	Medium	DRO TEM LPS RRC	SAL NUP
Cotinus coggygria	smoketree	No	4.90	High	DRO RRC LPS NUP	FLO
Crataegus crusgalli	cockspur thorn	Yes	4.47	Medium	DRO TEM LPS RRC NUP	INS AIP DISE FLO
Crataegus viridis 'Winter King'	green hawthorn 'Winter King'	No	4.15	Medium	LPS RRC	FLO
Diospyros virginiana	common persimmon	No	4.80	High	NUP RRC TEM ESP FLO DRO	-
Elaeagnus angustifolia	Russian olive	No	4.95	High	DRO TEM NUP SAL PLE LPS ESP	INPO WIN ICE DISE
Eucommia ulmoides	hardy rubber tree	No	4.69	High	DRO	FLO
Fagus grandifolia	American beech	Yes	3.55	Medium	TEM NUP	FLO AIP LPS RRC
Fagus sylvatica	European beech	No	3.80	Medium	NUP	DRO RRC LPS
Fraxinus americana	white ash	Yes	3.22	Low	NUP	INS AIP RRC

Scientific Name	Common Name	Native ?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Fraxinus excelsior	European ash	No	3.83	Medium	FLO	INS LPS
Fraxinus nigra	black ash	Yes	2.57	Low	FLO	INS DRO AIP ESP LPS RRC NUP
Fraxinus pennsylvanica	green ash	Yes	3.90	Medium	FLO LPS NUP	INS MAR
Ginkgo biloba	ginkgo	No	5.97	High	DRO TEM LPS RRC NUP	FLO
Gleditsia aquatica	water locust	Yes	4.18	Medium	FLO	-
Gleditsia triacanthos	honeylocust	No	4.26	Medium	DRO TEM RRC NUP	-
Gleditsia triacanthos inermis	honeylocust (thornless)	No	4.26	Medium	DRO TEM RRC NUP	-
Gymnocladus dioicus	Kentucky coffeetree	Yes	4.60	High	DRO LPS NUP	AIP
Halesia tetraptera	mountain silverbell	Yes	3.77	Medium	DRO TEM	NUP
Hibiscus syriacus	rose of Sharon	No	4.55	High	NUP	-
Juglans nigra	black walnut	Yes	2.73	Low	DRO	AIP LPS RRC DISE MAR NUR
Juglans regia	English walnut	No	3.66	Medium	-	-
Juniperus chinensis	Chinese juniper	No	4.50	High	-	-
Juniperus virginiana	eastern red cedar	Yes	4.71	High	DRO TEM LPS RRC	AIP
Koelreuteria paniculata	goldenrain tree	No	4.71	High	DRO TEM LPS RRC NUP	INPO
Larix decidua	European larch	No	3.67	Medium	-	DRO TEM AIP
Larix laricina	tamarack	Yes	3.86	Medium	FLO NUP	DRO AIP
Liquidambar styraciflua	sweetgum	No	3.49	Low	FLO	INS DRO RRC LPS
Liriodendron tulipifera	tulip tree	Yes	3.47	Low	NUP	DRO AIP RRC
Maackia amurensis	amur maackia	No	4.85	High	DRO TEM RRC NUP	FLO
Maclura pomifera	osage-orange	Yes	4.46	Medium	DRO TEM ESP RRC NUP	AIP
Magnolia grandiflora	southern magnolia	No	3.97	Medium	NUP	RRC
Magnolia stellata	star magnolia	No	4.37	Medium	NUP	-
Magnolia tripetala	umbrella magnolia	No	4.36	Medium	-	AIP
Magnolia virginiana	sweetbay magnolia	No	5.03	High	TEM LPS RRC NUP PLE	AIP
Magnolia x soulangiana	saucer magnolia	No	4.63	High	TEM NUP	DRO FLO
Malus pumila	paradise apple	No	4.01	Medium	TEM LPS RRC NUP	DISE INS AIP
Malus spp.	apple	Yes (not all spp.)	4.01	Medium	TEM LPS RRC NUP	INS
Metasequoia glyptostroboides	dawn redwood	No	4.10	Medium	TEM FLO	AIP COL
Morus alba	white mulberry	No	4.06	Medium	TEM NUP SAL	LPS INPO
Morus rubra	red mulberry	Yes	4.00	Medium	TEM NUP	AIP
Nyssa sylvatica	black gum	Yes	4.72	High	RRC	AIP
Ostrya virginiana	Eastern hophornbeam/Ironwood	Yes	5.41	High	DRO TEM LPS RRC NUP	FLO AIP

Scientific Name	Common Name	Native ?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Oxydendrum arboreum	sourwood	No	4.60	High	-	-
Parrotia persica	Persian parrotia	No	5.47	High	DRO TEM LPS RRC NUP	SAL
Paulownia tomentosa	princess tree	No	5.55	High	NUP	INPO
Phellodendron amurense	amur corktree	No	4.46	Medium	TEM NUP	RRC INPO
Picea abies	Norway spruce	Yes	3.61	Medium	NUR	INS FLO AIP
Picea glauca	white spruce	Yes	4.15	Medium	-	INS
Picea pungens	Colorado spruce	No	3.95	Medium	NUP	INS FLO AIP
Picea rubens	red spruce	No	4.22	Medium	DRO TEM	-
Pinus banksiana	jack pine	Yes	3.40	Low	-	-
Pinus bungeana	lacebark pine	No	4.15	Medium	DRO AIP NUP	-
Pinus mugo	mugo pine	No	4.35	Medium	WIN AIP RRC	FLO
Pinus nigra	Austrian pine	No	3.91	Medium	DRO TEM RRC	DISE INS
Pinus parviflora	Japanese white pine	No	4.00	Medium	-	LPS
Pinus resinosa	red pine	Yes	2.70	Low	-	INS DRO AIP RRC
Pinus strobus	eastern white pine	Yes	2.90	Low	NUP	DISE INS DRO TEM AIP LPS RRC
Pinus sylvestris	Scots pine	No	4.42	Medium	TEM RRC NUP	INS
Pinus virginiana	Virginia pine	No	3.41	Low	NUP	AIP
Platanus occidentalis	American sycamore	Yes	4.11	Medium	TEM NUP FLO SAL	DRO
Platanus x acerifolia	London planetree	No	4.33	Medium	DRO FLO TEM NUP	DISE INS AIP
Populus alba	white poplar	No	3.59	Medium	DRO TEM ESP NUP	
Populus balsamifera	balsam poplar	Yes	3.30	Low	FLO	DRO TEM
Populus deltoides	eastern cottonwood	Yes	3.61	Medium	TEM NUP FLO SAL PLE TEM	DISE INS AIP LPS RRC WIN ICE
Populus grandidentata	bigtooth aspen	Yes	3.50	Medium	-	DRO AIP LPS NUP
Populus nigra	black poplar	No	3.56	Medium	TEM	-
Populus tremuloides	quaking aspen	Yes	3.92	Medium	TEM WIN MAR PLE	INS DRO AIP RRC INPO
Prunus avium	sweet cherry	No	4.01	Medium	TEM	FLO INPO DISE
Prunus cerasifera	cherry plum	No	3.82	Medium	NUP	AIP INS
Prunus persica	peach	No	3.61	Medium	NUP	-
Prunus sargentii	sargent cherry	No	3.80	Medium	DRO TEM RRC LPS	WN AIP
Prunus serotina	black cherry	Yes	2.10	Low	CRO TEM	FLO AIP LPS RRC DRO
Prunus serrulata	Japanese cherry	No	4.31	Medium	TEM LPS NUP	-
Prunus subhirtella	higan cherry	No	4.00	Medium	SAL DRO	FLO AIP RRC
Prunus virginiana	chokecherry	Yes	3.56	Medium	NUP	DISE FLO AIP
Prunus x yedoensis	yoshino cherry	No	3.20	Low	-	AIP LPS
Pseudotsuga menziesii	douglas fir	No	2.70	Low	NUP	DRO FLO TEM LPS ESP SAL INS DISE

Scientific Name	Common Name	Native ?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Pyrus calleryana	callery pear	No	4.20	Medium	DRO TEM RRC NUP SAL AIP	INS INPO DISE
Pyrus communis	European pear	No	3.52	Medium	-	AIP
Quercus acutissima	sawtooth oak	No	5.48	High	DRO FLO TEM LPS RRC NUP	INPO
Quercus alba	white oak	Yes	3.34	Low	TEM NUP SAL DRO	FLO AIP ESP LPS RRC DISE PLE
Quercus bicolor	swamp white oak	Yes	5.15	High	TEM RRC NUP SAL LPS TEM FLO	AIP
Quercus cerris	turkey oak	No	3.92	Medium	DRO TEM	-
Quercus coccinea	scarlet oak	Yes	3.82	Medium	TEM LPS	AIP ESP FLO DISE
Quercus ellipsoidalis	northern pin oak	Yes	3.20	Low	DRO LPS	TEM AIP DISE ESP
Quercus imbricaria	shingle oak	Yes	4.50	High	DRO NUP	AIP ESP DISE
Quercus lyrata	overcup oak	No	4.63	High	DRO FLO	-
Quercus macrocarpa	bur oak	Yes	4.92	High	DRO TEM AIP LPS NUP FLO ESP	DISE
Quercus macrocarpa x robur	heritage oak	No	5.19	High	DRO TEM LPS NUP	INS
Quercus marilandica	blackjack oak	No	2.87	Low	DRO	FLO AIP LPS
Quercus muehlenbergii	chinkapin oak	Yes	4.65	High	DRO TEM LPS ESP	-
Quercus palustris	pin oak	Yes	3.52	Medium	FLO RRC NUP	AIP DRO SAL ESP DISE
Quercus phellos	willow oak	No	4.80	High	FLO LPS RRC NUP	-
Quercus prinus	chestnut oak	No	4.51	High	DRO LPS SAL	AIP DISE RRC
Quercus robur	common oak	No	4.22	Medium	DRO TEM	-
Quercus rubra	northern red oak	Yes	4.05	Medium	TEM LPS NUP	DISE FLO RRC ESP
Quercus shumardii	Shumard oak	Yes	3.99	Medium	DRO FLO TEM LPS RRC NUP	DISE PLE ESP
Quercus stellata	post oak	No	2.92	Low	TEM	FLO AIP RRC NUP
Quercus velutina	black oak	Yes	2.98	Low	DRO TEM	FLO NUP PLE RRC DISE
Rhamnus cathartica	European buckthorn	No	5.86	High	DRO TEM ESP NUP	INPO
Rhamnus frangula	glossy buckthorn	No	5.80	High	FLO TEM ESP NUP	INPO
Rhus typhina	staghorn sumac	Yes	3.95	Medium	DRO TEM	-
Robinia pseudoacacia	black locust	Yes	3.91	Medium	DRO TEM ESP SAL PLE	INS FLO AIP LPS RRC INPO WIN
Salix babylonica	weeping willow	No	3.57	Medium	FLO TEM NUP	INS LPS RRC
Salix discolor	pussy willow	Yes	3.90	Medium	FLO TEM NUP	INS AIP
Salix matsudana	Chinese willow	No	3.66	Medium	FLO	-
Salix nigra	black willow	Yes	3.06	Low	FLO	DRO AIP RRC MAR WIN DISE
Sassafras albidum	sassafras	Yes	4.10	Medium	DRO TEM ESP	FLO AIP NUP RRC
Sorbus americana	American mountain ash	Yes	4.20	Medium	NUP	DRO AIP
Sorbus aucuparia	European mountain ash	No	3.72	Medium	LPS RRC NUP	ESP DRO SAL AIP DISE INS

Scientific Name	Common Name	Native ?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Styphnolobium japonicum	Japanese pagoda tree	No	5.27	High	DRO TEM LPS RRC NUP SAL ESP AIP	FLO
Syringa reticulata	Japanese tree lilac	No	4.55	High	LPS RRC NUP ESP PLE	AIP FLO INPO DISE
Syringa vulgaris	common lilac	No	3.88	Medium	NUP	AIP
Taxodium distichum	bald cypress	Yes	4.90	High	FLO RRC NUP	AIP
Thuja occidentalis	northern white cedar	Yes	4.77	High	NUP ESP FLO	DRO AIP ICE BRO WIN
Tilia americana	American linden or basswood	Yes	4.38	Medium	TEM NUP LPS PLE	AIP RRC INS DRO WIN SAL
Tilia cordata	littleleaf linden	No	5.18	High	LPS NUP PLE ESP AIP	INS SAL WIN
Tilia tomentosa	silver linden	No	4.15	Medium	TEM NUP	AIP
Tilia x euchlora	Crimean linden	No	5.30	High	TEM LPS RRC NUP	-
Tilia x europaea	common lime	No	4.26	Medium	TEM	-
Tsuga canadensis	eastern hemlock	Yes	2.68	Low	NUP	DRO AIP LPS INS MAR RRC SAL
Ulmus Accolade	accolade elm	No	4.76	High	NUP	INS
Ulmus alata	winged elm	No	4.17	Medium	FLO LPS RRC	AIP
Ulmus americana	American elm	Yes	4.45	Medium	TEM NUP DRO FLO LPS SAL	DISE INS MAR
Ulmus crassifolia	cedar elm	No	5.77	High	NUP FLO	-
Ulmus parvifolia	lacebark elm	No	5.50	High	DRO TEM ESP LPS RRC NUP	INPO
Ulmus pumila	Siberian elm	No	3.76	Medium	DRO TEM DISE	WIN INPO
Ulmus rubra	slippery elm	Yes	4.25	Medium	TEM LPS FLO DRO	DISE INS
Viburnum lentago	nannyberry	Yes	5.15	High	NUP	-
Zelkova serrata	Japanese zelkova	No	4.87	High	TEM LPS RRC NUP SAL DRO	-

Overall Vulnerability of the Detroit Region's Trees

Vulnerability is the susceptibility of a system to the adverse effects of climate change (IPCC, 2007). It is a function of potential climate change impacts and the adaptive capacity of the system. 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 5.4 and 5.5) together in a matrix (Table 5.6).

Table 5.6. Vulnerability Scoring Matrix Based on Brandt et al. (2017).

Habitat or Zone Suitability-end of century	**Adapt Class**		
	Low	**Medium**	**High**
Not suitable	High Vulnerability	Moderate-high Vulnerability	Moderate Vulnerability
Suitable	Moderate Vulnerability	Low-moderate Vulnerability	Low Vulnerability

One hundred eighty-seven species and cultivars were evaluated for their vulnerability. This overall approach is meant to give a coarse picture of vulnerability, and is best combined with local expertise about a species suitability for a given site. Each species was given a vulnerability rating under low emissions and high emissions (Table 5.7). Under the low emissions scenario, 22% of species fell into the low category, 51% fell into the low-moderate category, 20% fell into the moderate category, 5% fell into the moderate-high category, and 1% fell into the high category. Under the high emissions scenario, 14% of species fell into the low category, 21% fell into the low-moderate category, 20% fell into the moderate category, 35% fell into the moderate-high category, and 10% fell into the high category.

The most vulnerable *native* species (moderate-high vulnerability under both emissions scenarios, or high vulnerability under high emissions scenarios) 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 emissions scenarios) include bur oak, common hackberry, downy serviceberry, Eastern hophornbeam, eastern red cedar, Kentucky coffeetree, musclewood, and red maple.

We can also examine the most (moderate-high vulnerability under high emissions scenario) and least (low or low-moderate vulnerability under both emissions scenarios) vulnerable species that are most *commonly* found in the Detroit region. The most vulnerable common, *native* species include American linden, boxelder, northern catalpa, pin oak, silver maple, and sugar maple. The least vulnerable common, *native* species include American sycamore, apple, common hackberry, green ash, northern red oak, and red maple. Rare (>50)/not planted species with low vulnerability under both scenarios include downy serviceberry, fringetree, smoketree, common persimmon, Kentucky coffeetree, Chinese juniper, goldenraintree, sweetbay magnolia, saucer magnolia, black gum, sourwood, heritage oak, willow oak, European buckthorn, and Japanese pagoda tree.

Table 5.7. Vulnerability Ratings for Trees in the Detroit Region.

