Climate Change Field Guide for Northern Michigan Forests:

Site-level considerations and adaptation

USDA

Northern Forests Climate Hub
U.S. DEPARTMENT OF AGRICULTURE

NIACS

The Nature Conservancy
nature.org

Forest Carbon and Climate Program
Department of Forestry
MICHIGAN STATE UNIVERSITY

Created by:

This is a joint product of the USDA Northern Forests Climate Hub and the Northern Institute of Applied Climate Science, a multi-partner collaborative led by the USDA Forest Service.

With significant contributions from:

- The Nature Conservancy, nature.org
- Michigan State University Forest Carbon and Climate Program, canr.msu.edu/fccp
- Michigan Forest Stewardship Program, michigan.gov/dnr/managing-resources/forestry/private/stewardship

Contact:

Stephen Handler, stephen.handler@usda.gov
Northern Institute of Applied Climate Science, USDA Forest Service, Northern Research Station

Suggested Citation:

Handler, S., T. Bishop, L. Cooper, J. Crick, M. Felde, D. Gadoth-Goodman, J. Hartman, A. Helman, A. Henriksen, T. Hobbs, R. Janowiak, K. Konen, B. O'Brion, T. Ontl, M. Peters, G. Peterson, K. Marcinkowski, K. Ross, B. Schram, M. Smalligan, M. Strieter, C. Young, and M. Janowiak. 2022. Climate change field guide for northern Michigan forests: Site-level considerations and adaptation. White Paper. Houghton, MI: U.S. Department of Agriculture, Northern Forests Climate Hub. 100p.

Available at: forestadaptation.org/northern_MI_fieldguide

TABLE OF CONTENTS

Northern Institute of Applied Climate Science

The Northern Institute of Applied Climate Science (NIACS) is a multi-organization partnership, led by the USDA Forest Service, focused on bridging the gap between research and management in the fields of climate adaptation and carbon science (niacs.org). NIACS leads a community effort called the Climate Change Response Framework (CCRF, forestadaptation.org) that helps land managers integrate climate change into their work. NIACS has created numerous tools and resources for forest managers, as well as a growing network of real-world adaptation projects.

NIACS
Northern Institute of Applied Climate Science

USDA Northern Forests Climate Hub

The USDA Northern Forests Climate Hub is operated by NIACS, and was created to deliver locally-relevant information to natural resources managers and landowners (climatehubs.usda.gov/hubs/northern-forests). This field guide is an example of how the USDA Climate Hubs are helping people with real-world decisions.

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

INTRODUCTION

Climate change is a growing concern for Michigan's forests. Foresters and land managers are considering how to prepare for future conditions and evaluate risks. This field guide is a quick reference on climate change for northern Michigan forests. We hope it will help you consider climate change risks together with local site characteristics, and also that it will help you design adaptation actions that help meet management goals.

There are companion field guides for other regions in the Northwoods, available at: forestadaptation.org/northwoods

This field guide will:

- **Summarize climate change effects on northern Michigan's forests**
- **Identify existing site conditions that could increase or reduce risk from climate change**
- **Help you start discussions about potential climate risks and management responses with co-workers, partners, and clients**

This field guide won't:

- **Tell you exactly how to respond to climate change risks**
- **Replace your own planning processes, local knowledge, or management experience**

Using this Field Guide

1. **Review general climate information**
   Pages 5–15 describe regional climate change trends and high-level climate impacts for northern Michigan forests. Pages 18–35 contain tables for each Ecological Section that show whether tree species are projected to increase or decrease in suitable habitat by the end of the century.

2. **Find your forest type**
   This guide is organized around nine northern Michigan forest types (p. 36–71). Notes and illustrations at the start of each section describe the forest type, and following pages explain climate change vulnerability ratings and adaptive capacity factors.

3. **Consider site-level conditions**
   Some forest stands may be more vulnerable to climate risks, based on their specific conditions. The Site-Level Considerations pages (p. 39, 43, 47, etc.) will help you consider local factors that may modify the climate change risk for your stand, such as soils; species diversity; management history; and forest health threats.

4. **Brainstorm adaptation actions**
   The adaptation section (p. 72–92) includes the complete Forest Adaptation Menu, as well as example adaptation actions to address major risk factors. This section will help you generate adaptation ideas to apply to your own unique management situation.

Forest Type Information in this Field Guide

This field guide is organized around 9 common forest types, listed below. Here's what you'll find in each forest type section:

- **Aspen-Birch**
- **Jack Pine**
- **Lowland Conifer**
- **Lowland-Riparian Hardwoods**
- **Northern Hardwoods**
- **Oak**
- **Pine and Oak Barrens**
- **Red Pine**
- **Upland Spruce-Fir**

- **Forest Type Characteristics**, including background information on typical soils, landforms, disturbance regimes, and tree species.
- **Climate Change Information**, including a Vulnerability Rating, a Confidence Rating based on amount of available evidence and agreement among that evidence, a list of Climate Change Impacts for the community, and a map of Ecological Sections with higher or lower vulnerability.
- **Adaptive Capacity Factors**, or key features that influence the community's ability to cope with climate change.
- **Site-level Factors** that can make an individual stand more or less vulnerable to climate change, including descriptions of "low risk" and "high risk" conditions.

5

CLIMATE CHANGE AND NORTHERN MICHIGAN FORESTS

Climate change will continue to affect northern Michigan forests in many ways. An expert panel of researchers and managers examined the best available information on climate change, and came up with several major impacts that climate change will have on the state's forests. In many cases, climate change acts like a "threat multiplier" by interacting with stressors or threats that already occur. In the section that follows, you'll see short summaries of these major impacts. More complete information is available in Forest Ecosystem Vulnerability Assessments for Michigan forests (p. 17).

Key topics in this section include:

- Temperature increases
- Longer growing season
- Winter operations
- Precipitation changes
- Changing hydrology
- Soil moisture and drought stress
- Wildfire and prescribed fire
- Invasive plants
- Forest pests and diseases
- Deer browse damage

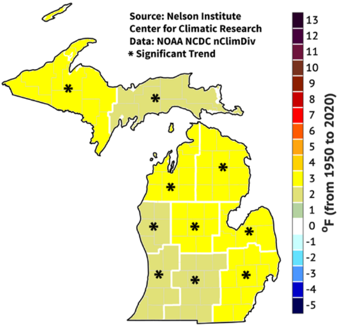
Temperature Increases

Temperatures have already warmed by about 2-3° F in northern Michigan over the past 70 years. **Winter has warmed more rapidly than other seasons,** and minimum temperatures are increasing faster than maximum temperatures.

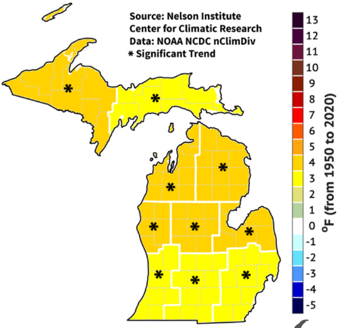
Temperatures are projected to continue to increase by 5 to 11° F in northern Michigan over the next century, depending on future greenhouse gas emissions and other factors, with 20-40 fewer nights below 0° F.

As you'll see in the pages that follow, warmer temperatures will have cascading effects related to snowfall, snowpack, frozen ground, growing season length, germination success, and other changes.

Historical Change in Annual Mean Temp, 1950–2020



Historical Change in Winter Mean Temp, 1950–2020



Longer Growing Season

Michigan's growing season has already increased by almost two weeks over the past 70 years. This trend is expected to continue, as **some studies have projected that frost-free growing seasons across northern Michigan could increase by 20 to 60 days by the end of the century.**

A longer growing season could benefit some tree species in northern Michigan, because it means more available time for growth. Native boreal tree species may not be able to extend their growing seasons later in the year, however, and non-native species or southern species may be better able to take advantage of the longer growing season. Also, early warm spring conditions raise the risk of frost damage if trees break bud before the last frost.


Kailey Marcinkowski, NIACS

Winter Operations

Forest management in much of northern Michigan requires frozen ground or a deep snowpack to protect soils, water, and roads. During the 20th century, frozen ground conditions declined across northern Michigan. **Frozen ground duration is expected to shrink by another 1–2 months by 2100.** This has consequences for harvest and hauling operations, as well as actions for soil and water protection.

As winter temperatures have increased, snow conditions have become more variable. Snowfall has increased in lake-effect snow belts as ice cover on the Great Lakes has declined. Contrastingly, warmer winters have resulted in more melting between snowfalls, wetter snow, more winter rain and ice, and earlier spring snowmelt. Short-term increases in lake-effect snow may continue while air temperatures are reliably below freezing, but long-term winter warming will dramatically reduce snowfall in northern Michigan.