Scientific Name	Common Name	Estimated Trees in Detroit	Vulnerability - Low Emissions	Vulnerability - High Emissions
Abies balsamea	balsam fir	13	moderate-high	moderate-high
Abies concolor	white fir	2	low-moderate	moderate-high
Acer buergerianum	trident maple	7	low-moderate	low-moderate
Acer campestre	hedge maple	304	low-moderate	moderate-high
Acer griseum	paperbark maple	5	moderate	high
Acer miyabei	miyabei maple	17	low	moderate
Acer negundo	boxelder***	1,002	low-moderate	moderate-high
Acer nigrum	black maple	67	low-moderate	moderate-high
Acer palmatum	Japanese maple	235	low-moderate	moderate-high
Acer platanoides	Norway maple***	30,157	moderate	moderate
Acer pseudoplatanus	sycamore maple	58	low-moderate	moderate-high
Acer rubrum	red maple*	7,287	low	low
Acer saccharinum	silver maple*	20,476	low-moderate	moderate-high
Acer saccharum	sugar maple	5,240	low-moderate	moderate-high
Acer tataricum	tatarian maple		low-moderate	moderate-high
Acer tataricum ginnala	amur maple	107	low-moderate	moderate-high
Acer x freemanii	freeman maple	873	low-moderate	moderate-high
Aesculus glabra	Ohio buckeye	31	low-moderate	moderate-high
Aesculus hippocastanum	common horse chestnut	1,180	low-moderate	moderate-high
Aesculus x carnea	red horse chestnut		low-moderate	moderate-high
Ailanthus altissima	tree of heaven**	984	low	moderate
Albizia julibrissin	Persian silk tree***		moderate	moderate
Alnus glutinosa	black alder		low-moderate	moderate-high
Alnus rugosa	grey alder*	1	low-moderate	moderate-high
Amelanchier arborea	downy serviceberry	8	low	low

Scientific Name	Common Name	Estimated Trees in Detroit	Vulnerability - Low Emissions	Vulnerability - High Emissions
Amelanchier x grandiflora	apple serviceberry		low-moderate	moderate-high
Asimina triloba	pawpaw	6	low-moderate	moderate-high
Betula alleghaniensis	yellow birch		moderate	moderate
Betula nigra	river birch	202	low-moderate	low-moderate
Betula papyrifera	paper birch	130	low-moderate	moderate-high
Betula pendula	silver birch	24	moderate	high
Betula platyphylla	Japanese white birch		low-moderate	moderate-high
Betula populifolia	gray birch	40	high	high
Carpinus betulus	European Hornbeam	171	low-moderate	moderate-high
Carpinus caroliniana	musclewood/American hornbeam	200	low	low
Carya cordiformis	bitternut hickory**	26	low-moderate	low-moderate
Carya glabra	pignut hickory	9	low-moderate	moderate-high
Carya illinoinensis	hardy pecan	7	moderate	moderate
Carya laciniosa	shellbark hickory	1	moderate	high
Carya ovata	shagbark hickory	70	moderate	high
Carya texana	black hickory**		moderate	moderate
Carya tomentosa	mockernut hickory	3	low-moderate	low-moderate
Castanea dentata	American chestnut	4	moderate	high
Castanea mollissima	Chinese chestnut	1	low-moderate	moderate-high
Catalpa speciosa	northern catalpa	1,238	low-moderate	moderate-high
Celtis laevigata	southern hackberry/sugarberry**		low-moderate	low-moderate
Celtis occidentalis	common hackberry**	2,270	low	low
Cercidiphyllum japonicum	katsura tree	49	moderate	high
Cercis canadensis	eastern redbud*	416	low-moderate	low-moderate
Chionanthus virginicus	fringetree		low	low
Cladrastis kentukea	yellowwood	79	low-moderate	low-moderate
Cornus alternifolia	pagoda dogwood	6	low-moderate	moderate-high
Cornus florida	flowering dogwood	99	low-moderate	low-moderate
Cornus kousa	kousa dogwood	71	low	moderate
Cornus mas	Cornelian cherry dogwood	31	low-moderate	moderate-high
Cornus racemosa	gray dogwood	4	low-moderate	moderate-high
Corylus colurna	Turkish hazel or Turkish filbert	11	low-moderate	moderate-high
Cotinus coggygria	smoketree	29	low	low
Crataegus crusgalli	cockspur thorn	27	low-moderate	moderate-high
Crataegus viridis 'Winter King'	green hawthorn 'Winter King'	1	low-moderate	moderate-high
Diospyros virginiana	common persimmon	1	low	low
Elaeagnus angustifolia	Russian olive	11	low	moderate
Eucommia ulmoides	hardy rubber tree		moderate	moderate
Fagus grandifolia	American beech	37	low-moderate	low-moderate
Fagus sylvatica	European beech	21	low-moderate	moderate-high
Fraxinus americana	white ash	855	moderate	moderate
Fraxinus excelsior	European ash		low-moderate	moderate-high
Fraxinus nigra	black ash*		moderate	high
Fraxinus pennsylvanica	green ash*	5,705	low-moderate	low-moderate
Ginkgo biloba	ginkgo	1,220	low	low
Gleditsia aquatica	water locust		low-moderate	low-moderate
Gleditsia triacanthos	honeylocust**	187	low-moderate	low-moderate
Gleditsia triacanthos inermis	honeylocust (thornless)	22,971	low-moderate	low-moderate
Gymnocladus dioicus	Kentucky coffeetree**	12	low	low
Halesia tetraptera	mountain silverbell	2	low-moderate	moderate-high
Hibiscus syriacus	rose of Sharon		low	low
Juglans nigra	black walnut	181	moderate	moderate

Scientific Name	Common Name	Estimated Trees in Detroit	Vulnerability - Low Emissions	Vulnerability - High Emissions
Juglans regia	English walnut		low-moderate	moderate-high
Juniperus chinensis	Chinese juniper	10	low	low
Juniperus virginiana	eastern red cedar**	107	low	low
Koelreuteria paniculata	goldenrain tree**	48	low	low
Larix decidua	European larch	2	moderate-high	moderate-high
Larix laricina	tamarack		moderate-high	moderate-high
Liquidambar styraciflua	sweetgum*	632	moderate	moderate
Liriodendron tulipifera	tulip tree	509	moderate	moderate
Maackia amurensis	amur maackia	2	low	moderate
Maclura pomifera	osage-orange**	6	low-moderate	low-moderate
Magnolia grandiflora	southern magnolia	1	moderate-high	moderate-high
Magnolia stellata	star magnolia	34	low-moderate	low-moderate
Magnolia tripetala	umbrella magnolia	1	low-moderate	low-moderate
Magnolia virginiana	sweetbay magnolia	18	low	low
Magnolia x soulangiana	saucer magnolia		low	low
Malus pumila	paradise apple	64	low-moderate	low-moderate
Malus spp.	apple		low-moderate	low-moderate
Metasequoia glyptostroboides	dawn redwood	108	low-moderate	low-moderate
Morus alba	white mulberry	2,308	low-moderate	moderate-high
Morus rubra	red mulberry	41	moderate	moderate
Nyssa sylvatica	black gum	42	low	low
Ostrya virginiana	Eastern hophornbeam/Ironwood*	95	low	low
Oxydendrum arboreum	sourwood	1	low	low
Parrotia persica	Persian parrotia	4	low	moderate
Paulownia tomentosa	princess tree	14	low	moderate
Phellodendron amurense	amur corktree	9	low-moderate	moderate-high
Picea abies	Norway spruce	90	low-moderate	moderate-high
Picea glauca	white spruce	82	moderate-high	moderate-high
Picea pungens	Colorado spruce	450	low-moderate	moderate-high
Picea rubens	red spruce	3	moderate-high	moderate-high
Pinus banksiana	jack pine	5	high	high
Pinus bungeana	lacebark pine	3	low-moderate	moderate-high
Pinus mugo	mugo pine		low-moderate	moderate-high
Pinus nigra	Austrian pine	535	low-moderate	moderate-high
Pinus parviflora	Japanese white pine		low-moderate	low-moderate
Pinus resinosa	red pine	11	moderate	high
Pinus strobus	eastern white pine	106	moderate	high
Pinus sylvestris	Scots pine		low-moderate	moderate-high
Pinus virginiana	Virginia pine	10	moderate	high
Platanus occidentalis	American sycamore*	5,771	low-moderate	low-moderate
Platanus x acerifolia	London planetree	6,971	low-moderate	low-moderate
Populus alba	white poplar	52	low-moderate	low-moderate
Populus balsamifera	balsam poplar*		moderate	moderate
Populus deltoides	eastern cottonwood	885	low-moderate	low-moderate
Populus grandidentata	bigtooth aspen	2	moderate-high	moderate-high
Populus nigra	black poplar		low-moderate	low-moderate
Populus tremuloides	quaking aspen	20	low-moderate	moderate-high
Prunus avium	sweet cherry		low-moderate	moderate-high
Prunus cerasifera	cherry plum	12	low-moderate	low-moderate
Prunus persica	peach	5	low-moderate	low-moderate
Prunus sargentii	sargent cherry	4	low-moderate	low-moderate
Prunus serotina	black cherry	31	moderate	moderate
Prunus serrulata	Japanese cherry	29	moderate-high	moderate-high
Prunus subhirtella	higan cherry	3	low-moderate	moderate-high
Prunus virginiana	chokecherry	12	low-moderate	moderate-high

Scientific Name	Common Name	Estimated Trees in Detroit	Vulnerability - Low Emissions	Vulnerability - High Emissions
Prunus x yedoensis	yoshino cherry	6	moderate	high
Pseudotsuga menziesii	Douglas fir	26	moderate	high
Pyrus calleryana	callery pear	2,936	low-moderate	moderate-high
Pyrus communis	European pear		low-moderate	low-moderate
Quercus acutissima	sawtooth oak	4	low	moderate
Quercus alba	white oak	232	moderate	high
Quercus bicolor	swamp white oak	858	low	moderate
Quercus cerris	turkey oak		low-moderate	moderate-high
Quercus coccinea	scarlet oak	38	low-moderate	low-moderate
Quercus ellipsoidalis	northern pin oak**		moderate	high
Quercus imbricaria	shingle oak**	181	low	moderate
Quercus lyrata	overcup oak		low	moderate
Quercus macrocarpa	bur oak**	595	low	low
Quercus macrocarpa x robur	heritage oak		low	low
Quercus marilandica	blackjack oak**		moderate	moderate
Quercus muehlenbergii	chinkapin oak**	6	low	moderate
Quercus palustris	pin oak*	2,033	low-moderate	moderate-high
Quercus phellos	willow oak	3	low	low
Quercus prinus	chestnut oak**	8	low	moderate
Quercus robur	common oak	530	low-moderate	moderate-high
Quercus rubra	northern red oak	2,234	low-moderate	low-moderate
Quercus shumardii	Shumard oak***	34	low-moderate	low-moderate
Quercus stellata	post oak**		moderate	moderate
Quercus velutina	black oak**	20	moderate	high
Rhamnus cathartica	European buckthorn**	19	low	low
Rhamnus frangula	glossy buckthorn*		low	moderate
Rhus typhina	staghorn sumac**	1	low-moderate	moderate-high
Robinia pseudoacacia	black locust**	324	low-moderate	low-moderate
Salix babylonica	weeping willow	93	low-moderate	low-moderate
Salix discolor	pussy willow	15	low-moderate	moderate-high
Salix matsudana	Chinese willow		moderate	moderate
Salix nigra	black willow*	13	moderate	moderate
Sassafras albidum	sassafras	31	low-moderate	low-moderate
Sorbus americana	American mountain ash		moderate-high	moderate-high
Sorbus aucuparia	European mountain ash	26	low-moderate	moderate-high
Styphnolobium japonicum	Japanese pagoda tree	18	low	low
Syringa reticulata	Japanese tree lilac	556	moderate	moderate
Syringa vulgaris	common lilac	16	low-moderate	moderate-high
Taxodium distichum	bald cypress*	36	low	low
Thuja occidentalis	northern white cedar	594	moderate	moderate
Tilia americana	American linden or basswood*	2,482	low-moderate	moderate-high
Tilia cordata	littleleaf linden	5,396	low	moderate
Tilia tomentosa	silver linden	198	low-moderate	low-moderate
Tilia x euchlora	Crimean linden	6	moderate	moderate
Tilia x europaea	common lime		low-moderate	moderate-high
Tsuga canadensis	eastern hemlock	5	moderate	high
Ulmus Accolade	accolade elm		low	moderate
Ulmus alata	winged elm		low-moderate	moderate-high
Ulmus americana	American elm	2,509	low-moderate	low-moderate
Ulmus crassifolia	cedar elm***		moderate	moderate
Ulmus parvifolia	lacebark elm**	136	low	low
Ulmus pumila	Siberian elm**	4,897	low-moderate	low-moderate
Ulmus rubra	slippery elm**	729	low-moderate	low-moderate
Viburnum lentago	nannyberry	1	low	moderate
Zelkova serrata	Japanese zelkova	528	low	low

*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. Projected heat and hardiness zone shifts, adaptive capacity of urban trees, and overall vulnerability ratings can be used to help inform decisions about what species may be suitable for tree 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

- **Modeling Native Trees:** Species distribution modeling of native species suggests that suitable habitat will decrease for 19 species (31%) and remain stable for eight species (13%). Suitable habitat is expected to increase for eight species (13%), while 16 species (26%) may be able to colonize new, suitable habitats. The rest of the species evaluated had mixed results (17%).
- **Projected Heat and Hardiness Zone Shifts and Species Ranges:** Under a low emissions scenario, the majority of the 187 evaluated species are projected to be in a suitable range (94%), while 6% are not suitable. Under a high emissions scenario, 42% are projected to be in a suitable range, and 58% are not suitable.
- **Adaptive Capacity of Urban Trees:** Adaptive capacity of 187 species was evaluated using scoring systems for planted (187 species) and natural (94 species) environments. For planted/developed conditions, 50 species received a high adaptability score, 30 received a low adaptability score, and the remaining 107 received a medium adaptability score. For natural areas (both native and naturalized), 42 species received a high adaptability score, eight received a low adaptability score, and 43 received a medium adaptability score.
- **Overall Vulnerability of the Detroit Region's Trees:** Under a low emissions scenario, the majority of Detroit tree species fell into the low-moderate vulnerability category (51%). Over 22% were categorized as low vulnerability, nearly 20% as moderate vulnerability, 5% as moderate-high vulnerability, and 1% as high vulnerability. Under a high emissions scenario, more trees were considered vulnerable. Nearly 14% were categorized as low vulnerability, 21% as low-moderate vulnerability, 20% as moderate vulnerability, 35% as moderate-high vulnerability, and nearly 10% as high vulnerability.
    - Common species with moderate-high vulnerability include boxelder, silver maple, sugar maple, common horse chestnut, northern catalpa, white mulberry, callery pear, pin oak, American linden, and winged elm.
    - Uncommon species with low vulnerability include common persimmon, downy serviceberry, fringetree, mockernut hickory, osage-orange, sourwood, southern hackberry, umbrella magnolia, and water locust.

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CHAPTER 6

Neighborhood Resilience and Urban Forest Vulnerability

Drawing on information from the previous chapters, this chapter summarizes potential climate impacts and adaptive capacity factors in the Detroit region to provide an overview of vulnerability in Detroit's urban forest. In addition, we examine the vulnerability of each of the Detroit districts, which can be helpful in strategically implementing adaptation strategies. 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.

Potential Climate Impacts on Detroit's Urban Forest

Potential impacts are 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. Impacts could be beneficial or harmful to a particular forest or ecosystem type. The summary below includes the potential impacts of climate change on the Detroit region's 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 the IPCC's (Intergovernmental Panel on Climate Change) guidance for 119 Chapter 6: Ecosystem Vulnerabilities authors (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 as well as 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.

- **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/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%), the number of hot, dry summer days increased by 3 (338%), and the number of cool, dry days decreased by 10.5 (70%). Temperatures in Detroit are projected to increase by 5°F to 13°F by the end of this century compared to the 1980-2009 average.
- **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/decade since 1960. Comparing the 1961-1990 average to the 1981-2010 average, the total annual precipitation in southeast Michigan increased by 11%. In the SEMCOG region, precipitation has increased in each season from 1960-2019. The increasing trend is the greatest in March to May (+0.42 inches/decade) and September to November (+0.43 inches/decade), and the least in June to August (+0.15 inches/decade). Average annual precipitation is expected to increase by 16% on average, equivalent to about 5 inches. Although the amount of 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 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 three months of days above 90 degrees, compared to a current average of just over one week.

- **Heavy precipitation events causing inland flooding are expected to increase in frequency and intensity (medium evidence, high agreement, Chapter 2).** Increased flooding can stress trees, causing defoliation, leaf yellowing, crown dieback, and potential mortality. By the end of the century, Detroit could 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 three months of days above 90 degrees, compared to a current average of just over one week. Heavy rain events (≥1 inch per day) are projected to become more frequent on average.
- **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 in plant productivity, and alter nutrient and water cycling.
- **Heat and hardiness zones are projected to shift by the end of the century (robust evidence, high agreement, Chapter 2).** Assuming a substantial reduction in global GHG emissions, the hardiness zone is projected to shift from zone 6 (-23.3°F to -17.8°F) to zone 7 (-17.7°F to -12.2°F) by mid-century and the heat zone is projected to shift from zones 4 and 5 (>14-30 and >30-45 days exceeding 86°F) to zone 7 (>61-90 days exceeding 86°F) by mid-century. Under a business-as-usual scenario, the hardiness zone is projected to shift to zone 8 (-12.1°F to -6.7°F) by the end of the century and the heat zone is projected to shift to zone 9 (>21-150 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, 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 in addition to climate stressors on trees (medium evidence, medium agreement, Chapter 3).** The European oak borer attacks weakened or recently dead oak species, which increases the risk for trees under stress. Milder winters may be more beneficial for the emerald ash borer, which has a significant history as an established pest in Detroit. Asian longhorn 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 a moderate GHG emissions scenario, the climate suitability of oak wilt remains relatively high in the Detroit region through this century.
- **A changing climate has the potential to worsen existing health issues and create new issues (medium evidence, high agreement, Chapter 4).** These 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 volatile organic compounds, and pests and pathogens.
- **Species vulnerability depends on the degree of projected temperature increases (medium evidence, medium agreement, Chapter 5).** Under a low emissions secnario, most species are considered to have a low to moderate vulnerability (93%), while just 6% have a moderate to high vulnerability. Under a high emissions scenario, most are considered to have a low to moderate vulnerability (55%), while 45% are considered to have a moderate to high vulnerability.
- **Native species habitat suitability will shift (medium evidence, high agreement, Chapter 5).** Species distribution modeling suggests that suitable habitat will decrease for 19 species, increase for eight species, and remain stable for eight species, and 16 species may be able to colonize new,

suitable habitats.