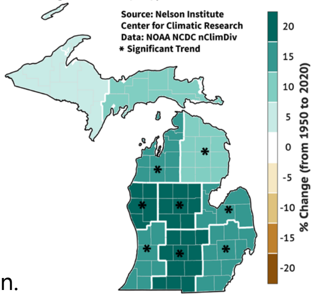

Luke Nave, NIACS

Precipitation Changes

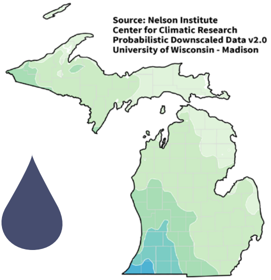
Over the past 70 years Michigan has received more annual rainfall, with the largest increases in the southern part of the state. The summer and fall have been getting drier in the Upper Peninsula, while spring and winter have been getting wetter. In the northern Lower Peninsula summer rain has remained constant while the other seasons have gotten wetter. Annual precipitation is projected to increase slightly across Michigan by the end of the century, mostly in spring and winter.

Perhaps more importantly, **a larger share of total precipitation is coming from heavy rainfall events.** Extreme precipitation events are projected to occur more frequently as climate change continues. Heavy rainfall has significant impacts on soil moisture, flooding, and erosion.

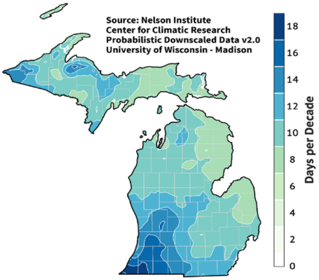
Historical Change in Annual Precipitation (%), 1950–2020



Days per Decade with Precipitation >2 inches 1981-2010 Conditions(Historical)



Days per Decade with Precipitation >2 inches 2061-2080 Conditions (RCP8.5)



Changing Hydrology

Intense rainstorms are happening much more frequently in recent decades, and this trend is occurring across the entire Midwest and Northeastern U.S. **Flooding and erosion from heavy rainfall have severe consequences for ecosystems, infrastructure, and local communities. Flooding frequency is likely to increase under climate change.** These events also disrupt and delay forest management operations.

Shorter, milder winters also shift the timing of snowmelt, runoff, and peak streamflow earlier in the year. Peak flow amounts in winter and spring could more than double by the end of the century, depending on ground conditions, timing, and amount of rainfall.


Michigan.gov

Soil Moisture and Drought Stress

Droughts are major stressors on forests, and they can make trees more vulnerable to insect outbreaks and other impacts. Northern Michigan has received slightly more annual rainfall in recent decades, but drought conditions can still occur when increases in snowfall are offset by earlier snowmelt and decreased summer precipitation. Elevated carbon dioxide in the atmosphere may help some tree species withstand short-term drought stress.

A handful of trends may cause drought stress to increase in the future:

- Warmer temperatures will increase evaporative demand on trees and soil (vapor pressure deficit).
- More water will be lost with longer growing seasons.
- Warmer winters will reduce snowpack and accelerate snowmelt, so water release in the spring will be less gradual.
- More water will be lost to runoff during intense rain events rather than being stored in the soil, and there may be longer dry periods between rains.

Even if total rainfall increases, these factors may lead to net drier conditions for Michigan's forests.

Joseph O'Brien, USFS

Wildfire and Prescribed Fire

Wildfire is an important natural and cultural disturbance for some forests in northern Michigan. The area's fire regime may be affected by changes in climate, such as growing season length, snowmelt dates, and evapotranspiration. **Fire models tend to agree that wildfires are expected to be more frequent and burn more acres by the end of the century, particularly in boreal forests and temperate conifer forests.** More wildfire could be beneficial for some forest types in the area, such as jack pine or barrens.

Fire suppression policies and land conversion have limited the influence of wildfire, so land managers now use prescribed fire as a tool. It's uncertain how climate change will affect prescribed fire application. Warmer, drier conditions may lengthen the window of opportunity for burning. Conversely, widespread tree mortality, wetter conditions, or decreased risk tolerance could limit prescribed fire implementation. Because prescribed fire depends on advance planning and staff availability, erratic conditions will be a serious challenge.


Huron-Manistee National Forest

Invasive Plants

Invasive species are already a major threat to some forests in northern Michigan. We don't have a great understanding of the ecology of many invasive species. **It is generally expected that invasive plants will "disproportionally benefit" under climate change, because they readily track environmental changes (e.g., longer growing seasons) and rapidly colonize disturbed areas.** Woody invasive species and vines (e.g., honeysuckle) may also benefit from elevated carbon dioxide in the atmosphere.

Northern Michigan may lose some of the protection offered by a traditionally cold climate and short growing season. Japanese barberry, buckthorn, non-native earthworms, garlic mustard, and reed canary grass may benefit from ongoing climate change, and other invasive species may emerge in the years ahead.

Forest Pests and Diseases

Unfortunately, we lack basic information on the climatic thresholds for many forest pests, and we can't predict the pathways of infection, dispersal, and transmission for diseases. **Based on our current knowledge, we assume that forest pests and diseases may be more damaging in Michigan's forests under climate change.** Forest pests and diseases are generally more damaging in stressed forests, so there is high potential for interactions with other climate change impacts. For example, drought stress can weaken a tree's defenses to natural pest outbreaks, while pests such as hemlock woolly adelgid could expand their ranges northward under future climate scenarios.

Additionally, we expect longer growing seasons could allow some insects to complete multiple life cycles. These factors can allow populations to grow rapidly. Furthermore, new pests or pathogens will likely enter northern Michigan during the 21st century.


Wisconsin Department of Natural Resources (CC BY-ND 2.0)

Deer Browse Damage

Climate change is expected to favor white-tailed deer. Warmer winters and reduced snow depth lower energy requirements for deer and increase access to forage during winter. Milder winters reduce the need for deer to yard up in sheltered areas.

As deer benefit from climate change over the 21st century, they could have even greater impacts on forests across Michigan. Deer browsing pressure may limit the ability of forests to respond to climate change, because species anticipated to gain suitable habitat in northern Michigan, such as sugar maple, white oak, and northern red oak, are browsed so heavily. Deer herbivory may also favor species which are not browsed heavily, such as ironwood and black cherry, or invasive species like buckthorn or Japanese barberry.


Ryan Pennesi, USDA Forest Service

CLIMATE CHANGE VULNERABILITY

Vulnerability is the susceptibility of a system to adverse effects from climate change. Vulnerability depends on the potential impacts of climate change on a system, as well as the ability of the system to tolerate those impacts without undergoing significant change (adaptive capacity). A forest could be considered to be vulnerable if it is at risk of significant composition change or substantial declines in health or productivity.

You can consider regional climate change information and use your expertise to identify how your specific project area or property may be vulnerable to climate change. The Site-Level Considerations pages in this field guide can help (p. 39, 43, 47, etc.).

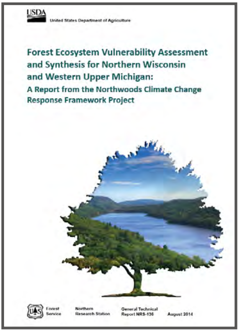
Factors that could influence climate change risk for a specific location include:

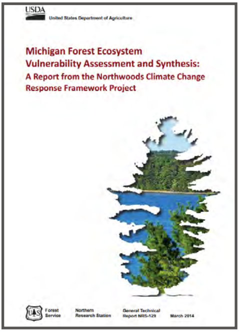
- Soils and topographic position
- Species diversity, age class diversity, and density
- Management history
- Presence of or susceptibility to pests, disease, or non-native species
- The local rate or magnitude of climate change

Climate Change Vulnerability Assessments

Much of the information in this guide was drawn from two Forest Ecosystem Vulnerability Assessments produced by NIACS—one for northern Wisconsin and Michigan's western Upper Peninsula, and a separate one for Michigan's eastern Upper Peninsula and northern Lower Peninsula (fs.usda.gov/treesearch/pubs/46393 and fs.usda.gov/treesearch/pubs/45688). These reports were a collaborative effort among dozens of authors from academia; forest industry; conservation groups; and federal, state, and tribal agencies. Published in 2014, the assessments brought together the best available information on climate change from published research, ecosystem models, and manager expertise to draw conclusions about major risks and vulnerabilities for forests through the end of the century.

The authors of this guide re-examined the original vulnerability assessments as well as updated tree species model results (p. 18–35) to confirm that the conclusions are still appropriate. The field guide authors represent a diversity of organizations and perspectives.





TREE SPECIES PROJECTIONS

This section shows future projections of suitable habitat for tree species in northern Michigan by the end of the century. These results are from the Climate Change Tree Atlas model, using two climate scenarios to "bracket" a range of plausible futures (Low = Representative Concentration Pathway 4.5, High = RCP 8.5). You will find tree species information organized by Ecological Section (see following page), which provides a detailed picture of how tree species are projected to fare in different parts of the state. To conserve space, we are showing results only for 43 species in each Ecological Section. Learn more about the Tree Atlas and get complete results at: fs.usda.gov/nrs/atlas/.

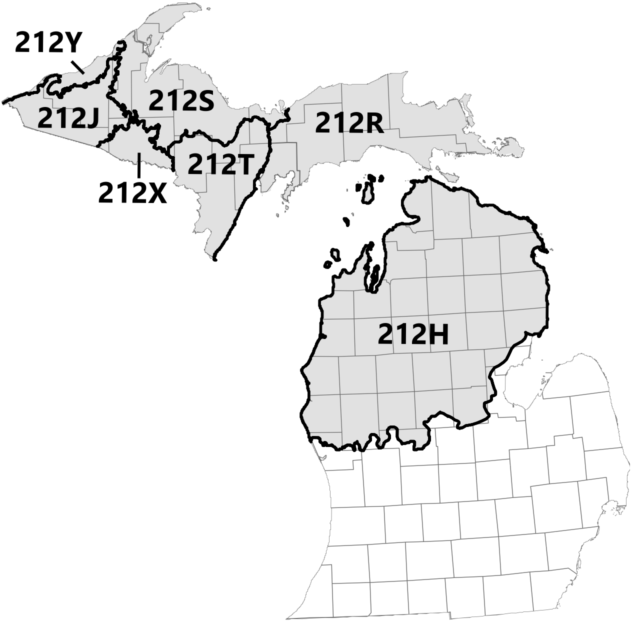
Remember that models are just tools, and they're not perfect. Models don't account for some factors that could be modified by climate change, like droughts, wildfire, and invasive species. These factors could cause a species to perform better or worse than the model projects. Management choices, such as planting species that are projected to increase, will continue to influence forest trajectories.

Despite these limits, models provide useful information about future growing conditions. It's probably best to think of these projections as indicators of potential change and direction.

For more tree species projections visit:
forestadaptation.org/northern_MI_fieldguide

Ecological Sections

In this section, you'll find Tree Atlas results for individual Ecological Sections in northern Michigan. The map below will help you determine which Ecological Section to explore.



LEGEND:

County lines

Ecological Section borders

Laurentian Mixed Forest Province (212)

Using the Tree Species Table

ADAPTABILITY

Factors not modeled, such as disturbance tolerance, may make a species more or less adaptable to future conditions.

- \+ **High:** Species may perform better than modeled
- · **Medium**
- − **Low:** Species may perform worse than modeled

SUITABLE HABITAT CHANGE CLASS

A comparison of future and current "suitable habitat" in an area. Suitable habitat is modeled on 30+ factors, such as soils, topography, and climate.

- ▲ **Increase:** Projected increase of >20% by 2100
- ● **No change:** Little change (<20%) projected by 2100
- ▼ **Decrease:** Projected decrease of >20% by 2100
- ★ **New Habitat:** Tree Atlas projects new habitat for species not currently present

CAPABILITY

A rating of a species' ability to cope or persist with climate change, based on suitable habitat change (statistical modeling), adaptability (literature review and expert opinion), and abundance (FIA data).

- △ **Good:** Increasing suitable habitat, medium or high adaptability, and common or abundant
- ○ **Fair:** Increasing suitable habitat with low adaptability, decreasing suitable habitat with high adaptability, or other mixed combinations
- ▽ **Poor:** Decreasing suitable habitat, medium or low adaptability, and uncommon or rare

212H Northern Lower Peninsula

- Great Lakes moderate the local climate close to the shore (mild temps, more precip and snow) but the inland has a more continental climate.
- Sandy glacial drift is widespread, with moraines, hills, lake plains, and dunes near the Great Lakes shoreline.

+ high	▲ increase	▼ decrease	△ good
· medium	● no change	★ new habitat	○ fair
– low	*species with low model reliability		▽ poor

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
American basswood	·	▲	△	▲	△
American beech	·	▲	△	▲	△
American elm	·	▲	△	▲	△
Balsam fir	–	▼	▽	▼	▽
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▼	○	▼	○
Bitternut hickory*	+	●	○	●	○
Black ash	–	●	▽	▼	▽
Black cherry	–	▲	△	▲	○
Black oak	·	▲	△	▲	△
Black spruce	·	▼	▽	▼	▽
Black walnut*	·	★		★	
Blackgum	+	▲	△	▲	△
Bur oak	+	●	○	●	○
Chestnut oak	+	★		★	

		LOW CHANGE		HIGH CHANGE	
Species	Adapt	Habitat Change Class	Species Capability	Habitat Change Class	Species Capability
Eastern hemlock	–	●	▽	▼	▽
Eastern redcedar	·	▲	△	▲	△
Eastern white pine	–	▼	▽	▼	▽
Green ash*	·	▲	△	▲	△
Hackberry	+	★		★	
Ironwood*	+	▼	○	▼	○
Jack pine	+	▼	○	▼	○
Northern pin oak	+	▼	○	▼	○
Northern red oak	+	●	△	●	△
Northern white-cedar	·	▼	▽	▼	▽
Paper birch	·	●	○	●	○
Post oak	+	★		★	
Quaking aspen	·	▼	○	▼	○
Red maple	+	●	△	▼	△
Red pine	–	▼	○	▼	○
Sassafras*	·	▲	△	▲	△
Serviceberry*	·	▼	▽	▼	▽
Shagbark hickory	·	▲	△	▲	△
Silver maple*	+	●	△	●	△
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	▲	○	▲	○
Sycamore*	·	★		★	
Tamarack (native)	–	●	▽	●	▽
White ash	–	●	▽	▲	▽
White oak	+	▲	△	▲	△
White spruce	·	▼	▽	▼	▽
Yellow birch	·	▲	○	▲	○
Yellow-poplar	+	★		★	

212J Southern Superior Uplands

- Lake Superior affects local climate (mild temps, more precip and snow)
- Glacial moraines, lake plains, and hillier uplands with escarpments

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low		**species with low model reliability*			▽	poor

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
American basswood	·	▲	△	▲	△
American elm	·	▲	△	▲	△
Balsam fir	–	▼	○	▼	○
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▲	△	▲	△
Bitternut hickory*	+	★		★	
Black ash	–	●	▽	●	▽
Black cherry	–	▲	△	▲	△
Black oak	·	★		★	
Black spruce	·	▼	▽	▼	▽
Black walnut*	·	★		★	
Bur oak	+	★		★	
Chestnut oak	+	★		★	
Eastern cottonwood*	·	★		★	
Eastern hemlock	–	▼	○	▼	○

Species	Adapt	LOW CHANGE		HIGH CHANGE	
		Habitat Change Class	Species Capability	Habitat Change Class	Species Capability
Eastern redcedar	·	★		★	
Eastern white pine	–	▲	△	▲	△
Hackberry	+	★		★	
Honeylocust*	+	★		★	
Ironwood*	+	▲	△	▲	△
Jack pine	+	▼	○	▼	○
Live oak	·	★		★	
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	●	○	▲	△
Paper birch	·	▲	△	▲	△
Pignut hickory	·	★		★	
Post oak	+	★		★	
Quaking aspen	·	●	△	●	△
Red maple	+	●	△	●	△
Red pine	–	▲	○	▲	○
Scarlet oak	·	★		★	
Shagbark hickory	·	★		★	
Silver maple*	+	●	○	▲	△
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	★		★	
Sycamore*	·	★		★	
Tamarack (native)	–	▲	○	▲	○
White ash	–	▲	△	▲	△
White oak	+	★		★	
White spruce	·	▼	▽	▼	▽
Yellow birch	·	▼	○	▼	○
Yellow-poplar	+	★		★	

212R Eastern Upper Peninsula

- Lake Michigan and Lake Superior affect local climate (mild temps, more precip and snow)
- Flat and rolling landscape with thick glacial drifts of sand and clay

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low		**species with low model reliability*			▽	poor

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
American basswood	·	▲	△	▲	△
American beech	·	●	○	●	○
American elm	·	▲	△	▲	△
Balsam fir	–	▼	▽	▼	▽
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▲	△	▲	△
Bitternut hickory*	+	★		★	
Black ash	–	▲	△	▲	△
Black cherry	–	▲	△	▲	△
Black oak	·	★		★	
Black spruce	·	▼	○	▼	○
Black walnut*	·	★		★	
Bur oak	+	▲	△	▲	△
Eastern cottonwood*	·	★		★	
Eastern hemlock	–	●	▽	▼	▽

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
Eastern redcedar	·	★		★	
Eastern white pine	–	▲	○	●	▽
Hackberry	+	★		★	
Honeylocust*	+	★		★	
Jack pine	+	▼	△	▼	△
Mockernut hickory	+	★		★	
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	▼	○	▼	○
Paper birch	·	●	○	▼	▽
Pignut hickory	·	★		★	
Pin oak*	–	★		★	
Post oak	+	★		★	
Quaking aspen	·	●	△	●	△
Red maple	+	●	△	●	△
Red pine	–	●	○	●	○
Scarlet oak	·	★		★	
Shagbark hickory	·	★		★	
Silver maple*	+	▲	△	▲	△
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	★		★	
Sycamore*	·	★		★	
Tamarack (native)	–	▲	○	▲	○
White ash	–	▲	▽	▲	▽
White oak	+	★		★	
White spruce	·	▼	▽	▼	▽
Yellow birch	·	●	○	●	○
Yellow-poplar	+	★		★	