Adaptive Capacity Factors

Adaptive capacity is the ability of a species or ecosystem to accommodate or cope with potential climate change impacts with minimal disruption. It is strongly related to the concept of resilience. Resilience refers to the ability to predict, prepare for, respond to, and recover from climate disturbances. Summarized below are factors that could affect the adaptive capacity of the Detroit region, influencing overall vulnerability to climate change.

- **Adaptive capacity of Detroit species in planted and natural environments vary (medium evidence, medium agreement).** For planted/developed conditions, 27% of species received a high adaptability score, 16% received a low adaptability score, and the remaining 57% received a medium adaptability score. For natural areas (both native and naturalized), 45% of species received a high adaptability score, almost 9% received a low adaptability score, and 46% received a medium adaptability score.
- **Detroit has a high species richness, but a high abundance of maples (medium evidence, high agreement).** Detroit's temperate climate supports a wide range of species, and this is reflected in the tree inventory that includes over 144 species and 75 genera. However, maple species account for 43% of street trees according to the most recent street tree inventory data, and that could reduce the ability of the tree canopy to adapt if a pest or pathogen targeting maples becomes prevalent.
- **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).** 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.

Vulnerability by District

Detroit is subdivided into seven city council districts, each of which has its own unique features (Figure 6.1, Table 6.1). Detroit's districts can be examined by their key climate change impacts as well as adaptive capacity factors to determine how each can adjust to projected damage and take advantage of opportunities. Households below the poverty level by district are also summarized in Table 6.2, ranging from 29.44% to 38.85%.

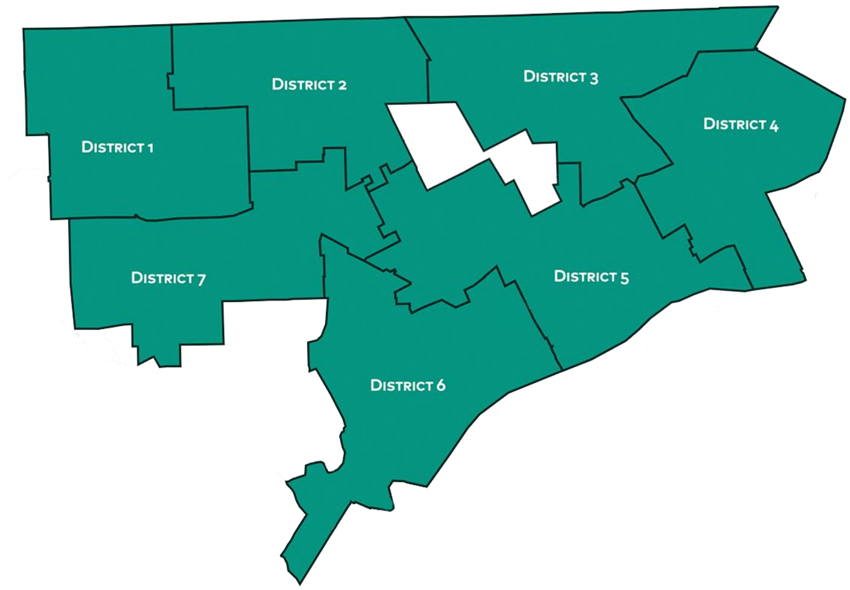


Figure 6.1 Detroit's City Council Districts. Source: www.theneighborhoods.org

Table 6.1. Overview of Detroit's City Council Districts.

District	Description	Homes	Neighborhoods	Parks	% Impervious
District 1, Northwest	District 1's thriving business corridor stretches along Grand River Avenue, one of Michigan's oldest trading lines. An eclectic community, District 1's interests vary from a theater district to community gardening. Residents have significant working relationships and partnerships with community leaders and other residents in the district.	36,582	31	31	40.1%
District 2, North Central	A historic district, District 2 encompasses strong communities, active organizations, stable homes, vibrant businesses, and a variety of neighborhoods, including the notable Avenue of Fashion. With its beautiful tree-lined streets, District 2 contains several high-quality educational institutions and high-end neighborhoods.	32,621	24	20	47.3%
District 3, Northeast	District 3 is home to the City Airport, contains Gratiot Avenue as one of the main streets, and is home to many successful politicians, business leaders, and singing groups. Located in the southwestern section of District 3, Banglatown is a flourishing neighborhood home to Bangladeshi immigrants.	29,149	25	48	47.9%
District 4, East	District 4 contains houses bordering canals as well as 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 is also a location that experiences significant flooding.	27,812	20	21	46.6%
District 5, Central	As the heart of Detroit, District 5 is the largest district and contains the city's "downtown" as well as Belle Isle, the country's largest island park. It is considered the epicenter of Detroit, made up of culture, education, medicine, business, entertainment, and a mix of historic neighborhoods.	10,899	51	60	47.1%
District 6, Southwest	As one of Detroit's most diverse and cultural areas, District 6 is home to many Latino, African American, and Middle Eastern communities as well as some of the city's oldest	13,786	23	74	51.0%

	black-owned businesses. Midtown has a developing millennial population and also contains Wayne State, Detroit's largest university. District 6 is heavily industrialized, and there are more than 150 facilities regulated for air emissions by the EPA in a 4-mile area. When the Gordie Howe International Bridge is completed, it will increase vehicle emissions considerably in the district.				
District 7, West	District 7 contains community-centric neighborhoods and beautiful parks such as Rouge Park, one of the area's centerpieces. It is home to active community organizations, a variety of architectural styles, and a large population of Middle Eastern immigrants.	34,969	25	30	42.7%

Source: www.theneighborhoods.org

Table 6.2. Households Below the Poverty Level by District (2018).

District	2018 Households Below the Poverty Level	2018 Households Below the Poverty Level (%)
District 1, Northwest	12,643	31.05%
District 2, North Central	11,856	29.44%
District 3, Northeast	9,546	31.57%
District 4, East	10,688	34.61%
District 5, Central	15,115	36.10%
District 6, Southwest	15,431	38.85%
District 7, West	13,304	36.26%

Key Climate Change Impacts

The top two climate change impacts include extreme heat and increased precipitation, both of which have the potential to increase public health challenges and amplify inequality hot spots in Detroit. The burden typically falls harder on areas with low-income populations; however, the city of Detroit as a whole has a high population of low-income residents. The poverty rate in Detroit is 30.6%, more than double the rate of Michigan as a whole (13%) and nearly triple the rate of the U.S. as a whole (10.5%) (U.S. Census Bureau, 2019b). Here, we examine key climate change impacts at the district level.

Extreme Heat

Detroit's Climate Change Vulnerability Report from the University of Michigan's Taubman College of Architecture and Urban Planning included a heat assessment combining 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 Detroit's downtown core as well as the adjacent neighborhoods northwest of the downtown.

Twenty-nine percent of Detroit's population lives within a 15-minute walk of designated cooling centers, which are designated by the city (Gregg et al., 2012). Cooling center access is relatively distributed across the north half of Detroit, but there are several notable deserts in areas west of downtown (District 7) and on the east side of downtown (District 5) crossing through District 4, while some cooling stations are clustered and overlapping in Districts 1, 5, and 6. Populations decline and cooling centers are designated annually, but access remains unequal for all, and is a concern especially for areas that have high heat vulnerability due to urban heat islands.

On August 8, 2020, local organizers and volunteers in Detroit collected over 130,000 temperature and humidity data points in the morning, afternoon, and evening to create a heat watch report for the area (CAPA Strategies, 2020). This provided images of the distribution of temperature and humidity, describing how heat varies among urban neighborhoods due to local landscape features. Notable observations for the Detroit area include the presence of asphalt roadways and canopy cover. Wide, asphalt roadways absorb heat and remain hot during the day and hotspots are created by residential stretches of low canopy cover. Cooler areas of the city are seen in shaded, residential neighborhoods that are kept cooler during heat waves by the high canopy cover.

Increased Precipitation

Detroit's Climate Change Vulnerability Report from the University of Michigan's Taubman College of Architecture and Urban Planning also conducted a flood assessment that examined the vulnerability of infrastructure systems and household-level vulnerability (Gregg et al., 2012; Figure 6.3). 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), and household sensitivity is determined by the age of housing stock as well as the median household income. System flood vulnerability, similar to the heat assessment, is concentrated around the downtown core, extending northward. Household flood vulnerability is present in southeast Detroit and along the Rouge River in the northwest (Gregg et al., 2012).

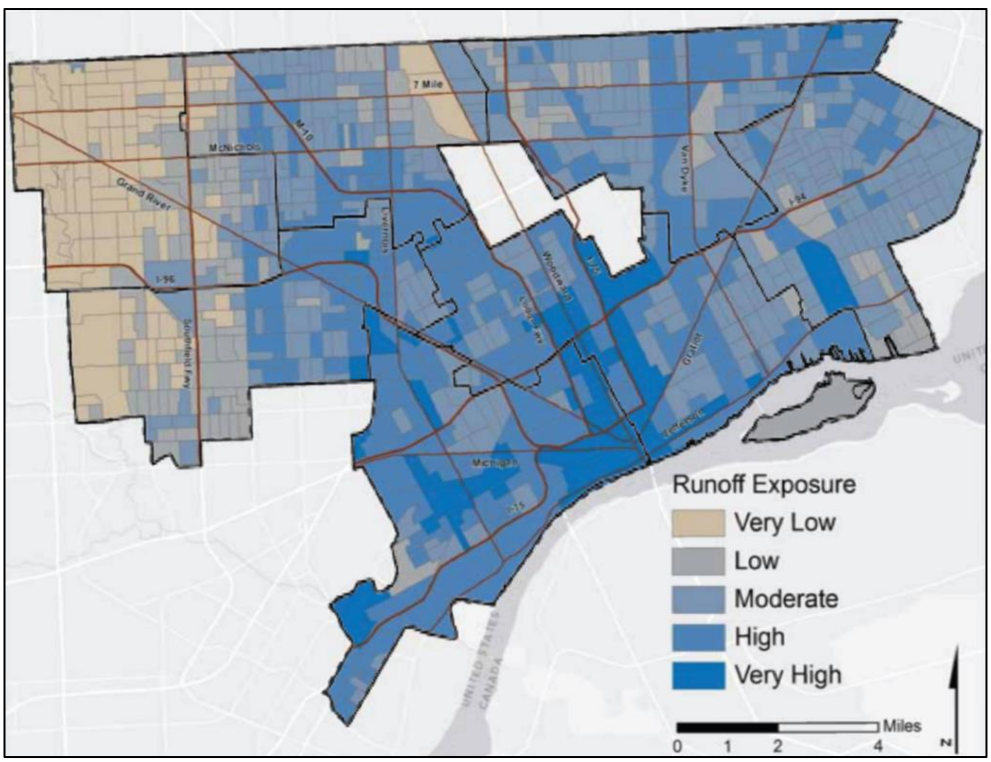


Figure 6.3. Total Runoff Exposure by Block Group. Source: Michigan Geographic Data Library; Michigan Digital Elevation Model; USGS GloVis LandSat 7 ETM+; US Census 2010. Map Prepared By: University of Michigan Detroit Climate Capstone.

Much of the soil is poorly drained throughout Detroit. In the spring and fall when the ground is already wet and less likely to hold more water, Detroit will be met with more rainfall—up to 25% by the end of the century (Molnar, 2015). Detroit's aging stormwater systems could be overwhelmed by increased precipitation, resulting in flooded streets and basements and leading to sewage overflows in the Detroit River and Lake Erie. Extreme weather events, such as the storm that caused flooding across the region in August 2014, will also become more frequent.

Adaptive Capacity Factors

Although climate change impacts will be significant for each district, there are several districts less equipped to handle change. Districts with lower canopy cover may experience warmer temperatures and an increase in stormwater runoff as trees play an important role in mitigating the urban heat island effect and intercepting rainfall. The average canopy cover in Detroit is 25.11%. Canopy coverage varies by district; the highest canopy coverage can be found in District 1 (37.5%), followed by District 2, District 4, and District 7 at nearly 27%, while the lowest coverage is found in District 3 (22.5%), District 5 (19.6%), and District 6 (15.6%) (Figure 6.4).

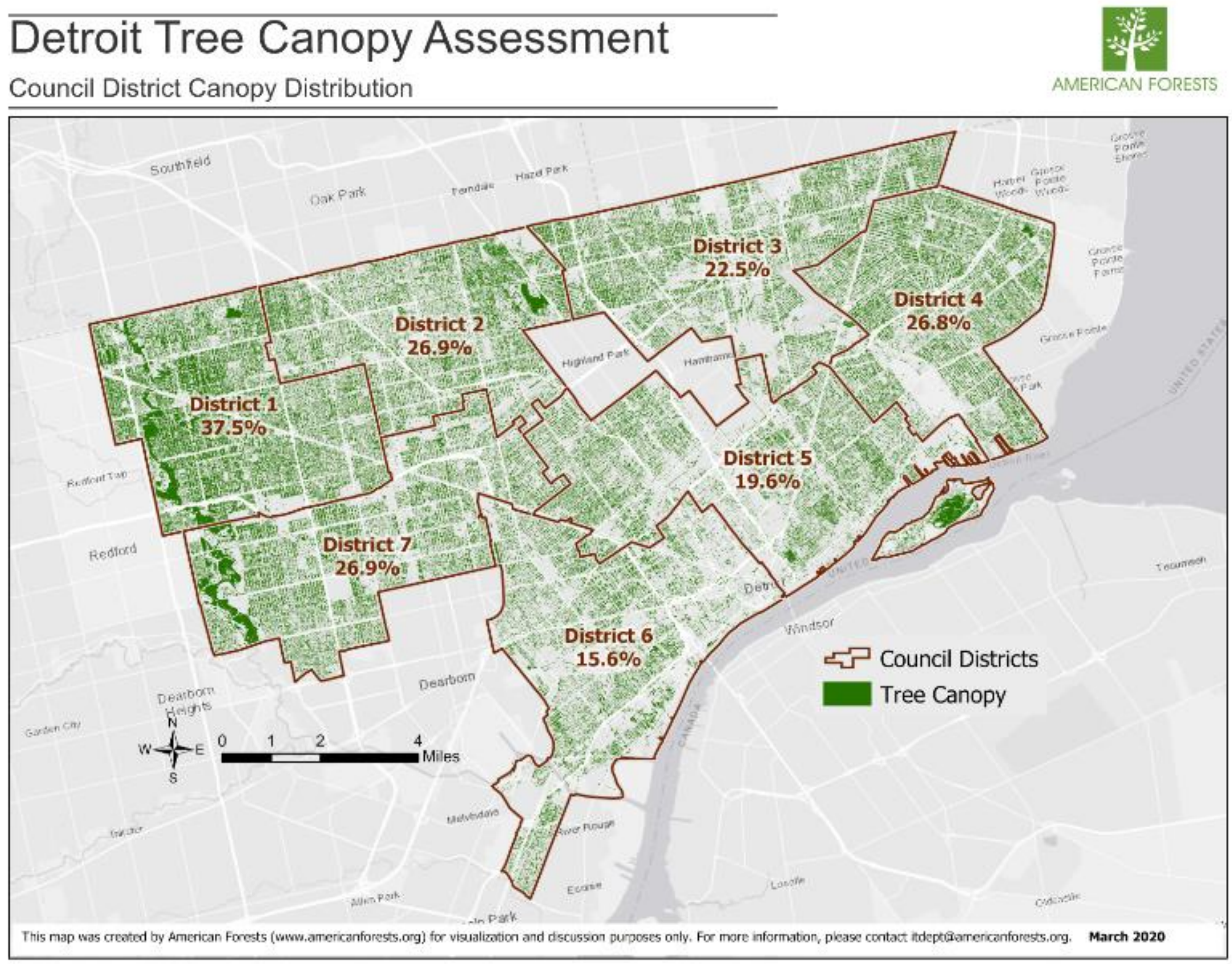


Figure 6.4. Canopy Coverage in the Detroit Region by District. Source: American Forests, 2020.

The presence of vacant lots and impervious surfaces can help us understand the impacts of increased temperatures and precipitation on each district. Each district has a notable amount of vacant residential land, and varying amounts of vacant commercial and 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 (Figure 6.5). 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. This 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 larger-scale blue-green infrastructure, which could reduce stormwater runoff and flooding that lead to combined sewage overflows into rivers.

Regarding impervious surfaces, District 6 has the highest percentage (51%) and District 1 (40.1%) has the lowest, covering a range of about 10% (Table 6.1) It's also important to note that this calculation does not include roads, which would increase the percentage in each district.