212S Northern Upper Peninsula

- Lake Superior affects local climate (mild temps, more precip and snow)
- Flat glacial outwash plains with exposed bedrock knobs of basalt and granite

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low		**species with low model reliability*			▽	poor

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
American basswood	·	▲	△	▲	△
American beech	·	▲	△	▲	△
American elm	·	▲	△	▲	△
Balsam fir	–	▼	○	▼	○
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▲	△	▲	△
Bitternut hickory*	+	★		★	
Black ash	–	▲	△	▲	△
Black cherry	–	▲	△	▲	△
Black oak	·	★		★	
Black spruce	·	▼	▽	▼	▽
Black walnut*	·	★		★	
Bur oak	+	★		★	
Chestnut oak	+	★		★	
Eastern cottonwood	·	★		★	

		LOW CHANGE		HIGH CHANGE	
Species	Adapt	Habitat Change Class	Species Capability	Habitat Change Class	Species Capability
Eastern hemlock	–	●	▽	●	▽
Eastern redcedar	·	★		★	
Eastern white pine	–	▲	△	▲	△
Ironwood*	+	▲	△	▲	△
Jack pine	+	▼	○	▼	○
Mockernut hickory	+	★		★	
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	●	△	●	△
Paper birch	·	▲	△	▲	○
Pignut hickory	·	★		★	
Post oak	+	★		★	
Quaking aspen	·	▲	△	▲	△
Red maple	+	●	△	●	△
Red pine	–	▲	○	▲	○
Scarlet oak	·	★		★	
Shagbark hickory	·	★		★	
Silver maple*	+	▲	△	▲	△
Striped maple	·	▼	▽	▼	▽
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	★		★	
Sycamore*	·	★		★	
Tamarack (native)	–	▲	△	▲	○
White ash	–	▲	○	▲	○
White oak	+	★		★	
White spruce	·	▼	▽	▼	▽
Yellow birch	·	▼	▽	▼	▽
Yellow-poplar	+	★		★	

212T Northern Green Bay Lobe

- Lake Michigan affects local climate (mild temps, more precip and snow)
- Ground moraines and areas of lake plains, sand dunes, glacial outwash to the west

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low		**species with low model reliability*			▽	poor

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
American basswood	·	▲	△	▲	△
American beech	·	▲	△	▲	△
American elm	·	▲	△	▲	△
Balsam fir	–	▼	▽	▼	▽
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▲	△		△
Bitternut hickory*	+	★		★	
Black ash	–	●	▽	●	▽
Black cherry	–	▲	△	▲	△
Black oak	·	★		★	
Black spruce	·	▼	▽	▼	▽
Black walnut*	·	★		★	
Blackgum	+	★		★	
Bur oak	+	▲	△	▲	△
Eastern cottonwood*	·	★		★	

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
Eastern hemlock	–	▼	▽	▼	▽
Eastern redcedar	·	★		★	
Eastern white pine	–	▲	○	▲	○
Green ash*	·	▲	△	▲	△
Ironwood*	+	▲	△	▲	△
Jack pine	+	▼	○	▼	○
Mockernut hickory	+	★		★	
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	▼	○	▼	○
Paper birch	·	▲	△	▲	△
Post oak	+	★		★	
Quaking aspen	·	●	△	●	△
Red maple	+	▲	△	●	△
Red pine	–	▲	○	▲	○
Sassafras*	·	★		★	
Scarlet oak	·	★		★	
Shagbark hickory	·	★		★	
Silver maple*	+	▲	△	▲	△
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	★		★	
Sycamore*	·	★			
Tamarack (native)	–	▲	○	▲	○
White ash	–	▲	△	▲	△
White oak	+	★		★	
White spruce	·	▼	▽	▼	▽
Yellow birch	·	●	○	▲	△
Yellow-poplar	+	★		★	

212X Northern Highlands

- Glacial outwash plain, end and ground moraines, and smaller areas of hilly terrain
- Kettle lakes and depressions common in the north

+ high	▲ increase	▼ decrease	△ good
· medium	● no change	★ new habitat	○ fair
– low	*species with low model reliability		▽ poor

		LOW CHANGE		HIGH CHANGE	
Species	Adapt	Habitat Change Class	Species Capability	Habitat Change Class	Species Capability
American basswood	·	▲	△	▲	△
American beech	·	★		★	
American elm	·	▲	△	▲	△
American hornbeam*	·	★		★	
Balsam fir	–	▼	▽	▼	▽
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▲	△	▲	△
Black ash	–	▲	△	▲	△
Black cherry	–	▲	○	▲	△
Black oak	·	★		★	
Black spruce	·	▼	▽	▼	▽
Black walnut*	·	★		★	
Black willow*	–	★		★	
Boxelder*	+	▲	△	▲	△
Bur oak	+	▲	△	▲	△

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
Eastern cottonwood*	·	★		★	
Eastern hemlock	–	▲	○	▲	▽
Eastern redcedar	·	★		★	
Eastern white pine	–	▲	△	▲	○
Ironwood*	+	▲	△	▲	△
Jack pine	+	●	△	●	△
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	▲	△	▲	△
Paper birch	·	▲	△	▲	△
Pignut hickory	·	★		★	
Quaking aspen	·	●	△	●	△
Red maple	+	▲	△	▲	△
Red pine	–	▲	○	▲	○
Red spruce	–	★		★	
Sassafras*	·	★		★	
Scarlet oak	·	★		★	
Serviceberry*	·	▼	▽	▼	▽
Shagbark hickory	·	★		★	
Silver maple*	+	★		★	
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	●	▽	▲	○
Sycamore*	·	★		★	
Tamarack (native)	–	▲	○	▲	○
White ash	–	▲	○	▲	○
White oak	+	★		★	
White spruce	·	▼	▽	▼	▽
Yellow birch	·	▼	▽	▼	▽

212Y Southwest Lake Superior Clay Plain

- Lake Superior affects local climate (mild temps, more precip and snow)
- Level topography, clay soils and moraines

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low		**species with low model reliability*			▽	poor

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
American basswood	·	●	○	●	○
American elm	·	▲	△	▲	△
Balsam fir	–	▼	○	▼	○
Balsam poplar	·	▼	▽	▼	▽
Bigtooth aspen	·	▲	△	▲	△
Bitternut hickory*	+	★		★	
Black ash	–	●	▽	●	▽
Black cherry	–	▲	△	▲	△
Black oak	·	★		★	
Black spruce	·	●	○	●	○
Black walnut*	·	★		★	
Bur oak	+	★		★	
Chestnut oak	+	★		★	
Eastern cottonwood*	·	★		★	
Eastern hemlock	–	▼	○	▼	▽

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
Eastern redcedar	·	★		★	
Eastern white pine	–	▲	△	▲	△
Hackberry	+	★		★	
Honeylocust*	+	★		★	
Ironwood*	+	▲	△	●	△
Jack pine	+	●	○	●	○
Live oak	·	★		★	
Mockernut hickory	+	★		★	
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	▲	△	▲	△
Paper birch	·	▲	△	▲	△
Pignut hickory	·	★		★	
Post oak	+	★		★	
Quaking aspen	·	▼	○	▼	○
Red maple	+	●	△	●	△
Red pine	–	▲	○	▲	○
Shagbark hickory	·	★		★	
Silver maple*	+	▲	△	▲	△
Sugar maple	+	▼	△	▼	△
Swamp white oak*	·	★		★	
Sycamore*	·	★		★	
Tamarack (native)	–	▲	○	▲	○
White ash	–	▲	○	▲	△
White oak	+	★		★	
White spruce	·	▼	▽	▼	▽
Yellow birch	·	▼	○	▼	○
Yellow-poplar	+	★		★	

Assisted Migration Considerations

The tree species tables in this field guide include several species that are projected to have new suitable habitat in northern Michigan by the end of the century (indicated with a blue star). Though some of these species may already be present but rare, many are unlikely to naturally migrate to the state. **Intentionally planting these species outside of their current range would be considered “assisted range expansion” or “assisted species migration.”**

If climate change or other factors result in the loss of tree species, and if suitable local surrogates aren’t available to fill their ecological niche or provide other values, managers might consider planting trees from the central and southern United States. Using non-native tree species will ideally be contingent on credible evidence that the species in question is not invasive, will not create significant risks to forest health, is from appropriate provenances that are adapted to the planting site, and is consistent with your organization or agency’s guidance. New species will ideally be carefully monitored to determine how they interact with other species.

For more information on assisted migration, visit:
fs.usda.gov/ccrc/topics/assisted-migration

ASPEN-BIRCH

Community Description

Dominated by early-successional species, which require natural disturbance or management to persist.

Aspen species reproduce heavily from root suckers and can form pure stands.

Birch and other early-successional species require exposed mineral soil to regenerate from seed.

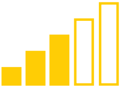
Tolerates a wide range of soil, nutrient, and moisture conditions.

Climate Change Vulnerability

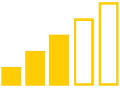
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?

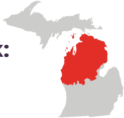


Medium evidence



Medium agreement

Geographic Risk:
Higher risk in 212H



Climate Change Impacts: Disruptive-Moderate

Drought during the growing season could cause stress and mortality on dry and poor-quality sites.

Temperatures may be beyond the physiological limits of aspen and birch by the end of the century. These species are near their southern range limits in Michigan.

Insect pests such as forest tent caterpillar and spongy moth, and diseases like hypoxylon canker, may become damaging under a warmer climate.

Deer populations are expected to increase with warmer winters and reduced snow cover, so herbivory may increase.

Adaptive Capacity: Moderate

- Increased wildfire activity or wind events could help maintain this forest type.
- Vegetative reproduction helps these species tolerate many forms of disturbance.
- These forests occur on a wide variety of soils and landforms. Stands with access to groundwater or mesic soils may be less vulnerable.
- Paper birch may be at greater risk than aspen, because paper birch is less common and faces regeneration challenges.


Maria Janowiak, USDA Forest Service

Site-level Considerations

Site-level factors could make an aspen-birch forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
Aspen or birch dominates the site and other species are absent.	**Species Diversity**	Site has a diverse mix of native tree species.
Simple structure and a single age class.	**Structural Diversity**	A diversity of age classes on the site or across the landscape.
On-going damage or looming threats such as earthworms, hypoxylon canker, or *Armillaria.*	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow.	**Access & Operability**	Can occur in seasons other than winter.
Deer, health issues, competition, or other factors may limit regeneration.	**Regeneration Potential**	Conditions are suitable for good regeneration.
Drought-prone soils or south-facing aspect.	**Drought Risk**	Mesic soils or north-facing aspect.

JACK PINE

Community Description

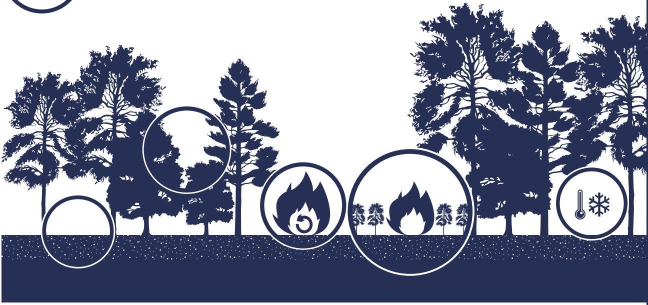
Occurs on the most drought-prone sites with low nutrient availability, typically upland landscape positions, outwash plains, and lacustrine/dune features.

Associates include eastern white pine, northern red oak, northern pin oak, aspen, and black oak.

Stand-replacing fire naturally occurs every 50-250 years for serotinous jack pine, and surface fires occur more frequently in barrens.

Jack pine stands require fire, or management practices that mimic fire, for regeneration and maintaining favorable site conditions.

Favored by cold temperatures and tolerates growing-season frost.

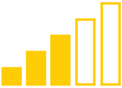


Climate Change Vulnerability

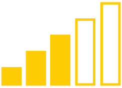
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?

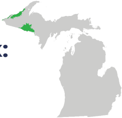


Medium evidence



Medium agreement

Geographic Risk:
Less risk in 212X, Y



Climate Change Impacts: Moderate

Some jack pine sites may become too hot or dry in the future.

A more intense or more frequent fire regime might hurt regeneration and cause these forests to shift to barrens.

Jack pine is currently at the southern extent of its range in Michigan.

Insect pests like jack pine budworm and diseases like Scleroderis and Diplodia shoot blight may become more damaging under a warmer climate.

The window of opportunity to apply prescribed fire may shift under future climate change, but it is unclear how this change would affect the ability to use fire as a management tool.

Adaptive Capacity: Moderate-high

- Established jack pine may be able to tolerate the projected decreases in soil moisture during the summer.
- Seedlings are more susceptible to drought and regeneration failure may occur more frequently.
- Mesic sites currently occupied by red pine or white pine may become more suitable for jack pine, which can persist on dry and poor soils.
- The potential for increased fire frequency or intensity under warmer and drier conditions could favor jack pine relative to other forest types.
- Low tree species diversity in this forest type provides few options if conditions shift beyond the physiological limits of jack pine.


Stephen Handler, USDA Forest Service

Site-level Considerations

Site-level factors could make a jack pine forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
Jack pine dominates the site and other species are absent.	**Species Diversity**	Red and white pines, or other fire and drought-tolerant tree species, are present.
Simple structure and a single age class.	**Structural Diversity**	A diversity of age classes on the site or across the landscape.
On-going damage or looming threats such as jack pine budworm or *Armillaria.*	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Regeneration limited by unsuitable seedbed conditions or competition.	**Natural Regeneration Potential**	Conditions are suitable for good regeneration.
Hazardous fuels or ladder fuels create extreme or elevated fire risk.	**Wildfire Risk**	Fuel loads are within acceptable levels.
Site is small and isolated, surrounded by agricultural or developed land.	**Size & Connectivity**	Site is part of a large complex of dry forests, barrens, and wetlands.
Deer, health issues, or competition may limit planting success.	**Planting Success**	Planting is likely to be successful.
Landscape context, stand size, and lack of fuels or firebreaks limit the use of prescribed fire.	**Prescribed Fire**	Site is well-suited for prescribed fire. Has been managed with prescribed fire in the past.

LOWLAND CONIFERS

Community Description

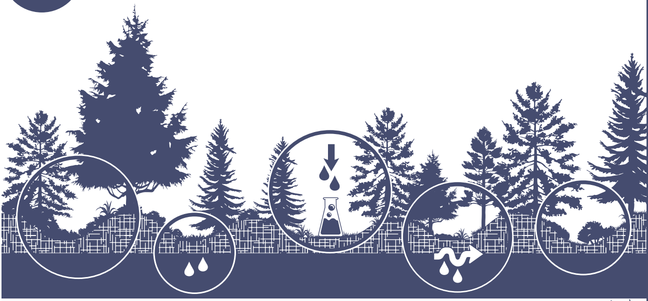
Conifer-dominated wetlands on peat, mineral soil, or poorly drained outwash channels.

Low, poorly drained landscape positions that are moist or saturated throughout the growing season.

Systems that are strictly precipitation fed are nutrient-poor and very acidic. These sites favor black spruce and tamarack.

Systems that are fed by groundwater have higher nutrient availability and may be acidic or alkaline. These sites may contain a more diverse mix of trees including eastern white pine and northern white-cedar.

Microtopography is undulating with hummocks and tip-up mounds from wind events.

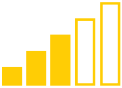


Climate Change Vulnerability

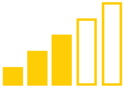
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-High

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?



Medium evidence



Medium agreement

Geographic Risk:
Higher risk in 212H

Climate Change Impacts: Negative

Hydrologic conditions could change in a variety of ways, through flood, drought, precipitation, or groundwater input.

Longer, warmer growing seasons could cause peat to dry and decompose.

Stand-replacing fire may become more frequent if sites become particularly dry.

Droughts may promote more frequent outbreaks of pests like tamarack sawfly and spruce budworm, which would increase fire risk.

Warmer winters and reduced snow cover may increase deer populations. Herbivory may increase for preferred species such as northern white-cedar.

Dominant tree species are projected to lose suitable habitat, and many are near their southern range limits in Michigan.

Adaptive Capacity: Low-Moderate

- Sites that are connected to groundwater may be buffered from short-term droughts.
- Low-lying areas on the landscape may remain cooler than surrounding uplands.
- Increased winter and spring precipitation could be retained in low-lying areas on the landscape and compensate for summer droughts.
- Acidic or alkaline soil conditions may make these areas less susceptible to invasive species or competing forest types.
- These forests are unlikely to expand to new territory or outcompete other forest types.
- Water table changes may be more likely where roads, drainage ditches, or beaver dams have altered local hydrology.

Site-level Considerations

Site-level factors could make a lowland conifer forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
Only a few species dominate the site.	**Species Diversity**	Site has a diverse mix of native tree species.
Simple structure and a single age class.	**Structural Diversity**	A diversity of age classes on the site or across the landscape.
Damage from forest pests or diseases such as eastern larch beetle, hemlock woolly adelgid, or mistletoe.	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow.	**Access & Operability**	Can occur in seasons other than winter.
Regeneration limited by deer or non-native species.	**Regeneration Potential**	Tree regeneration is not limited; conditions are suitable for good regeneration.
Ditches, roads, dams, or other changes have altered local hydrology.	**Natural Hydrology**	Natural hydrology has been maintained.
Small site that relies on precipitation inputs, prone to extreme water table changes.	**Water Table Fluctuations**	Large wetland with groundwater inputs and a stable water table.

LOWLAND-RIPARIAN HARDWOODS

Community Description

Occurs on wet mineral soils, alluvial soils, organic muck, or locations with clay layers that restrict drainage.

Seasonally or annually saturated, but typically dries out in the summer.

Tip-up mounds, hummocks, and nurse logs provide locations for tree establishment.