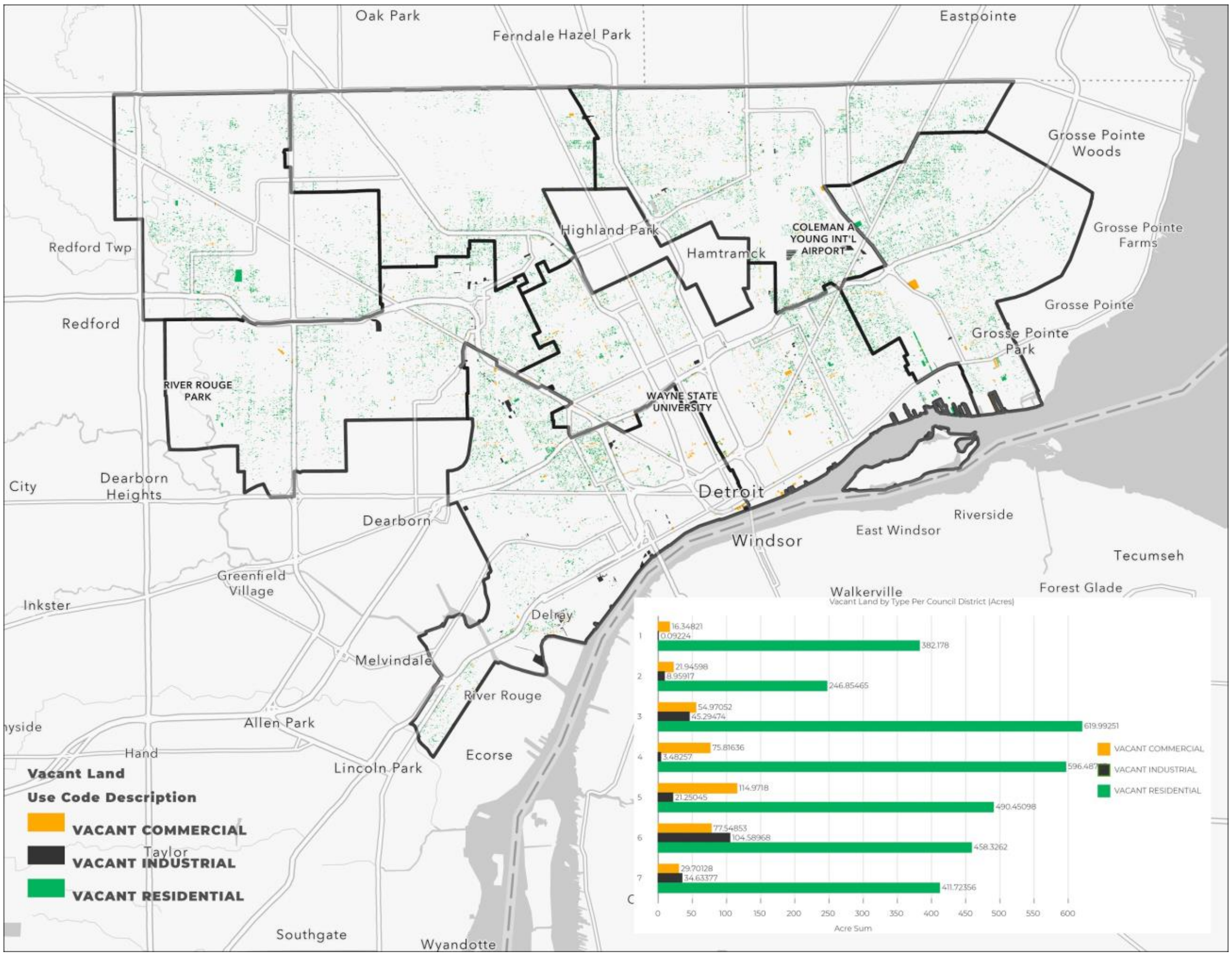
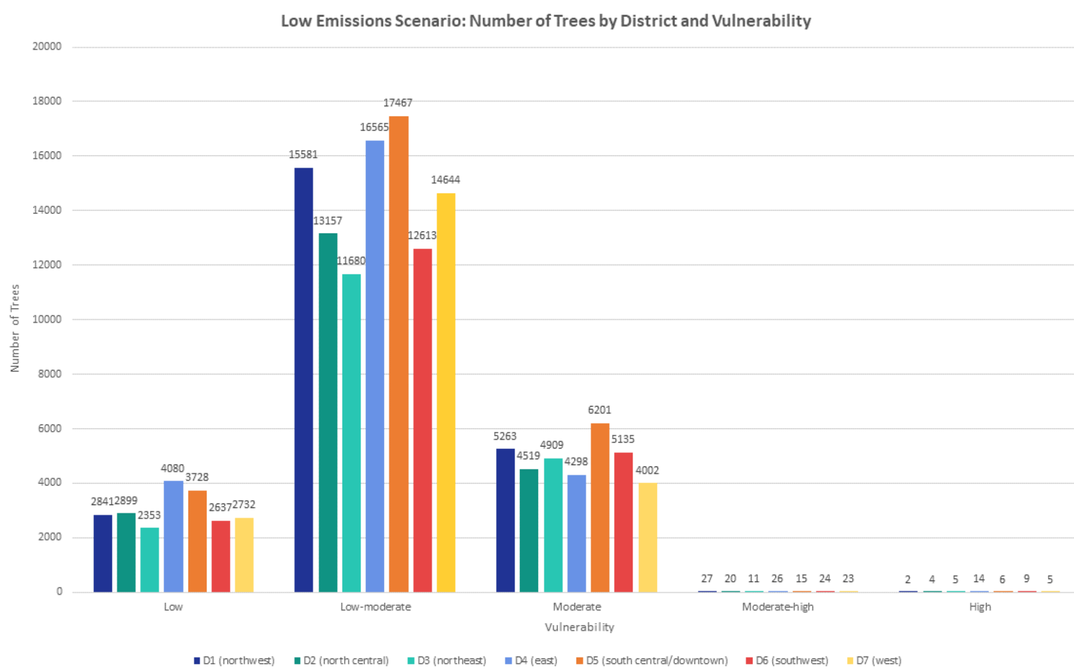


Figure 6.5. Vacant Commercial, Industrial, and Residential Land in Detroit, Michigan for Districts 1-7.

Districts 5 and 6 have notable heat islands present, higher populations without vehicle access, and higher runoff exposure as they are situated along the Detroit River. However, greater downtown Detroit's social and physical traits allow it to be more resilient to climate change (Molnar, 2015). Neighborhoods most vulnerable are concentrated in southwest Detroit. This area is ideal for building green infrastructure, but resulting gentrification is a concern (Molnar, 2015). It is beneficial when adaptation strategies and infrastructure are paired with public good and welfare, such as encouraging community farming and planting native species.

Based on our assessment in Chapter 5, the number of vulnerable trees is displayed below for each district (Figure 6.6). Under a low emissions scenario, there are few trees under the moderate-high or high vulnerability level throughout 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 highest number of trees in the low-moderate and moderate vulnerability categories. Under a high emissions scenario, the 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 category, with Districts 4 and 5 not far behind. District 5 continues to have the highest number of trees under the low-moderate and moderate vulnerability category. Key impacts, adaptive capacity factors, and vulnerability for each district are summarized in Table 6.3, including the urban heat island, runoff, soil, canopy cover, vacant lots, and poverty rate.



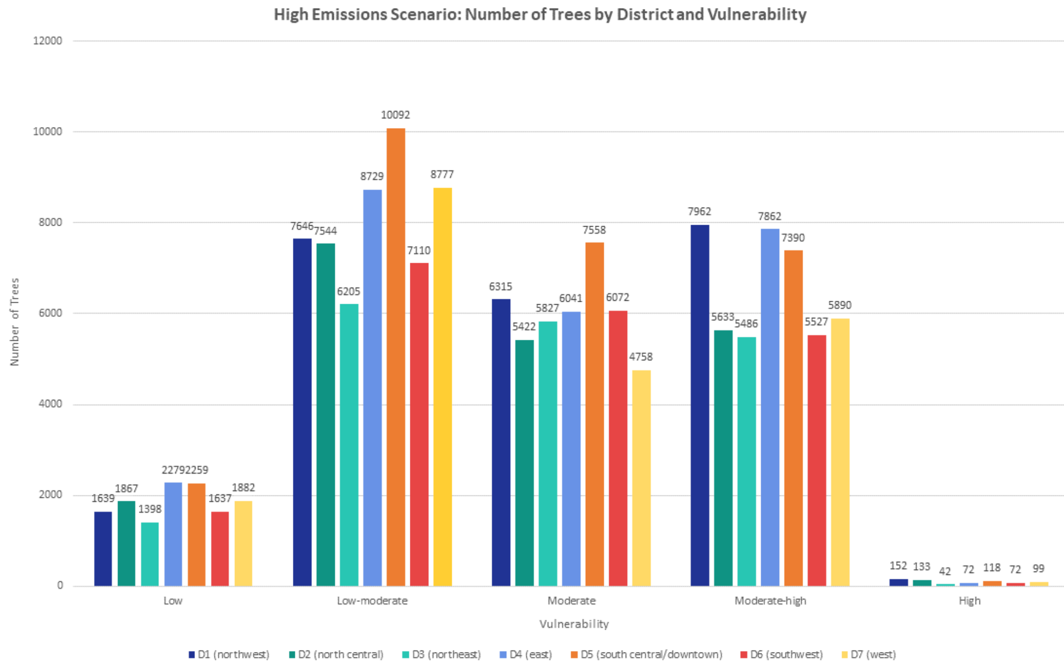


Figure 6.6. Number of Trees by Detroit District and Vulnerability (Low, Low-moderate, Moderate, Moderate-high, High) Under Low and High Emissions Scenarios.

Table 6.3. Summary of Key Impacts, Adaptive Capacity Factors, and Vulnerability of Detroit's City Council Districts.

District	Key Impacts	Key Adaptive Capacity Factors	Vulnerability
1	Low-moderate UHI, low runoff, moderate poorly drained soil	High canopy cover, high-moderate vacant land, high poverty rate	Low-Moderate
2	Moderate UHI, moderate runoff, low poorly drained soil	Moderate canopy cover, low-moderate vacant land, high poverty rate	Moderate
3	Moderate UHI, moderate runoff, high poorly drained soil	Moderate canopy cover, high vacant land, high poverty rate	Moderate-High
4	Moderate UHI, moderate runoff, high poorly drained soil	Moderate canopy cover, high vacant land, high poverty rate	Moderate-High
5	High UHI, high runoff, high poorly drained soil	Low canopy cover, high-moderate vacant land, high poverty rate	High
6	High UHI, high runoff, high poorly drained soil	Low canopy cover, high-moderate vacant land, high poverty rate	High
7	Moderate UHI, low-moderate runoff, high poorly drained soil	Moderate canopy cover, high-moderate vacant land, high poverty rate	Moderate-High

Summary

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

Key Points

- The urban forest of the Detroit region as a whole is vulnerable to increases in temperature, heavy rain events, and shifts in composition for native and nonnative invasive species, but also has the capacity to adapt through its robust community urban forestry efforts.
- Understanding district-level vulnerabilities can help guide resource allocation and climate adaptation strategies and the relationship between public health and inequality is critical in the planning and implementation process.
- The most vulnerable neighborhoods are located in Southwest Detroit. Vacant lots and impervious surfaces are an issue throughout the city. District 5 and 6 have notable heat islands present, have higher populations without vehicle access, and higher runoff exposure while situated along the Detroit River.
- Species composition is widely distributed across the City of Detroit, contributing to similar patterns of urban tree vulnerability across districts. District 5, south central/downtown, has the most species in a moderate-high to high vulnerability category under the high emissions scenario, but all districts have a siimlar distribution of species vulnerability across low and high emissions scenarios.

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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 impact 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. Management considerations in this chapter are summarized by theme and include a range of issues that urban foresters face. These themes, along with their descriptions, are not meant to be comprehensive. Instead, they provide a jumping-off point for thinking about the management implications of climate change in an urban setting. The More Information sections located throughout the chapter provide links to key resources for urban forestry professionals about the impacts of climate change on that 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 will likely 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.

Common goals for street tree managers include diversifying species planted, increasing and maintaining canopy cover, supporting urban forest health through best practices, and providing up-to-date decision-making information for 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. Tree planting lists may be based on the available nursery stock (see Nursery Industry section). Updating lists according to 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 ecologic and economic benefits they provide: https://www.opentreemap.org/thegreeningofdetroitstreemap/map/
- The Greening of Detroit also offers a recommended tree list that includes species' tolerances of drought and flooding: https://www.greeningofdetroit.com/caring-for-trees

Wildlife

Detroit's urban trees, parks, and vacant lands provide habitat to a wide variety of wildlife species. However, climate change poses substantial risks. Shifts in the phenological patterns of trees and the spread of nonnative invasive species may reduce the capacity of Detroit's 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 (Lipton et al., 2018). Migratory species are more vulnerable to phenological mismatch if their primary food sources are unavailable when they migrate to their feeding grounds or if they are unable to shift to other sources (Lipton et al., 2018). As previously mentioned, native trees provide value to the food web and ecosystem services. Understanding the insects that plant species attract and their role in wildlife food webs, through resources such as the Native Plant Finder, is an additional component to consider when selecting 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: www.audubon.org/climate/survivalbydegrees
- The National Phenology Network provides resources for analyzing phenological change and for participating in monitoring activities: www.usanpn.org
- The National Wildlife Federation provides a Native Plant Finder that ranks native plants in your 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 also 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://cityofdetroit.github.io/park-finder/

- “How Cities Use Parks for Climate Change Management” discusses the benefits city parks provide, such as storing carbon and reducing the urban heat island effect: 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 suitable habitat declines for some species, new species adapted to current and future climate 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 the area’s 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.

Regeneration techniques that promote genetic diversity of native trees may also need to be expanded, especially in natural areas. 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 Detroit’s tree canopy.

There is a note of caution in substituting potentially invasive trees for native trees with increased pests, as some genotypes of native trees can become invasive. In addition, the list of invasive species is constantly changing. To gather up-to-date information about invasive species in the region, check with local arboreta, botanical gardens, natural area programs, or use online resources such as the EEDMapS tool or the Invasive Plant Atlas of the United States.

More Information

- The Michigan Department of Natural Resources provides information about Michigan’s 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://michiganflora.net/
- The Invasive Plant Atlas provides a compilation of lists for agencies and organzations across the country: https://www.invasiveplantatlas.org/index.cfm

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 impact which trees and other plants can be grown on their land. 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 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 their 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 efforts can be tailored to community needs will likely 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: www.ucsusa.org/resources/climate-friendly-gardener
- The Detroit Biodiversity Network (DBN) engages students in hands-on projects to support sustainable, urban ecosystems on Wayne State University's campus as well as in surrounding communities: https://www.detroitbiodiversitynetwork.com/

Nursery Industry

With projected changes in habitat suitability and shifts in heat and hardiness 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 upon 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. However, uncertainty among climate model projections as well as the financial risks tied to expanding the diversity of species offered for changing conditions—for instance, anticipating when and where those new markets are—will pose challenges. 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 Detroit's largest park, Rouge Park, managed by The Greening of Detroit: https://www.greeningofdetroit.com/meyers-tree-nursery
- The Native Plant Nursery LLC provides a database of Michigan's native plants, 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/, 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). Faced with a changing climate, green infrastructure increases in importance 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, while 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 Sewage 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 used to understand and track 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. Although climate adaptation practices can offer opportunities to improve quality of life, sensitivity to how these practices may inadvertently benefit some individuals and communities over others can help ensure that these practices are achieved equitably. Low-income 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 lower canopy cover 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.

When thinking about activities to increase canopy cover or incorporate green infrastructure, considerations of historical issues of racial segregation and environmental effects on disparate populations can help these efforts be more effective in the long run. Unmitigated historical experiences of residents in Detroit have resulted in barriers when it comes to policies meant to create equity, and research has demonstrated a level of tension, uncertainty, and lack of trust among some residents. It is important to ensure policies and actions are accessible to all, provide adequate support, and are inclusive to communities within the city.

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 they focus on: https://www.environmentalcouncil.org/environmental_justice

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 a strong tree canopy through its Tree Management Plan (2016) as well as establishing the Detroit Climate Action Collaborative (DCAC, now Detroit Climate Action) and the Sustainability Action Agenda. There are also several organizations, such as The Greening of Detroit and Detroiters Working for Environmental Justice (DWEJ), that are working to integrate climate change considerations into aspects of planning. There are opportunities to implement additional regional and state-wide 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 enhance climate adaptation progress and increase landscape connectivity through strategic land acquisitions and restoration. Campaigns tied to various stakeholders, such as nonprofits, 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. Land managers can also work with utility companies to create educational programs and rebates to retain tree canopy. Lastly, collaborating with others to expand public outreach to diverse audiences may also help with challenges.

More Information

- Detroit's Tree Management Plan (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 the City of 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/mayors-office/office-sustainability/sustainability-action-agenda

Businesses and Institutions

A changing climate enhances risks associated with business operations, and some businesses will choose to incorporate adaptation strategies to overcome those risks. Adaptation strategies not only improve business practices, but could also 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 the 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 strong coalition around 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 co-working community in midtown Detroit that fosters a home for businesses and nonprofits. Located in a green-designed building, Green Garage aims to make decisions with the environment, community, and economy at the forefront of mind: https://greengaragedetroit.com/
- Businesses and instutions 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 greater risk of extreme heat exposure and reduced water quality from extreme events, which is a significant concern as Detroit is the lowest income major city 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 and providing access to cooling centers and parks. Emergency preparedness will become more important than ever before due to storm damage, flooding events, and increased day and night temperatures that 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 hazard 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 urban forests provide to communities while reducing climate change risks: https://www.vibrantcitieslab.com/guides/climate-health-action-guide/

Summary

A changing climate can have significant impacts on 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 Detroit's green spaces.
- 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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GLOSSARY OF TERMS

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.

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 (BVOC) 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.

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.

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.

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

trophic level the position an organism occupies in a food web.