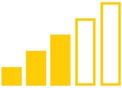
Species composition, dominance, and community structure vary regionally according to soils as well as flooding frequency and duration.

Climate Change Vulnerability

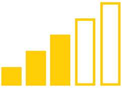
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-High

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?

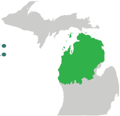


Medium evidence



Medium agreement

Geographic Risk:
Less risk in 212H



Climate Change Impacts: Negative

Emerald ash borer will severely reduce or eliminate ash species in most stands. Spongy moth and other forest pests may also be more damaging in climate-stressed forests.

Changes in hydrology could impair regeneration because the regeneration requirements of several tree species are linked to annual and seasonal water table fluxes.

Invasive species such as reed canary grass, Japanese barberry, and buckthorn may become more abundant under climate change.

Deer populations are expected to increase with warmer winters, which may hinder regeneration of preferred browse species.

More intense and variable precipitation events could cause waterlogging or prolonged droughts.

Adaptive Capacity: Low-Moderate

- Many species in this forest system can withstand intermittent flooding and drought, so they might be capable of tolerating some hydrologic changes.
- Increased winter and spring precipitation could be retained in low-lying areas on the landscape and compensate for summer droughts.
- Groundwater-fed systems may also have some additional resilience where cooler, wetter soil conditions are maintained over time.
- These forests are relatively diverse with tree species occupying a range of microsites, so there are many options as conditions change.
- Stands occupied by invasive species will be more likely to lose forest cover after EAB invasion.


Joshua Cohen, MNFI

Site-level Considerations

Site-level factors could make a lowland-riparian hardwoods stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
One or two species dominate the site.	**Species Diversity**	Site has a diverse mix of native tree species.
A single age class or simple topography.	**Structural Diversity**	A diversity of age classes or microsites from tip-up mounds and hummocks.
On-going ash decline or emerald ash borer in the area.	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow for harvest; difficult to access for restoration actions.	**Access & Operability**	Can occur in seasons other than winter, accessible for restoration actions.
Regeneration limited by deer or understory competition from native or non-native species.	**Regeneration Potential**	Tree regeneration is not limited; conditions are suitable for good regeneration.
Site is small and isolated, disconnected from the rest of the riparian corridor.	**Size & Connectivity**	Site is part of a long, connected riparian corridor.
Ditches, roads, dams, or floodplain alterations have affected local hydrology.	**Natural Hydrology**	Natural hydrology has been maintained.
Site is small and isolated, prone to extreme water table changes.	**Water Table Fluctuations**	Site is part of a large lowland complex, so water table changes may be buffered.

NORTHERN HARDWOODS

Community Description

Occurs on a wide variety of soils, most typically loamy sand to sandy loam and occasionally on sand, loam and clay.

Occurs on moist sites or dry-mesic sites where fire has been excluded for an extended period of time. Absence of fire may allow other forests to convert to this type.

Stand-replacing windthrow return interval is 400 years or longer, but small to medium wind disturbances are common.

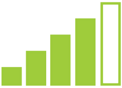
These forests develop dense, continuous canopies of shade-tolerant trees, such as sugar maple, and shade-tolerant understory plants. Can include shade-tolerant conifers such as eastern white pine and eastern hemlock.

Climate Change Vulnerability

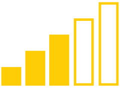
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?

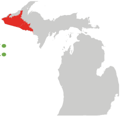


Medium-high evidence



Medium agreement

Geographic Risk:
More risk in 212J, X



Climate Change Impacts: Disruptive-Moderate

Droughts could increase stress in northern hardwood forests, and raise the risk of pests, diseases, and wildfire.

Increases in extreme weather events may lead to more frequent or widespread windthrow, which could favor more shade-intolerant species.

Reduced snow cover and more frequent freeze-thaw events could exacerbate ongoing hardwood decline.

Forest tent caterpillar and other pests may cause more damage in climate-stressed forests. New pests such as hemlock woolly adelgid and Asian longhorned beetle may be able to persist if introduced.

Deer populations will likely increase with warmer winters, which may limit regeneration of hardwood species.

Adaptive Capacity: Moderate-High

- Northern hardwood forests occur across a variety of soils and landforms and can contain many species, so there are many options for this system to persist.
- These forests could gain territory lost by other forest types under either wetter or drier future conditions.
- North-facing slopes and other localized areas may be buffered from change.
- Stands with low species and structural diversity may have lower adaptive capacity.


Joshua Cohen, MNFI

Site-level Considerations

Site-level factors could make a northern hardwoods forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
One or two species dominate the site.	**Species Diversity**	Site has a diverse mix of native tree species.
Simple structure and a single age class.	**Structural Diversity**	Diverse age classes and a complex structure.
On-going damage or looming threats.	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow.	**Access & Operability**	Can occur in seasons other than winter.
Regeneration limited by deer, earthworm damage, or competition from native or non-native species.	**Regeneration Potential**	Tree regeneration is not limited; conditions are suitable for good regeneration.
Drought-prone soils, high stocking level, south-facing aspect, or extensive earthworm damage.	**Drought Risk**	Mesic soils, moderate stocking, north-facing aspect, or minimal earthworm damage.

OAK

Community Description

Occurs on a range of soil types from sandy to disturbed mesic soils.

Mesic or high-site oak stands include northern red oak, bur oak, and white oak.

Requires disturbance to limit competition and provide suitable conditions for regeneration.

Tolerant of drought and episodic, unpredictable nutrient availability.

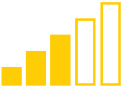
Limited by cold temperatures and growing-season frost.

Climate Change Vulnerability

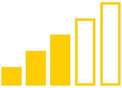
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Low-Moderate

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?



Medium evidence



Medium agreement

Geographic Risk:
Higher risk in 212H, T, X

Climate Change Impacts: Moderate

Fire suppression is allowing mesic species like red maple to invade these stands; a continued lack of fire may promote maple-dominated forests.

Excessive fire may encourage a shift from oak forests to pine forests and barrens.

Asian longhorned beetle, two-lined chestnut borer, and other insect pests may cause more frequent and severe damage under climate change.

Stressed forests may be more susceptible to oak wilt and oak decline.

Earlier spring warming may increase the risk of late spring frost damage on oak seedlings.

White-tailed deer populations may increase with warmer winters, further limiting regeneration and reducing the potential for oak forests to expand.

Adaptive Capacity: Moderate-High

- Oak-dominated forests are relatively drought tolerant and more drought stress might reduce competition from mesic species.
- Oak species are near their northern range limits in Michigan, so warming may allow them to expand into previously unsuitable areas.
- High species and genetic diversity of oak forests provides for many possible future trajectories.
- Oak forests could gain territory lost by other forest types under drier future conditions.
- Sites managed with prescribed fire will be in a better position to tolerate future climate stress.


USDA Forest Service Photo

Site-level Considerations

Site-level factors could make an oak forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
One or two species dominate the site.	**Species Diversity**	Site has a diverse mix of native tree species.
Simple structure and a single, old age class.	**Structural Diversity**	Diverse age classes and complex structure on the site or across the landscape.
Damage from forest pests or diseases such as forest tent caterpillar or oak wilt.	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow.	**Access & Operability**	Can occur in seasons other than winter.
Regeneration limited by deer, poor seedbed conditions, mesic species encroachment, or non-native species such as garlic mustard.	**Regeneration Potential**	Conditions are suitable for good oak regeneration.
Landscape context, stand size, and lack of fuels or firebreaks limit the use of prescribed fire.	**Prescribed Fire**	Site is well-suited for prescribed fire. Has been managed with prescribed fire in the past.

PINE AND OAK BARRENS

Community Description

Occurs on excessively drained and drought-prone coarse-textured soils in sandy glacial outwash and sandy glacial lakeplains.

Barrens depend on fire to limit competition and provide suitable conditions for barren understory species, with typical return intervals from 1 to 50 years.

Canopy cover is typically 5-25%; species composition and community structure vary with fire frequency and intensity.

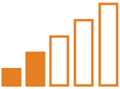
Intermittent canopy promotes frost pockets and large high/low temperature swings.

Climate Change Vulnerability

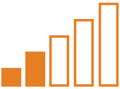
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Low-Moderate

Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?

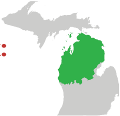


Limited-Medium evidence



Limited-Medium agreement

Geographic Risk:
Lower risk in 212H



Climate Change Impacts: Moderate-Supportive

Jack pine is near the southern edge of its range in Michigan and expected to experience declining suitable habitat over the next century.

Warmer conditions and more fire may tend to favor oaks and a conversion to oak barrens.

Forest pests and diseases may be more damaging under climate change.

Non-native species may benefit from longer growing seasons.

Shifting conditions may make applying prescribed fire more difficult in this community using conventional approaches.

Adaptive Capacity: Moderate-High

- Species in this community can tolerate drought and extreme heat.
- Sites that have been managed with fire more recently may be more adaptable.
- Sites that occur within a large matrix of forest may be better positioned for species to shift across the landscape as conditions change.
- Increasing drought risk may slow or reduce the risk of mesic species encroachment in barrens.


Chris Hoving, Michigan DNR

Site-level Considerations

Site-level factors could make a pine and oak barrens stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
Low native plant diversity, or dominated by invasive species.	**Shrub & Ground Flora Composition**	Mostly free of invasive species, with a diverse native ground layer.
Mesic species are encroaching. Canopy cover > 60%.	**Overstory Composition & Structure**	Barrens species dominate and are healthy. Trees are scattered or clumped.
Widespread mortality from forest pests or diseases such as forest tent caterpillar or oak wilt.	**Pests & Diseases**	Stand is vigorous and healthy, or mortality is limited to pockets within the barrens.
Site is small and isolated, surrounded by agricultural or developed land.	**Size & Connectivity**	Site is part of a large complex of dry forests, barrens, and grassland.
Landscape context, stand size, and lack of fuels or firebreaks limit the use of prescribed fire.	**Prescribed Fire**	Site is well-suited for prescribed fire. Has been managed with prescribed fire in the past.

RED PINE

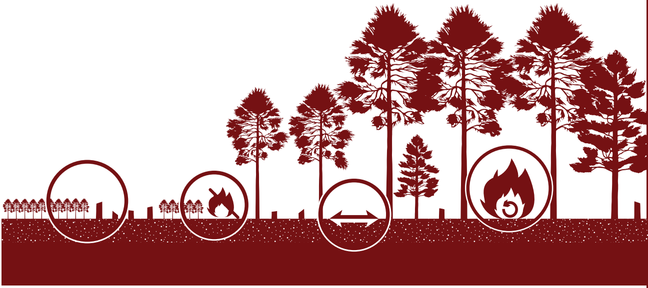
Community Description

Most red pine stands in northern Michigan are single-species plantations, with seedlings planted after canopy removal or in large gaps.

Red pine is shade-intolerant and has difficulty regenerating naturally in the absence of fire.

Occurs naturally on sites with a range of soil types – coarse-textured or shallow soils over bedrock, and also mesic soils. Eastern white pine is a common associate on dry to dry-mesic sites.

Historical fire return intervals were 50 to 250+ years, with more frequent surface fires.

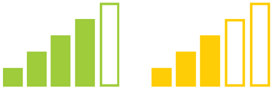


Climate Change Vulnerability

Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-High

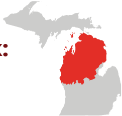
Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?



Medium-High evidence

Medium agreement

Geographic Risk:
Higher risk in 212H



Climate Change Impacts: Disruptive-Moderate

Drier summers or droughts may reduce survival of planted seedlings.

Diseases and insect pests may become more damaging under warmer conditions, especially in dense, overstocked stands.

Deer populations are anticipated to increase with warmer winters, increasing herbivory.

Moisture stress could favor jack pine or northern pin oak on dry red pine sites.

Ongoing fire suppression benefits red maple, black cherry, and other hardwoods species projected to increase under climate change.

Adaptive Capacity: Low-Moderate

- Red pine tolerates drought relatively well, particularly mature trees.
- Increased frequency of surface fires could be positive for this forest type.
- Red pine forests could expand to new favorable locations with increased drying, such as marginal aspen-birch, oak, or northern hardwood sites.
- Low structural and species diversity reduces options for red pine stands to respond to changing conditions.
- Red pine has low genetic diversity as a species, so there is limited ability to favor particular genotypes or for the species to evolve greater tolerance for future conditions.
- This cover type relies on artificial regeneration, which is a risk if seedling establishment becomes more challenging.


Huron-Manistee National Forest

Site-level Considerations

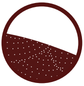
Site-level factors could make a red pine forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
Red pine dominates the site and other species are absent.	**Species Diversity**	Site has a diverse mix of native tree species.
Simple structure and a single age class.	**Structural Diversity**	Past management has yielded a diversity of age classes on the site or across the landscape.
On-going damage or looming threats such as shoot blight or *Heterobasidion* root disease.	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow.	**Access & Operability**	Can occur in seasons other than winter.
Drought-prone soils, south-facing aspect, or overstocked stand.	**Drought Risk**	Mesic soils, north-facing aspect, or moderate stocking.
Hazardous fuels or ladder fuels create extreme or elevated fire risk.	**Wildfire Risk**	Fuel loads are within acceptable levels.
Deer, health issues, or competition may limit planting success.	**Planting Success**	Conditions favor seedling survival.

UPLAND SPRUCE-FIR

Community Description

Occurs on dunes, glacial lake plains, or areas with thin soil over bedrock.



Competitive on nutrient-poor sites with sand, loamy sand, or sandy loam soils.

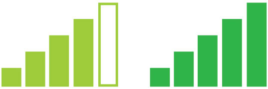
Favored in areas with high amounts of snow and short growing seasons; many associated species limited by high summer temperatures.

Adapted to frequent windthrow and infrequent catastrophic wildfire linked to periodic cycles of pest outbreaks such as spruce budworm.

Climate Change Vulnerability

Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

High



Confidence:
How much evidence is available from research and observations? Does the evidence tend to agree or conflict?

Medium-High evidence

High agreement

Geographic Risk:
Less vulnerable in the UP, more vulnerable in the LP

Climate Change Impacts: Disruptive

Several species in this system are near their southern range limits in Michigan.

Insect pests, like the native spruce budworm and the non-native balsam and hemlock woolly adelgids, may become more damaging under a warmer climate, especially where forests are already stressed.

White-tailed deer populations are anticipated to increase with warmer winters; herbivory may continue to hinder regeneration for preferred species like northern white-cedar.

Many planted upland spruce-fir forests have been affected by spruce decline and other forest health issues, which are expected to reduce their resilience to climate change impacts.

Adaptive Capacity: Low-Moderate

- Increases in stand-replacing wildfire could provide opportunities for regeneration where conditions remain suitable for the dominant species, which are prolific seeders and regenerate well after fire.
- Non-palatable boreal conifers may benefit from reduced competition if deer herbivory prevents hardwood expansion into these sites.
- Upland spruce-fir forests can persist on sandy, nutrient-poor soils and may be able to tolerate short-term moisture stress.
- These forests have relatively low diversity or contain primarily boreal species, which limits adaptability.
- This forest type will likely be confined to lake-effect zones or cold pockets on the landscape.


Joshua Cohen, MNFI

Site-level Considerations

Site-level factors could make an upland spruce-fir forest stand more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

Factors that increase climate risk	Topic	Factors that decrease climate risk
One or two species dominate the site.	**Species Diversity**	Site has a diverse mix of native tree species.
Simple structure and a single age class.	**Structural Diversity**	Diverse age classes and complex structure.
On-going damage from spruce budworm or other pests and diseases.	**Pests & Diseases**	No looming threats; stand is vigorous and healthy.
Requires frozen ground or deep snow.	**Access & Operability**	Can occur in seasons other than winter.
Drought-prone soils, south-facing aspect, or high stocking level.	**Drought Risk**	Mesic soils, north-facing aspect, or moderate stocking.
Hazardous fuels or ladder fuels create extreme or elevated fire risk.	**Wildfire Risk**	Fuel loads are within acceptable levels.
In a location prone to future warming.	**Thermal Conditions**	Located in a "frost pocket," cold-air drainage, or in a lake-effect area.

CLIMATE CHANGE ADAPTATION

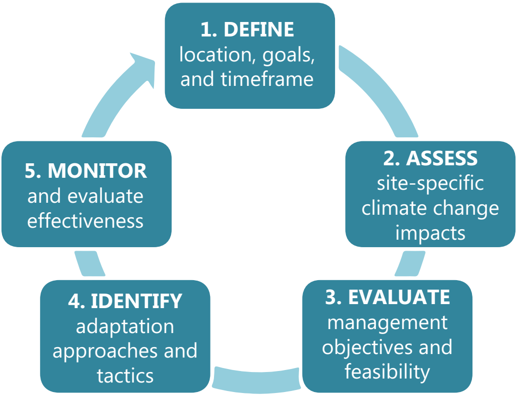
Climate change adaptation means taking action to address the effects of climate change. This is different than genetic or biological adaptation, which is how populations and species undergo genetic changes through time. The overarching purpose of climate change adaptation is to ensure ecosystem integrity and provide environmental benefits to people—in other words, to figure out how to meet your existing management goals despite changing conditions. Sustainable forest management, conservation, and restoration can all contribute to climate adaptation.

There is no "one size fits all" solution for adapting to climate change—each property presents unique conditions and each land manager will have a different set of goals and a different appetite for risk. So adaptation actions will be custom-built each time, and it will take foresters with local knowledge and experience to make informed decisions about the future!

Forest Adaptation Resources and the Adaptation Workbook

This guide includes information from *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (fs.usda.gov/treesearch/pubs/52760). The FAR provides a structured process to help land managers incorporate climate change considerations into management, called the Adaptation Workbook. There is also a "menu" of forest adaptation actions for managers to consider, which is copied on pages 76–78 of this guide. Learn more about the Adaptation Workbook at adaptationworkbook.org.