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 the zone of transition between wildland and human development.

LIST OF SPECIES NAMES

Scientific Name	Common Name	Scientific Name	Common Name
Abies balsamea	balsam fir	*Cornus florida*	flowering dogwood
Abies concolor	white fir	*Cornus kousa*	kousa dogwood
Acer buergerianum	trident maple	*Cornus mas*	cornelian cherry dogwood
Acer campestre	hedge maple	*Cornus racemosa*	gray dogwood
Acer griseum	paperbark maple	*Corylus colurna*	Turkish hazel or Turkish filbert
Acer miyabei	miyabei maple	*Cotinus coggygria*	smoketree
Acer negundo	boxelder	*Crataegus crusgalli*	cockspur thorn
Acer nigrum	black maple	*Crataegus viridis 'Winter King'*	green hawthorn 'Winter King'
Acer palmatum	Japanese maple	*Diospyros virginiana*	common persimmon
Acer platanoides	Norway maple	*Elaeagnus angustifolia*	Russian olive
Acer pseudoplatanus	sycamore maple	*Eucommia ulmoides*	hardy rubber tree
Acer rubrum	red maple	*Fagus grandifolia*	American beech
Acer saccharinum	silver maple	*Fagus sylvatica*	European beech
Acer saccharum	sugar maple	*Fraxinus americana*	white ash
Acer tataricum	tatarian maple	*Fraxinus excelsior*	European ash
Acer tataricum ginnala	amur maple	*Fraxinus nigra*	black ash
Acer x freemanii	freeman maple	*Fraxinus pennsylvanica*	green ash
Aesculus glabra	Ohio buckeye	*Ginkgo biloba*	ginkgo
Aesculus hippocastanum	common horse chestnut	*Gleditsia aquatica*	water locust
Aesculus x carnea	red horse chestnut	*Gleditsia triacanthos*	honeylocust
Ailanthus altissima	tree of heaven	*Gleditsia triacanthos inermis*	honeylocust (thornless)
Albizia julibrissin	Persian silk tree	*Gymnocladus dioicus*	Kentucky coffeetree
Alnus glutinosa	black alder	*Halesia tetraptera*	mountain silverbell
Alnus rugosa	grey alder	*Hibiscus syriacus*	rose of Sharon
Amelanchier arborea	downy serviceberry	*Juglans nigra*	black walnut
Amelanchier x grandiflora	apple serviceberry	*Juglans regia*	English walnut
Asimina triloba	pawpaw	*Juniperus chinensis*	Chinese juniper

Scientific Name	Common Name	Scientific Name	Common Name
Betula alleghaniensis	yellow birch	*Juniperus virginiana*	eastern red-cedar
Betula nigra	river birch	*Koelreuteria paniculata*	goldenrain tree
Betula papyrifera	paper birch	*Larix decidua*	European larch
Betula pendula	silver birch	*Larix laricina*	tamarack
Betula platyphylla	Japanese white birch	*Liquidambar styraciflua*	sweetgum
Betula populifolia	gray birch	*Liriodendron tulipifera*	tulip tree
Carpinus betulus	European hornbeam	*Maackia amurensis*	amur maackia
Carpinus caroliniana	musclewood or American hornbeam	*Maclura pomifera*	osage-orange
Carya cordiformis	bitternut hickory	*Magnolia grandiflora*	southern magnolia
Carya glabra	pignut hickory	*Magnolia stellata*	star magnolia
Carya illinoinensis	hardy pecan	*Magnolia tripetala*	umbrella magnolia
Carya laciniosa	shellbark hickory	*Magnolia virginiana*	sweetbay magnolia
Carya ovata	shagbark hickory	*Magnolia x soulangiana*	saucer magnolia
Carya texana	black hickory	*Malus pumila*	paradise apple
Carya tomentosa	mockernut hickory	*Malus spp.*	apple
Castanea dentata	American chestnut	*Metasequoia glyptostroboides*	dawn redwood
Castanea mollissima	Chinese chestnut	*Morus alba*	white mulberry
Catalpa speciosa	northern catalpa	*Morus rubra*	red mulberry
Celtis laevigata	southern hackberry/sugarberry	*Nyssa sylvatica*	black gum
Celtis occidentalis	common hackberry	*Ostrya virginiana*	American hophornbeam
Cercidiphyllum japonicum	katsura tree	*Oxydendrum arboreum*	sourwood
Cercis canadensis	eastern redbud	*Parrotia persica*	Persian parrotia
Chionanthus virginicus	fringetree	*Paulownia tomentosa*	princess tree
Cladrastis kentukea	yellowwood	*Phellodendron amurense*	amur corktree
Cornus alternifolia	pagoda dogwood	*Picea abies*	Norway spruce
Picea glauca	white spruce	*Quercus marilandica*	blackjack oak
Picea pungens	Colorado spruce	*Quercus muehlenbergii*	chinkapin oak
Picea rubens	red spruce	*Quercus palustris*	pin oak

Scientific Name	Common Name	Scientific Name	Common Name
Pinus banksiana	jack pine	*Quercus phellos*	willow oak
Pinus bungeana	lacebark pine	*Quercus prinus*	chestnut oak
Pinus mugo	mugo pine	*Quercus robur*	common oak
Pinus nigra	Austrian pine	*Quercus rubra*	northern red oak
Pinus parviflora	Japanese white pine	*Quercus shumardii*	Shumard oak
Pinus resinosa	red pine	*Quercus stellata*	post oak
Pinus strobus	eastern white pine	*Quercus velutina*	black oak
Pinus sylvestris	Scots pine	*Quercus virginiana*	live oak
Pinus virginiana	Virginia pine	*Rhamnus cathartica*	European buckthorn
Platanus occidentalis	American sycamore	*Rhamnus frangula*	glossy buckthorn
Platanus x acerifolia	London planetree	*Rhus typhina*	staghorn sumac
Populus alba	white poplar	*Robinia pseudoacacia*	black locust
Populus balsamifera	balsam poplar	*Salix babylonica*	weeping willow
Populus deltoides	eastern cottonwood	*Salix discolor*	pussy willow
Populus grandidentata	bigtooth aspen	*Salix matsudana*	Chinese willow
Populus nigra	black poplar	*Salix nigra*	black willow
Populus tremuloides	quaking aspen	*Sassafras albidum*	sassafras
Prunus avium	sweet cherry	*Sorbus americana*	American mountain ash
Prunus cerasifera	cherry plum	*Sorbus aucuparia*	European mountain ash
Prunus persica	peach	*Styphnolobium japonicum*	Japanese pagoda tree
Prunus sargentii	sargent cherry	*Syringa reticulata*	Japanese tree lilac
Prunus serotina	black cherry	*Syringa vulgaris*	common lilac
Prunus serrulata	Japanese cherry	*Taxodium distichum*	bald cypress
Prunus subhirtella	higan cherry	*Thuja occidentalis*	northern white cedar
Prunus virginiana	chokecherry	*Tilia americana*	American linden or basswood
Prunus x yedoensis	yoshino cherry	*Tilia cordata*	littleleaf linden
Pseudotsuga menziesii	Douglas fir	*Tilia tomentosa*	silver linden
Pyrus calleryana	callery pear	*Tilia x euchlora*	Crimean linden
Pyrus communis	European pear	*Tilia x europaea*	common lime

Scientific Name	Common Name	Scientific Name	Common Name
Quercus acutissima	sawtooth oak	*Tsuga canadensis*	eastern hemlock
Quercus alba	white oak	*Ulmus Accolade*	accolade elm
Quercus bicolor	swamp white oak	*Ulmus alata*	winged elm
Quercus cerris	turkey oak	*Ulmus americana*	American elm
Quercus coccinea	scarlet oak	*Ulmus crassifolia*	cedar elm
Quercus ellipsoidalis	northern pin oak	*Ulmus parvifolia*	lacebark elm
Quercus imbricaria	shingle oak	*Ulmus pumila*	Siberian elm
Quercus lyrata	overcup oak	*Ulmus rubra*	slippery elm
Quercus macrocarpa	bur oak	*Viburnum lentago*	nannyberry
Quercus macrocarpa x robur	heritage oak	*Zelkova serrata*	Japanese zelkova

APPENDIX 1
Seasonal Climate Trends

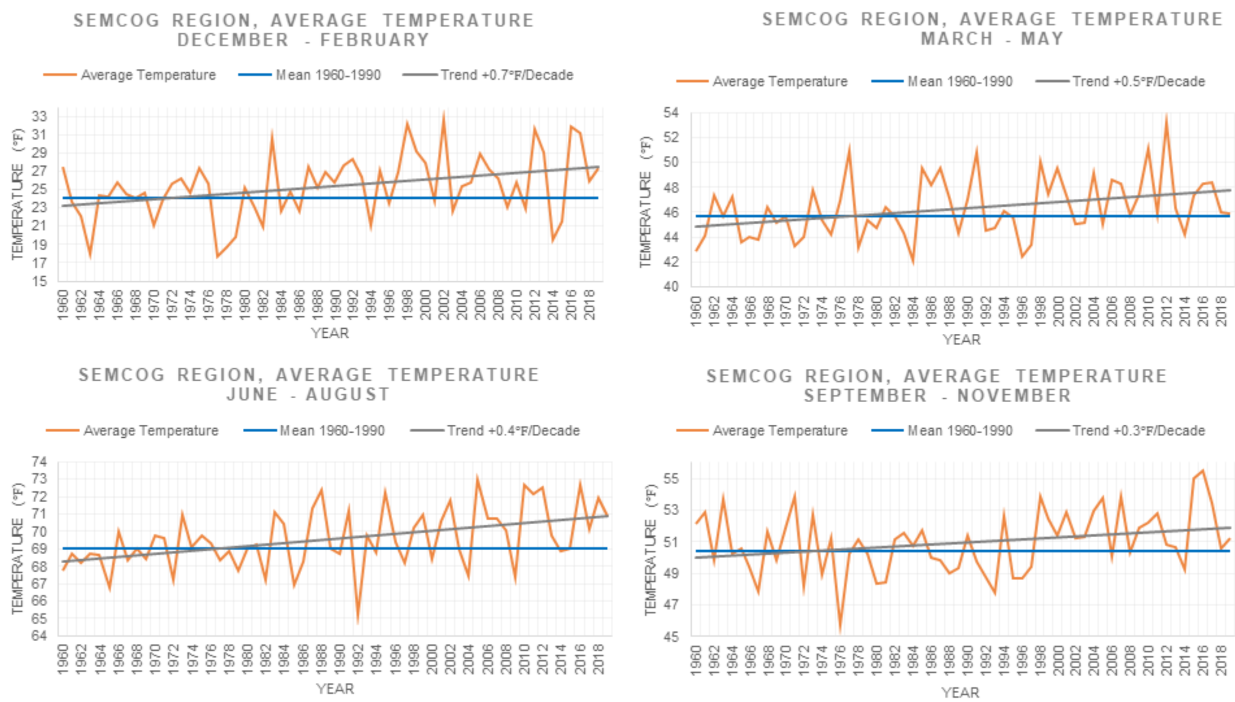


Figure A1.1. Seasonal Trends in Mean Temperature in SEMCOG Region. Source: https://www.ncdc.noaa.gov/cag/

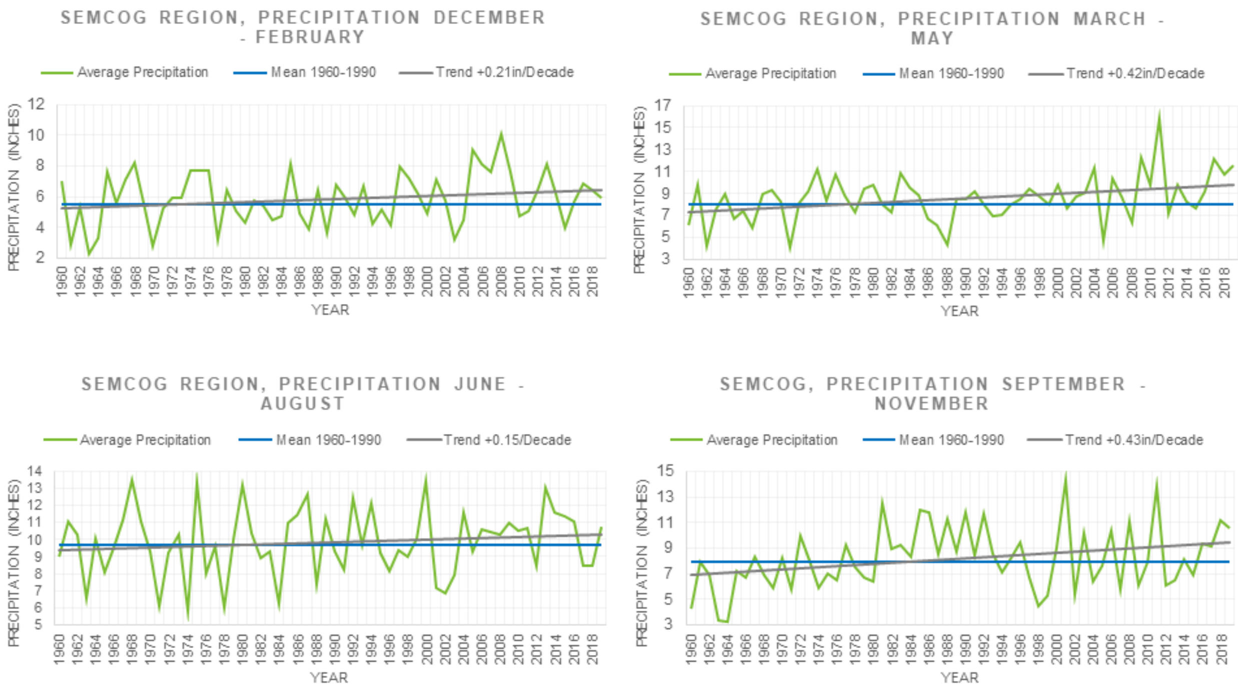
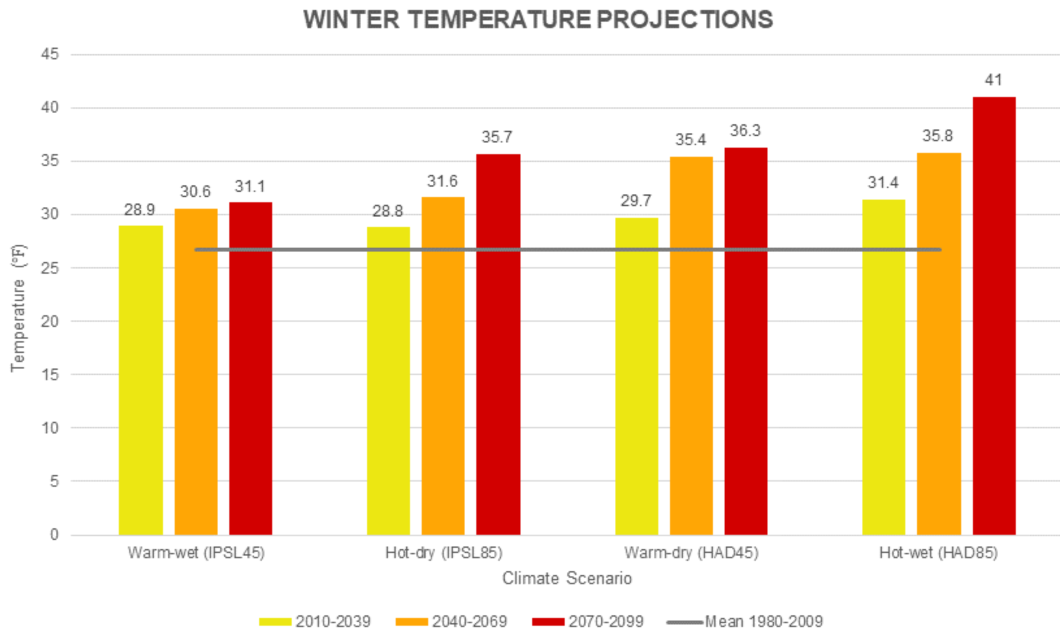
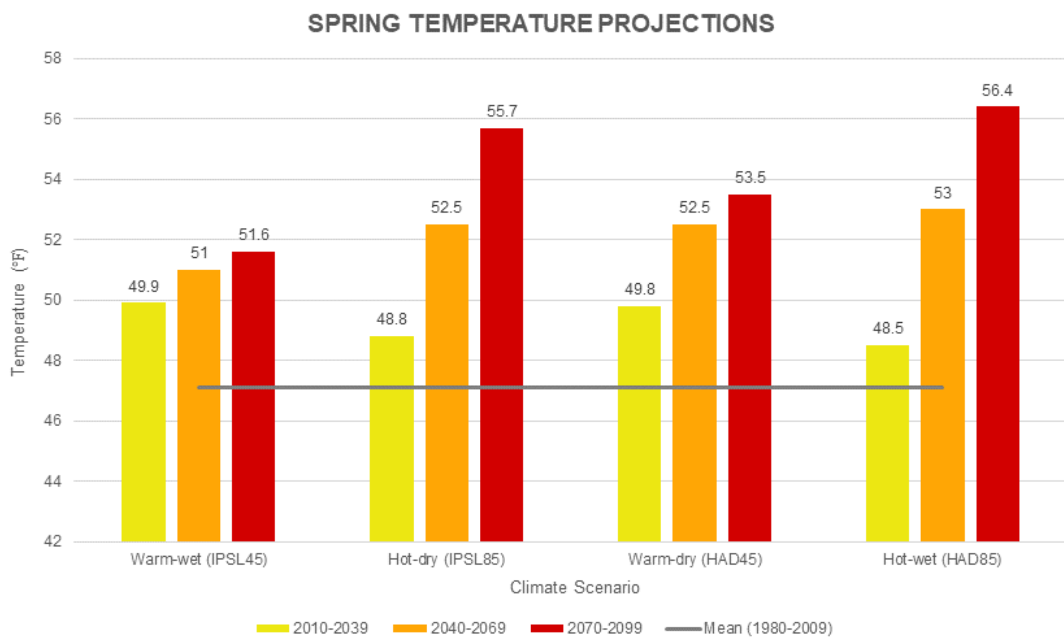


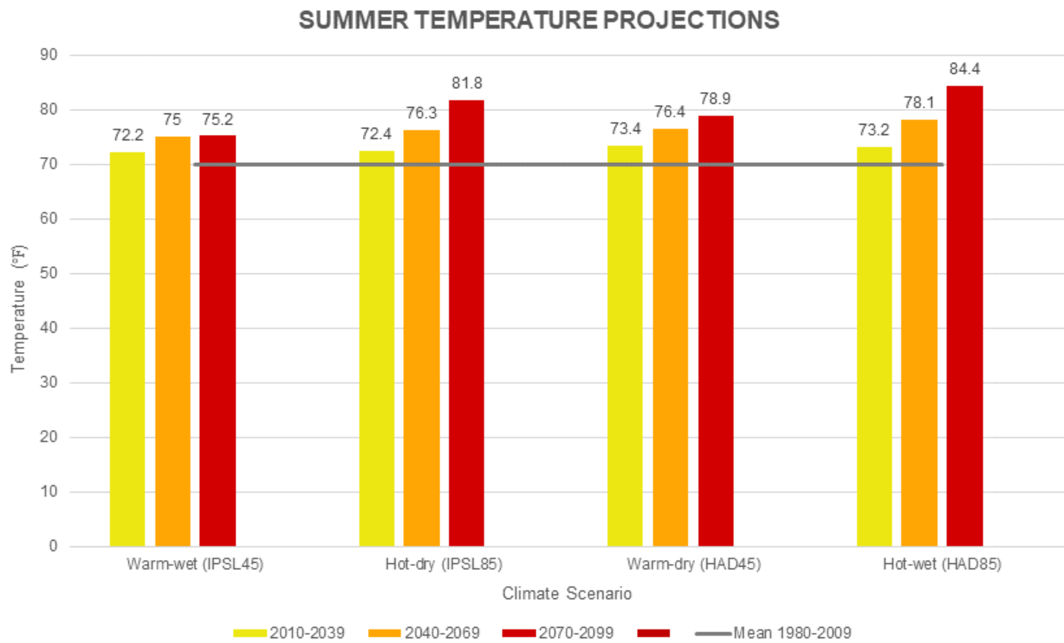
Figure A1.2. Seasonal Trends in Total Precipitation in SEMCOG Region. Source: https://www.ncdc.noaa.gov/cag/

APPENDIX 2

SEMCOG Temperature Projections







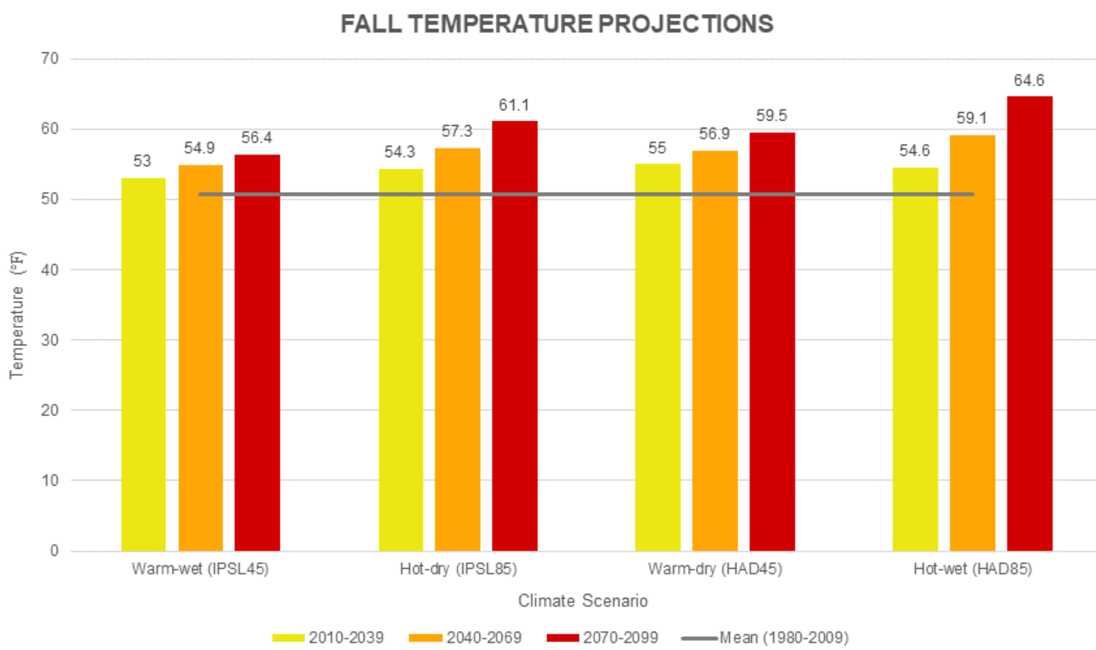


Figure A2.1. Temperature Projections by Season Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

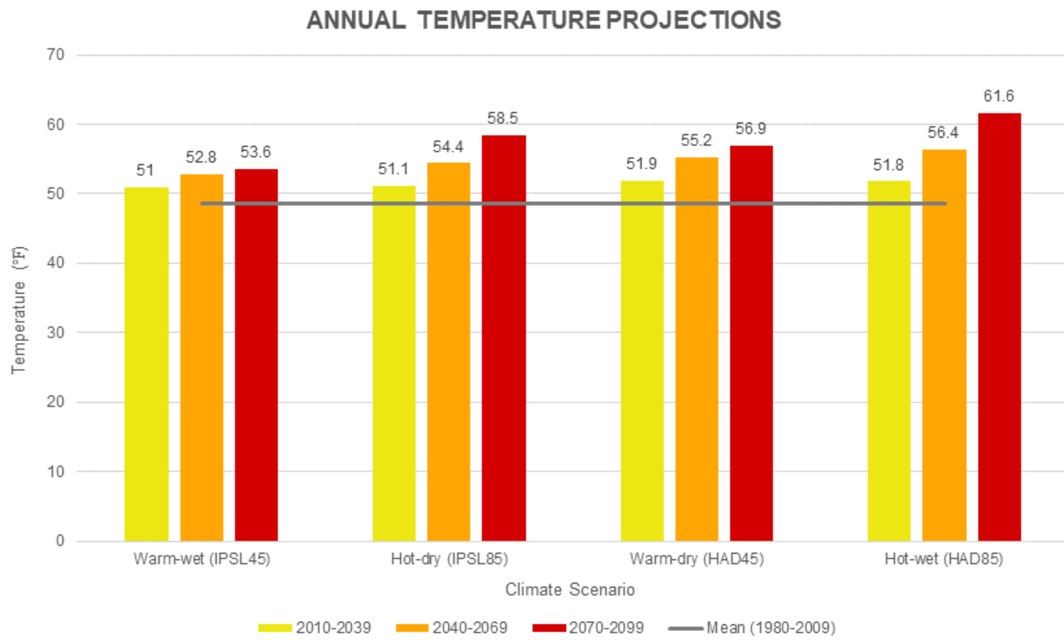
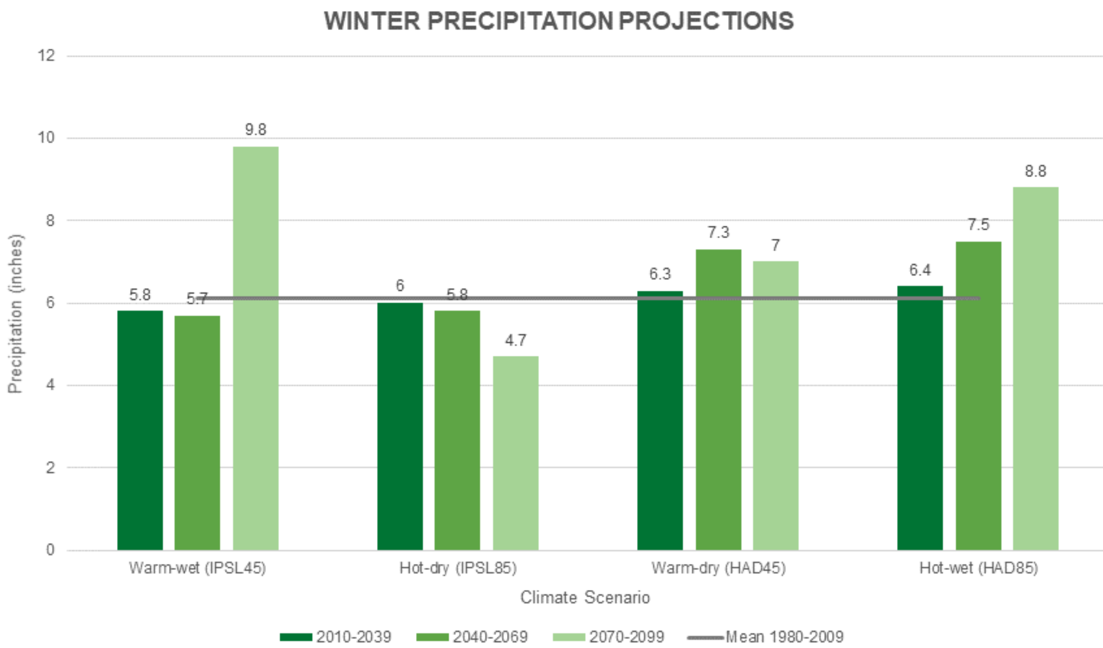
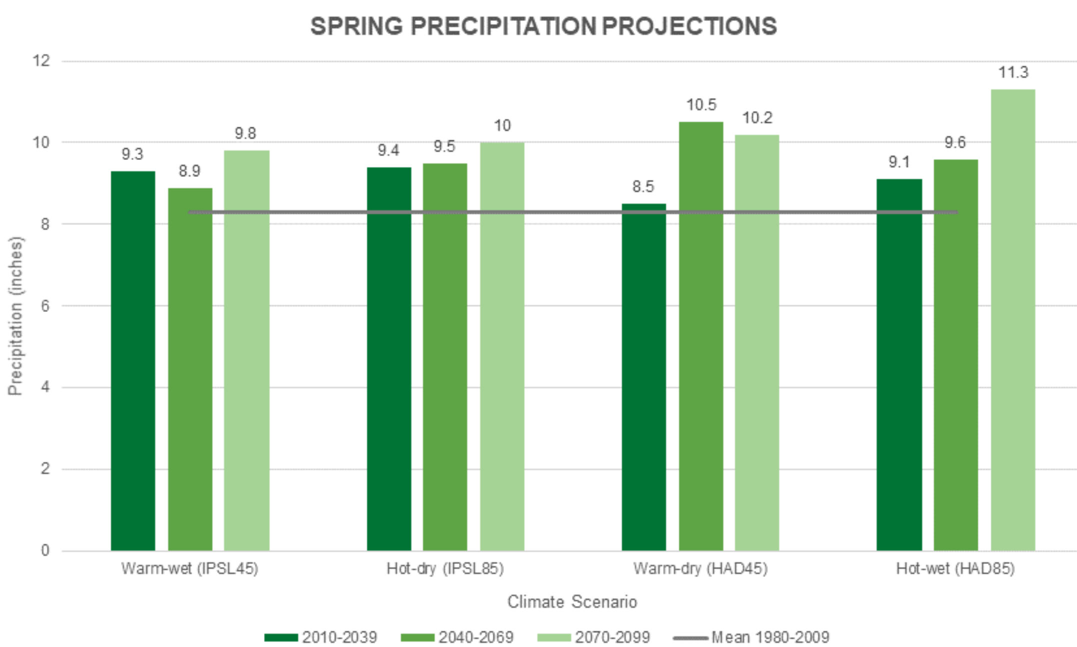


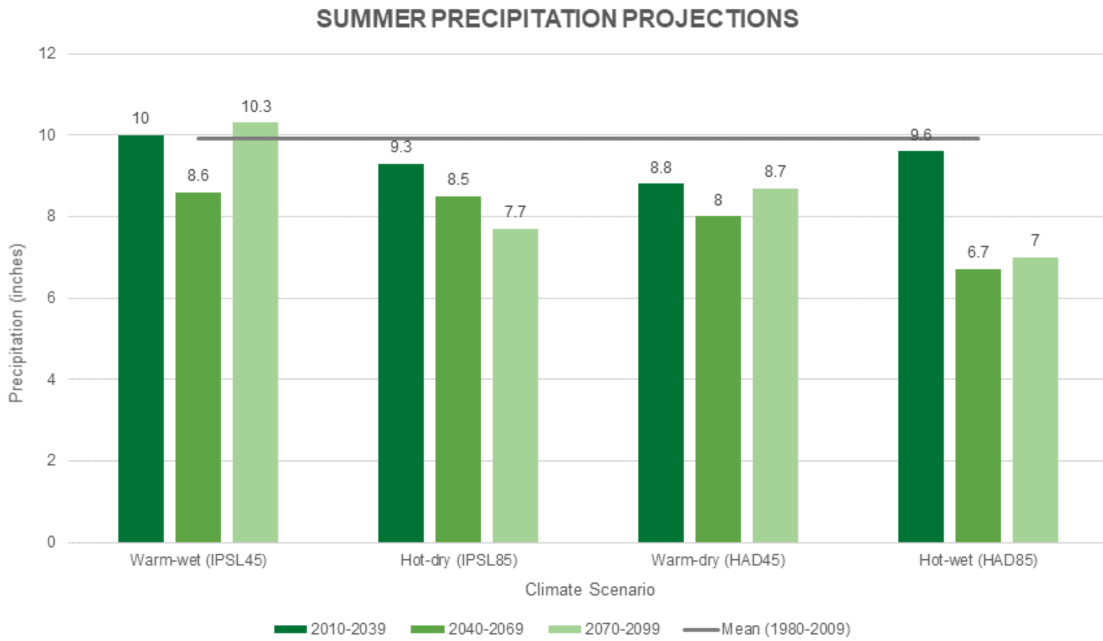
Figure A2.2. Annual Temperature Projections Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

APPENDIX 3

SEMCOG Precipitation Projections







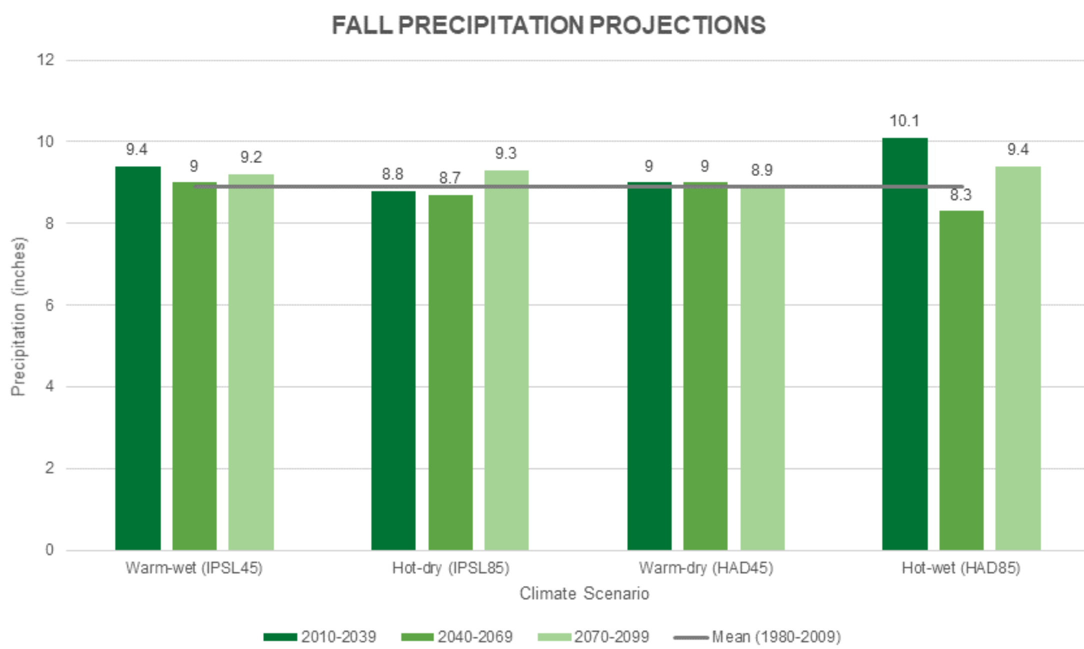


Figure A3.1. Precipitation Projections by Season Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

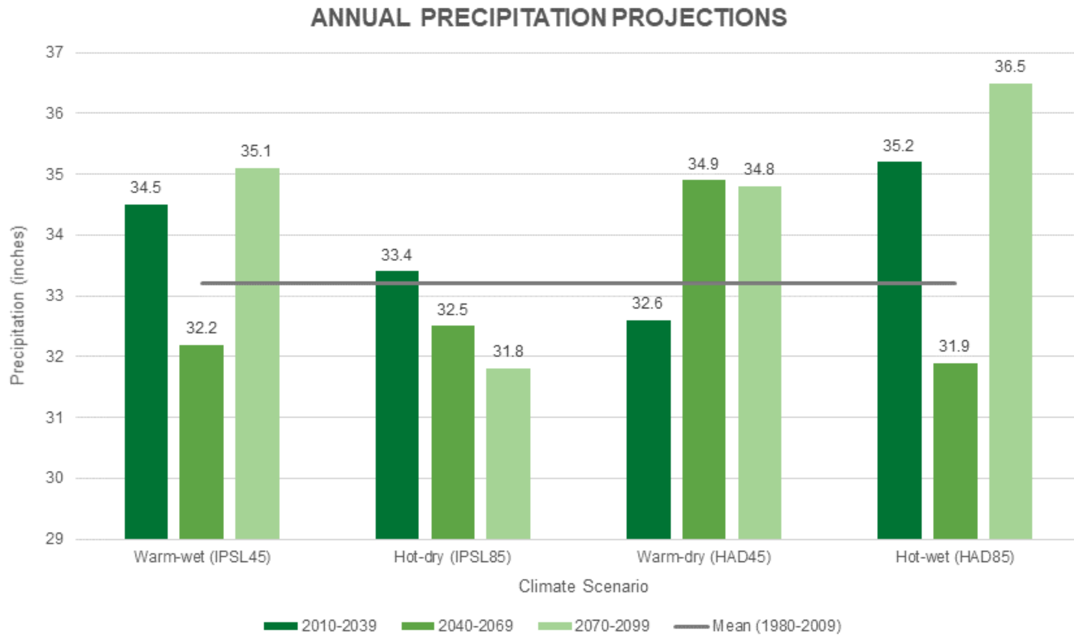


Figure A3.2. Annual Precipitation Projections Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

APPENDIX 4

Precipitation, Temperature, and Extreme Events Projections Data

Table A4.1. Precipitation, Temperature, and Extreme Events Projections Under Warm-wet (IPSL45), Hot-dry (IPSL85), Warm-dry (HAD45), and Hot-wet (HAD85) Climate Scenarios for Periods 2010-2039, 2040-2069, and 2070-2099 in the SEMCOG Region (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties).

Precipitation (inches) Projections by County													
	2010-2039				2040-2069				2070-2099				Average (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)	Hot-wet (HAD85)	
Livingston County													
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
Macomb County													
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
Monroe County													
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
Precipitation (inches) Projections by County													
	2010-2039				**2040-2069**				**2070-2099**				**Average (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)**	**Hot-wet (HAD85)**	
Oakland County													
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
St. Clair County													
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
Washtenaw County													
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
Wayne County													
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

Temperature (°F) Projections by County													
	2010-2039				2040-2069				2070-2099				Average (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)	Hot-wet (HAD85)	
Livingston County													
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
Macomb County													
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	612	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
Monroe County													
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
Oakland County													
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

Temperature (°F) Projections by County													
	2010-2039				**2040-2069**				**2070-2099**				**Average (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)**	**Hot-wet (HAD85)**	
St. Clair County													
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
Washtenaw County													
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
Wayne County													
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

Extreme Events (Average Days) Projections by County													
	2010-2039				**2040-2069**				**2070-2099**				**Average (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)**	**Hot-wet (HAD85)**	

Livingston County													
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”	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”	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
Macomb County													
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”	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”	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
Monroe County													
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”	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”	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

Extreme Events (Average Days) Projections by County													
	2010-2039				2040-2069				2070-2099				Average (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)	Hot-wet (HAD85)	
Oakland County													
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”	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”	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
St. Clair County													
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”	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”	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
Washtenaw County													
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”	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
Precipit	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

ation ≥2”													
Wayne County													
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”	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”	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

Plant Hardiness Zone and Heat Zone Mapping

The plant hardiness zone map is based on minimum annual temperature and is used as a standard to guide gardeners and growers on which plants may thrive in a particular location in the United States. The map helps to determine plants that may or may not be adapted to withstand winter cold temperatures. It was published in 1990 (Cathey, 1990) and updated in 2003 (Ellis, 2003) as well as 2010 (Daly et al., 2012). The heat zone map is based on the number of days exceeding 86°F (30°C) and is used to determine heat stress on organisms. It was produced in 1997 by the American Horticultural Society (Cathey, 1997).

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Ellis, D. J. (2003). The USDA plant hardiness map. *American Gardener, 82*(3), 30-30.

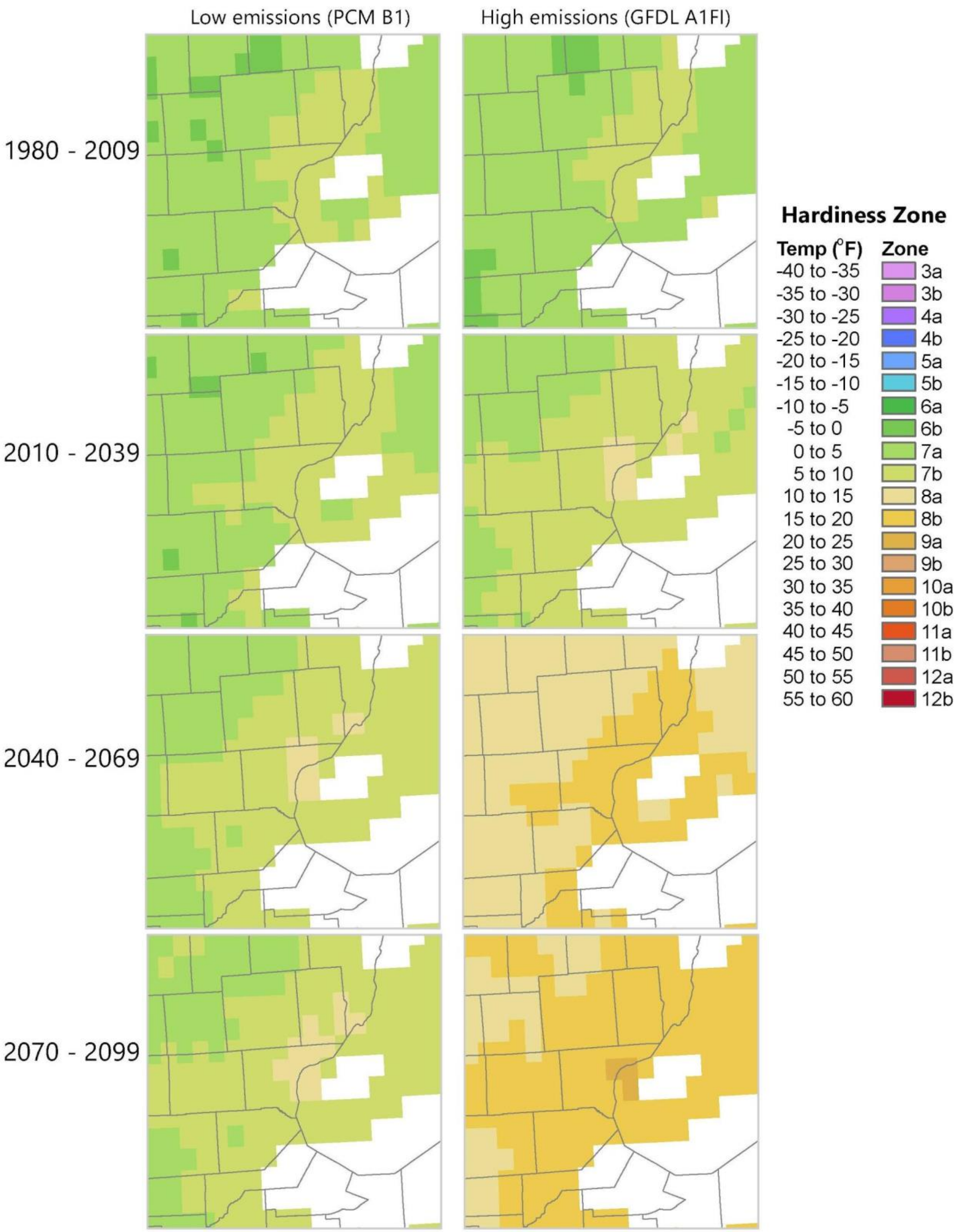

Figure A5.1. Detroit Hardiness Zones Under Low and High Emissions for Time Periods 2010-2039, 2040-2069, and 2070-2099.

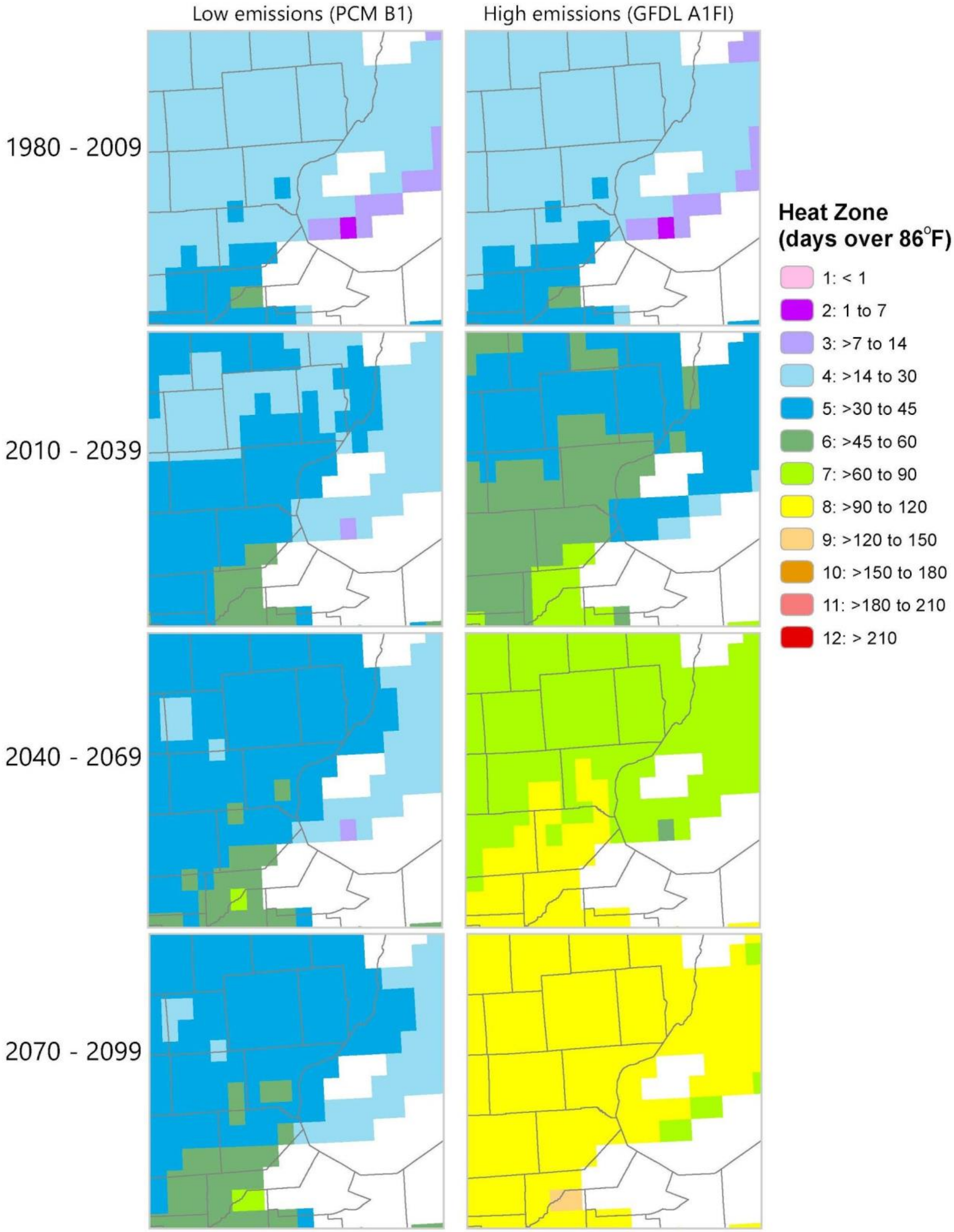

Figure A5.2. Detroit Heat Zones Under Low and High Emissions for Time Periods 2010-2039, 2040-2069, and 2070-2099.

APPENDIX 6

Modeled Projections of Habitat Suitability

The table below provides the current and modeled importance values for the species modeled using the DISTRIB-II species distribution model for trees in the 1-by-1-degree latitude/longitude grid cell. This list is limited to only species represented in the DISTRIB-II model and may include species that are found in the larger 1x1 grid cell but outside of the City of Detroit. Definitions for headings and supporting documentation are below.

Table A6.1. Modeled Projections of Habitat Suitability for Detroit Tree Species.

Scientific Name	Common Name	Range	MR	%Cell	FIAsum	FIAiv	ChngCl 45	ChngCl 85	Adapt	Abund	Capabil 45	Capabil 85
Acer negundo	boxelder	WSH	Low	10.7	196.63	22.31	Sm. dec.	Sm. dec.	High	Common	Fair	Fair
Acer nigrum	black maple	NSH	Low	1.1	1.73	1.3	Lg. dec.	Lg. dec.	High	Rare	Poor	Poor
Acer pensylvanicum	striped maple	NSL	Medium	0	0	0	Unknown	Unknown	Medium	Modeled	Unknown	Unknown
Acer rubrum	red maple	WDH	High	37	699.07	20.84	Sm. dec.	Sm. dec.	High	Abundant	Good	Good
Acer saccharinum	silver maple	NSH	Low	7.9	156.11	16.8	No change	No change	High	Common	Good	Good
Acer saccharum	sugar maple	WDH	High	12.4	232.78	22.31	Sm. inc.	No change	High	Common	Very Good	Good
Amelanchier spp.	serviceberry	NSL	Low	2.3	2.39	0.9	Very Lg. dec.	Very Lg. dec.	Medium	Rare	Lost	Lost
Asimina triloba	pawpaw	NSL	Low	0	0	0	Unknown	Unknown	Medium	Modeled	Unknown	Unknown
Betula alleghaniensis	yellow birch	NDL	High	2.3	29.2	11	Lg. dec.	Lg. dec.	Medium	Rare	Poor	Poor
Betula papyrifera	paper birch	WDH	High	2.3	3.66	1.38	Lg. dec.	Lg. dec.	Medium	Rare	Poor	Poor
Carpinus caroliniana	American hornbeam; musclewood	WSL	Low	4.5	12.48	2.35	Sm. dec.	Sm. dec.	Medium	Rare	Poor	Poor
Carya alba	mockernut hickory	WDL	Medium	0	0	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat
Carya cordiformis	bitternut hickory	WSL	Low	6.8	61.54	7.73	No change	No change	High	Common	Good	Good
Carya glabra	pignut hickory	WDL	Medium	9	63.4	5.97	No change	No change	Medium	Common	Good	Good
Carya illinoinensis	pecan	NSH	Low	0	0	0	New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat
Carya ovata	shagbark hickory	WSL	Medium	20.3	170.84	14.43	Sm. dec.	Lg. dec.	Medium	Common	Fair	Fair
Carya texana	black hickory	NDL	High	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Celtis laevigata	sugarberry	NDH	Medium	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Celtis occidentalis	hackberry	WDH	Medium	5.1	11.36	12.01	Sm. inc.	Sm. inc.	High	Rare	Good	Good
Cercis canadensis	eastern redbud	NSL	Low	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Cornus florida	flowering dogwood	WDL	Medium	1.1	1.55	1.17	Sm. dec.	Very Lg. dec.	Medium	Rare	Poor	Lost
Diospyros virginiana	common persimmon	NSL	Low	0	0	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat
Fagus grandifolia	American beech	WDH	High	4.5	39.51	7.44	No change	Sm. dec.	Medium	Rare	Fair	Poor
Fraxinus americana	white ash	WDL	Medium	20.3	75.45	5.39	Lg. inc.	Lg. inc.	Low	Common	Very Good	Very Good
Fraxinus nigra	black ash	WSH	Medium	4.5	59.5	11.21	Very Lg. dec.	Very Lg. dec.	Low	Common	Lost	Lost
Fraxinus pennsylvanica	green ash	WSH	Low	37.7	443.44	12.28	No change	No change	Medium	Common	Good	Good
Gleditsia	honeylocust	NSH	Low	0	0	0	New	New	High	Absent	New	New

Scientific Name	Common Name	Range	MR	%Cell	FIAsum	FIAiv	ChngCl 45	ChngCl 85	Adapt	Abund	Capabil 45	Capabil 85
triacanthos							Habitat	Habitat			Habitat	Habitat
Juglans cinerea	butternut	NSLX	FIA	1.1	2.06	1.55	Unknown	Unknown	Low	Rare	FIA Only	FIA Only
Juglans nigra	black walnut	WDH	Low	3.4	132.99	33.4	No change	No change	Medium	Common	Good	Good
Juniperus ashei	ashe juniper	NDH	High	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Juniperus virginiana	eastern red cedar	WDH	Medium	2.3	11.75	4.42	Lg. inc.	Lg. inc.	Medium	Rare	Good	Good
Larix laricina	tamarack (native)	NSH	High	3.4	43.14	10.83	Sm. dec.	Sm. dec.	Low	Rare	Poor	Poor
Liquidambar styraciflua	sweetgum	WDH	High	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Liriodendron tulipifera	yellow-poplar	WDH	High	1.1	3.72	2.8	Lg. inc.	Lg. inc.	High	Rare	Good	Good
Maclura pomifera	Osage-orange	NDH	Medium	0	0	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat
Magnolia acuminata	cucumber tree	NSL	Low	0	0	0	Unknown	Unknown	Medium	Modeled	Unknown	Unknown
Morus alba	white mulberry	NSL	FIA	3.4	11.1	2.79	Unknown	Unknown	NA	Rare	NNIS	NNIS
Morus rubra	red mulberry	NSL	Low	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Nyssa sylvatica	blackgum	WDL	Medium	4.5	0.46	1.4	Sm. inc.	Lg. inc.	High	Rare	Good	Good
Ostrya virginiana	eastern hophornbeam; ironwood	WSL	Low	6.8	64.93	8.15	Lg. dec.	Lg. dec.	High	Common	Fair	Fair
Picea abies	Norway spruce	NSH	FIA	2.3	47.42	17.87	Unknown	Unknown	NA	Rare	NNIS	NNIS
Picea glauca	white spruce	NSL	Medium	3.4	49.33	12.39	Lg. dec.	Lg. dec.	Medium	Rare	Poor	Poor
Pinus resinosa	red pine	NSH	Medium	3.4	65.92	16.56	Lg. dec.	Lg. dec.	Low	Common	Fair	Fair
Pinus strobus	eastern white pine	WDH	High	2.3	13.27	5	No change	Lg. dec.	Low	Rare	Fair	Poor
Pinus sylvestris	Scotch pine	NSH	FIA	7.9	52.04	13.56	Unknown	Unknown	NA	Common	NNIS	NNIS
Platanus occidentalis	sycamore	NSL	Low	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Populus deltoides	eastern cottonwood	NSH	Low	11.8	110.05	14.28	Lg. inc.	Lg. inc.	Medium	Common	Very Good	Very Good
Populus grandidentata	bigtooth aspen	NSL	Medium	10.1	34.51	5.31	Lg. dec.	Lg. dec.	Medium	Rare	Poor	Poor
Populus tremuloides	quaking aspen	WDH	High	9	82.78	13.82	Lg. dec.	Lg. dec.	Medium	Common	Fair	Fair
Prunus serotina	black cherry	WDL	Medium	34.7	501.19	13.47	No change	Sm. dec.	Low	Abundant	Very Good	Good
Prunus virginiana	chokecherry	NSLX	FIA	3.4	15.97	4.01	Unknown	Unknown	Medium	Rare	FIA Only	FIA Only
Quercus alba	white oak	WDH	Medium	21.2	269.85	12.86	Sm. inc.	No change	High	Common	Very Good	Good
Quercus bicolor	swamp white oak	NSL	Low	11.3	111.55	8.4	Sm. inc.	Sm. dec.	Medium	Common	Very Good	Fair
Quercus coccinea	scarlet oak	WDL	Medium	1.1	132.72	100	Very Lg. dec.	Very Lg. dec.	Medium	Common	Lost	Lost
Quercus ellipsoidalis	northern pin oak	NSH	Medium	1.1	40.75	30.7	Sm. dec.	Sm. dec.	High	Rare	Poor	Poor
Quercus incana	bluejack oak	NSL	Low	0	0	0	Unknown	Unknown	Medium	Absent	Unknown	Unknown
Quercus macrocarpa	bur oak	NDH	Medium	19.1	103.74	14.68	No change	No change	High	Common	Good	Good
Quercus marilandica	blackjack oak	NSL	Medium	0	0	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat
Quercus palustris	pin oak	NSH	Low	0	0	0	New	New	Low	Absent	New	New

Scientific Name	Common Name	Range	MR	%Cell	FIAsum	FIAiv	ChngCl 45	ChngCl 85	Adapt	Abund	Capabil 45	Capabil 85
							Habitat	Habitat			Habitat	Habitat
Quercus rubra	northern red oak	WDH	Medium	25.7	244.01	9.21	No change	No change	High	Common	Good	Good
Quercus shumardii	Shumard oak	NSL	Low	1.1	26.35	19.85	Sm. dec.	Sm. dec.	High	Rare	Poor	Poor
Quercus stellata	post oak	WDH	High	0	0	0	New Habitat	New Habitat	High	Absent	New Habitat	New Habitat
Quercus velutina	black oak	WDH	High	20.1	402.66	16.34	No change	No change	Medium	Common	Good	Good
Quercus virginiana	live oak	NDH	High	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Robinia pseudoacacia	black locust	NDH	Low	1.1	10.25	7.72	Sm. inc.	Lg. inc.	Medium	Rare	Good	Good
Salix nigra	black willow	NSH	Low	5.6	75.83	11.43	Sm. dec.	No change	Low	Common	Fair	Good
Sassafras albidum	sassafras	WSL	Low	12.2	114.38	7.69	No change	Lg. dec.	Medium	Common	Good	Fair
Thuja occidentalis	northern white-cedar	WSH	High	3.4	53.69	13.48	Sm. dec.	Sm. dec.	Medium	Common	Fair	Fair
Tilia americana	American basswood	WSL	Medium	18	140.83	8.39	No change	Sm. dec.	Medium	Common	Good	Fair
Ulmus alata	winged elm	WDL	Medium	0	0	0	New Habitat	New Habitat	Medium	Absent	New Habitat	New Habitat
Ulmus americana	American elm	WDH	Medium	43.9	409.88	9.66	Sm. inc.	Sm. inc.	Medium	Common	Very Good	Very Good
Ulmus crassifolia	cedar elm	NDH	Medium	0	0	0	New Habitat	New Habitat	Low	Absent	New Habitat	New Habitat
Ulmus pumila	Siberian elm	NDH	FIA	3.4	24.62	6.18	Unknown	Unknown	NA	Rare	NNIS	NNIS
Ulmus rubra	slippery elm	WSL	Low	1.1	3.45	2.6	No change	Sm. inc.	Medium	Rare	Fair	Good

Definitions

Heading	Heading Definition
Scientific Name	Species scientific name used by FIA.
Common Name	Species common name used by FIA.
Range	Code for species distribution characteristics throughout the eastern U.S. Codes for Distribution (Wide vs. Narrow, first letter), Commonness (Dense vs. Sparse, second letter), and Importance (High IV vs. Low IV, third letter). 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 percent of the eastern U.S. occupied by the species (Wide =>10% occupied, Narrow <10%). Commonness was based on the percent of 10x10 km cells with the species detected by FIA (Dense=>40%, Sparse <40%). 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 U.S.
MR	The model reliability of the species' model predicting current and future suitable habitat (High, Medium, Low). If coded 'FIA', the model is unacceptable for predicting into the future, thus the change classes and capability classes are unknown.
%Cell	The percentage of cells within the 1x1 degree of Lat/Lon (or other area) zone which has FIA records for the species according to the 10x10 or 20x20 km cells. It does not mean the species actually covers that amount of ground within the sample area. If the %Cell is <5% for any species, it is recorded as Abund = Rare regardless of the FIAsum.
FIAsum	The area-weighted sum of the importance values (IV) per 100 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 1x1 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 1x1 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 their proportion of a full 1x1 degree zone at mid latitudes (35 degrees).
FIAiv	The average importance value (IV) according to FIA records for the species. This provides 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 (2070-2099) suitable habitat for an average of 3 GCMs to current (1981-2010) modeled habitat at RCP4.5.
ChngCl85	Class of potential change in habitat suitability by 2100 according to the ratios of future (2070-2099) suitable habitat for an average of 3 GCMs to current (1981-2010) modeled habitat at RCP8.5.
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 (5.2 - 9.0), Medium (3.4 - 5.1), and Low (0.1 - 3.3).
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 50-500), Rare (FIAsum >0 and <50), Modeled (only in modeled output), and Absent (FIAsum = 0). If the %Cell is <5% for any species, it is recorded as Abund = Rare regardless of the FIAsum.
Capabil45	Capability at RCP 4.5. Estimate of capability for the species to cope with the changing climate, at RCP 4.5, within the study area. Based on its current abundance (Abund) within the zone, change class (ChngCl45), and adaptability (Adap). Ranks are coded Very Good, Good, Fair, Poor, Very Poor, FIA only (no model, no Capability assigned), NNIS (no model, non-native invasive species), Unknown (insufficient data to model), and New Habitat (potential to migrate into the zone).
Capabil85	Capability at RCP 8.5. Estimate of capability for the species to cope with the changing climate, at RCP 8.5, within the study area. Based on its current abundance (Abund) within the zone, change class (ChngCl85), and adaptability (Adap). 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).

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APPENDIX 7

Modification Factors for Assessing Adaptive Capacity of Trees in Urban Areas

Modification Factor scores, based on Matthews et al. (2011), were developed for 187 species that are either already present or have the potential to gain habitat in the Detroit region. The purpose of these scores is to provide managers and policy-makers 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 Atlas (Landscape Change Research Group, 2014) and other species distribution models.

Scoring System

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

Below 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 below for specific details relating to each ModFactor for planted and naturally occurring 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 on Score) of how uncertain the ModFactor is in influencing the distribution of the species. Scores are 0.5 = highly uncertain; 0.75 = somewhat uncertain; 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 next 50 years to 5 = likely to be an extremely important ModFactor.

Weighted - A weighted score based on multiplication of the three default values (ScoreX UncerX FutureRelevance) for the species throughout its range.

Average Disturbance Score - The average of all the Weighted Disturbance Factor Scores—and relates to the relative overall impact of these factors.

Average Biological Score - The average of all the Weighted Biological Factor Scores—and relates to 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 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 and Bio Score. Values can range from 0 to 8.5.

Adapt Class - Categories assigned based on Adapt Score. Low: less than 3.5. Moderate: 3.5-4.5. 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 others 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, 2015) and invasive species fact sheets developed by Federal and state agencies. Additional information for wind and ice storm susceptibility was taken from Hauer et al. (2006) and Duryea et al. (2007).

Defaults were kept consistent with Matthews et al. (2011), with a few exceptions. Insect and disease scores were modified to account for local pest and disease influences such as oak wilt and hypoxylon. Factors that received a weighted score of less than -4.5 or greater than 4.5 were listed as contributing negatively or positively to the species' overall adaptability score 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: -1 Score, 0.75 Uncert, and 2 FutureRelevance.

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: -1 Score, 0.5 Uncert, and 4 FutureRelevance.

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

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 invasives are usually more readily adapted to changing environments and can form monotypic stands that restrict regeneration. Defaults for all species: -3 Score, 0.5 Uncert, and 4 FutureRelevance.

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: -1 Score, 0.75 Uncert, and 5 FutureRelevance.

Flood - Frequent or prolonged periods of standing water. Species adapted to sustained flooding will be positively affected while species vulnerable to flooding will be negatively affected by the assumed greater flooding exposures under climate change. Defaults for all species: -1 Score, 0.75 Uncert, and 4 FutureRelevance.

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

Wind - The damaging effects of windstorms and uprooting potential (and top breakage) of a species: -1 Score, 0.75 Uncert, and 2 FutureRelevance. If a species is susceptible to windthrow, the standard default is -2 (Score); if resistant to windthrow, Score is +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, while species vulnerable to fire will be negatively affected. As a first approximation, bark thickness relates directly to this ModFactor. Defaults for all species: -1 Score, 0.75 Uncert, and 2 FutureRelevance.

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, consider how the species responds when it is an incidental species in harvested stands. Since harvesting is generally low in urban areas, this defaults to 0 and is not factored in unless there is an active attempt at managing this species (e.g., removal of woody invasives). Defaults for all species: 0 Score, 0.5 Uncert, and 2 FutureRelevance.

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 small range of temperatures. Defaults for all species: 1 Score, 0.75 Uncert, and 2 FutureRelevance.

Air Pollution - Airborne pollutants that affect, mostly negatively, a species' growth, health, and distribution. Includes acid rain, ozone. Defaults for all species: -2 Score, 0.75 Uncert, and 3 FutureRelevance.

Soil/Water Pollution - Pollutants in the soil and water that affect, mostly negatively, a species' growth, health, and distribution. Defaults for all species: -1 Score, 0.5 Uncert, and 1 FutureRelevance.

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 species tolerance level, and all with FutureRelevance of 3. Species intolerant to shade receive -3 (Score) 0.75 (Uncert), Intermediate either -1, 0, 1 (Score) 0.5 (Uncert). Intermediate default is 0, with flexibility to go +1 or -1. Tolerant species have scores of +3 (Score) 0.75 (Uncert).

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 with general requirements 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: 0 Score, 0.75 Uncert, and 2 FutureRelevance.

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

Dispersal - The species' ability 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: 1 Score, 0.5 Uncert, and 3 FutureRelevance.

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: 1 Score, 0.75 Uncert, and 4 FutureRelevance.

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

Fire Regeneration - The capability of the species to be enhanced in regeneration through fire, usually surface fires. This score will never be < 0 as it is only used if there is an extra benefit in fire to regenerate the species, above seedling establishment and vegetation reproduction. Defaults are 0 Score, 0.75 Uncert, and 2 FutureRelevance.

Below is an example natural score for boxelder (Table A7.1).

Table A7.1. Example of Natural Modification Factor Scores Generated for the Species Boxelder.

Factor Type	ModFactor	Score	Uncert	FutureRelevance	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	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 & 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 dist score				-0.09
	Average bio 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 environments experienced by trees in more developed areas. 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 nonnatives was taken from Gilman and Watson (1993). Additional information for wind and ice storm susceptibility were taken from Hauer et al. (2006) and Duryea et al. (2007).

Factors that received a weighted score of less than -4.5 or greater than 4.5 were listed as contributing negatively or positively to the species' overall adaptability score in tables. Weighted scores between these two values were not listed.

Disturbance Factors:

Disease - Same as natural scores. Insect Pests - Same as natural scores.

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

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

Drought - Same as for natural scores, but future relevance is reduced from 5 to 3 because it is assumed that many planted trees will be watered during drought periods.

Flood - Same as natural scores.

Ice - Same as natural scores.

Wind - Same as natural scores.

Temperature Gradients - Same as natural scores, except future relevance was increased from 2 to 3 because of the urban heat island effect.

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

Soil/Water Pollution - Same as natural scores, but default is reduced to -2 to account for greater pollution in developed areas.

Biological Factors:

Competition-Light - Same as natural scores.

Edaphic Specificity - Same as natural scores.

Land-Use/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 non-edaphic environmental characteristics (e.g., slope, aspect, topographic position, climatic modulation, specific associates) that the species requires. Defaults for all species: 0 Score, 0.75 Uncert, and 3 FutureRelevance.

Restricted Rooting Conditions and Soil Compaction - The ability of a species to grow and survive in narrow boulevards and other constrained spaces. Defaults for all species: -1 Score, 0.75 Uncert, and 3 FutureRelevance.

Nursery Production Potential - The ease and/or cost of producing the species in a nursery. Also relates to how widely available it is. Future Relevance is high for this factor because it will largely determine the extent to which the species is widely propagated and planted. For all species: 0.75 Uncert, and 4 FutureRelevance. If stock is widely available, Score is +2. If not currently available, Score is -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: 1 Score, 0.75 Uncert, and 2 FutureRelevance. -1 Score if not easily established.

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

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

Below is an example planted score for boxelder (Table A7.2).

Table A7.2. Example of Planted Modification Factor Scores Generated for the Species Boxelder.

Factor Type	ModFactor	Score	Uncert	FutureRelevance	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	Temperature Gradients	3	0.75	3	6.75
Disturbance	Air Pollution	-2	0.75	3	-4.50
Disturbance	Soil & 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 & Planting Site Specificity	1	0.75	3	2.25
Biological	Restricted Rooting Conditions	1	0.75	3	2.25
Biological	Nursery Propagation	-1	0.75	4	-3.00
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 dist score				0.02
	Average bio score				0.03
	Converted dist score				2.83
	Converted bio score				3.38
	Adapt score				4.41
	Adapt class				medium

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As the climate changes over the 21st century, Detroit's people, trees, and green spaces will face physical, biological, human health, and indirect impacts. This assessment evaluates the vulnerability of the Detroit region's urban forest. 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 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 aren't 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 Detroit. Major current threats to the region's urban forest include urban heat islands, invasive species and diseases, vacant lands, 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°F to 13°F by the end of the century compared to the 1980-2009 mean. Precipitation in Detroit has been increasing by 0.95 inches per decade since 1960 and spring precipitation is projected to increase, while other 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 heat zone 5 to between 7 and 9, depending on the emissions scenario. Species distribution modeling of native trees projects that suitable habitat will decrease for about a third of the tree species, increase for 13% of species, and remain stable for 13% of species, while 26% of native species evaluated for habitat suitability will be able to gain suitable habitat. In terms of adaptive capacity for planted/developed conditions, 27% of native species evaluated received a high adaptability score, 57% received a medium adapability score, and 16% received a low adaptability score. For natural areas (both native and naturalized), 45% of species received a high adaptability score, 46% received a medium adaptability score, and 9% received a low adaptability score. Under low emissions, the majority of Detroit tree species fell into the low-moderate vulnerability category (51%). However, more species received higher vulnerability ratings under the high emissions scenario. Nearly 14% were categorized as low vulnerability, 21% as low-moderate vulnerability, 20% as moderate vulnerability, 35% as moderate-high vulnerability, and nearly 10% 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.

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