Adaptation will work best if you generate your own ideas and actions based on local site conditions and management experience. Therefore, this field guide is designed to help you make your own climate-informed decisions for forest management and conservation.



Adaptation Options

Adaptation Options are large concepts that describe the general focus or pathway that land managers might want to take. There are three basic Adaptation Options: Resistance, Resilience, and Transition.

PERSISTENCE

Resistance: Protect the system from change. Useful when trying to maintain a resource with high economic, cultural, or ecological value in the short-term.

Resilience: Enable the system to rebound to prior conditions after disturbance. Useful with systems and species that can tolerate a wide range of environmental conditions and disturbance.

CHANGE

Transition: Actively encourage change for long-term success. Useful in highly vulnerable systems or when resistance and resilience actions may be too risky or costly.

Think about how each Option might apply to your particular site and management goals. This can help you judge what kind of adaptation actions will be most appropriate for you. More than one Option may be suitable!

Forest Adaptation Menu

The Forest Adaptation Menu can help you brainstorm management tactics for your needs, and it helps connect the dots between your management actions and broader adaptation intentions. For more complete descriptions of the Adaptation Strategies and Approaches listed in the menu, see the full version of the FAR (fs.usda.gov/treesearch/pubs/52760). See NIACS adaptation menus for other topics, including watershed management, wildlife, tribal perspectives, wetlands, and more (forestadaptation.org/strategies).

The Forest Adaptation Menu contains 10 general Strategies. Within each Strategy, there are several more specific Approaches. Select Approaches that make sense for your situation, and then add relevant details in order to make them real tactics that you can implement.

Strategies and Approaches are designed to help you **bridge the gap** between big, fuzzy concepts and real management tactics.

Strategy 1: Sustain fundamental ecological functions.

Approaches:

1.1. Reduce impacts to soils and nutrient cycling.

1.2. Maintain or restore hydrology.

1.3. Maintain or restore riparian areas.

1.4. Reduce competition for moisture, nutrients, and light.

1.5. Restore or maintain fire in fire-adapted ecosystems.

Strategy 2: Reduce the impact of biological stressors.

Approaches:

2.1. Maintain or improve the ability of forests to resist pests and pathogens.

2.2. Prevent the introduction and establishment of invasive plant species and remove existing invasive species.

2.3. Manage herbivory to promote regeneration of desired species.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances.

Approaches:

3.1. Alter forest structure or composition to reduce risk or severity of wildfire.

3.2. Establish fuelbreaks to slow the spread of catastrophic fire.

3.3. Alter forest structure to reduce severity or extent of wind and ice damage.

3.4. Promptly revegetate sites after disturbance.

Strategy 4: Maintain or create refugia.

Approaches:

4.1. Prioritize and maintain unique sites.

4.2. Prioritize and maintain sensitive or at-risk species or communities.

4.3. Establish artificial reserves for at-risk and displaced species.

Strategy 5: Maintain and enhance species and structural diversity.

Approaches:

5.1. Promote diverse age classes.

5.2. Maintain and restore diversity of native species.

5.3. Retain biological legacies.

5.4. Establish reserves to maintain ecosystem diversity.

Strategy 6: Increase ecosystem redundancy across the landscape.

Approaches:

6.1. Manage habitats over a range of sites and conditions.

6.2. Expand the boundaries of reserves to increase diversity.

Strategy 7: Promote landscape connectivity.

Approaches:

7.1. Reduce landscape fragmentation.

7.2. Maintain and create habitat corridors through reforestation or restoration.

Strategy 8: Maintain and enhance genetic diversity.

Approaches:

8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range.

8.2. Favor existing genotypes that are better adapted to future conditions.

Strategy 9: Facilitate community adjustments through species transitions.

Approaches:

9.1. Favor or restore native species that are expected to be adapted to future conditions.

9.2. Establish or encourage new mixes of native species.

9.3. Guide changes in species composition at early stages of stand development.

9.4. Protect future-adapted seedlings and saplings.

9.5. Disfavor species that are distinctly maladapted.

9.6. Manage for species and genotypes with wide moisture and temperature tolerances.

9.7. Introduce species that are expected to be adapted to future conditions.

9.8. Move at-risk species to locations that are expected to provide habitat.

Strategy 10: Realign ecosystems after disturbance.

Approaches:

10.1. Promptly revegetate sites after disturbance.

10.2. Allow for areas of natural regeneration to test for future-adapted species.

10.3. Realign significantly disrupted ecosystems to meet expected future conditions.

Site-Level Considerations and Climate Change Risks

Within a given forest type, individual stands may be more vulnerable to climate change because of site-level factors such as soils, topography, species diversity, management history, and forest health threats. The authors of this guide identified some of the most critical topics that may influence climate change risk for each forest type, as well as descriptions of potential "low risk" and "high risk" conditions. The Site-Level Considerations pages contain this information for each forest type (p. 39, 43, 47, etc.)

The table on the following pages shows site-level considerations for all nine forest types included in this guide. Considerations are listed in the first column, and the shaded dots for each forest type indicate the topics the authors felt would most influence a stand's climate change vulnerability. This gives an overall sense of risk factors that might be common across multiple forest types.

After the table, you'll find summary pages for each site-level consideration, with example adaptation actions to address the high-risk conditions in different forest types. Use these ideas as a starting point for your own brainstorming, and review the Forest Adaptation Menu (p. 75) for more ideas.

Site-Level Considerations by Forest Type Table

Risk Factors	Aspen-Birch	Jack Pine	Lowland Conifer	Lowland-Riparian Hardwoods
Species Diversity	●	●	●	●
Structural Diversity	●	●	●	●
Pests & Diseases	●	●	●	●
Access & Operability	●		●	●
Regeneration Potential	●	●	●	●
Drought Risk	●			
Wildfire Risk		●		
Size & Connectivity		●		●
Planting Success		●		
Thermal Conditions				
Prescribed Fire		●		
Natural Hydrology			●	●
Water Table Fluctuation			●	●

Site-Level Considerations by Forest Type Table (cont.)

Risk Factors	Northern Hardwoods	Oak	Pine & Oak Barrens	Red Pine	Upland Spruce-Fir
Species Diversity	●	●	●*	●	●
Structural Diversity	●	●	●*	●	●
Pests & Diseases	●	●	●	●	●
Access & Operability	●	●		●	●
Regeneration Potential	●	●			
Drought Risk	●			●	●
Wildfire Risk				●	●
Size & Connectivity			●		
Planting Success				●	
Thermal Conditions					●
Prescribed Fire		●	●		
Natural Hydrology					
Water Table Fluctuation					

*This topic is represented within Pine and Oak Barrens but is labeled differently. See the Site-Level Considerations page for this forest type for more detail.

Species Diversity: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (low species diversity). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Aspen-Birch	• Retain non-aspen species during a clearcut or coppice cut. (5.2) • Plant climate-adaptable seedlings, such as white pine, in any gaps and periodically thin around seedlings to reduce competition. (5.2/9.1)
Jack Pine	• Interplant shrubs and trees appropriate for the site, such as red pine, northern pin oak, and black oak. (5.2/9.1/9.7) • Retain aspen, oak, and other suitable associates in jack pine stands. (5.2)
Oak	• Implement expanding gaps in the stand through time, with gaps making up 30-40% of the stand area. Thin between gaps to encourage additional species. (5.2)
Red Pine	• Retain other species (white pine, oaks, aspen, black cherry, etc.) during thinning operations. (5.2) • Supplemental planting of climate-adapted species in any openings or gaps, such as white pine, oaks, or bitternut hickory. (9.1)
Upland Spruce-Fir	• Remove balsam fir to thin the stand and create suitable light conditions for white pine regeneration. Create larger openings around existing mature white pine. (9.1/9.2/9.7)

Structural Diversity: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (low structural diversity). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Aspen-Birch	• Reserve a portion of the stand (e.g., 20%) in uncut patches during a harvest. (5.1/5.4) • Manage for multiple age classes across the landscape. (5.1)
Lowland Conifer	• Break up the stand structure with strip cutting, thinning, or seed tree treatments. (5.1)
Northern Hardwoods	• Create openings of varying sizes. (5.1) • Adhere to Q-factor rules for managing an uneven-aged stand, with a target trees per acre for each diameter class. (5.1)
Oak	• Create canopy gaps and use high-density oak plantings or deer exclosures to establish regeneration in openings. (2.3/5.1) • Use intermediate treatments, such as crown thinning, to encourage diversity, vigor, and seed production of target species. (9.1/9.3)
Red Pine	• Conduct variable-density thinning to create areas of high and low stocking, as well as gaps. (5.1)

Pests & Diseases: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (pest and disease damage). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Jack Pine	• Remove trees over 50 years old, maintain a basal area between 70-110 ft^2/acre, and break up large homogeneous stands if jack pine budworm is a looming risk. (2.1/9.5)
Lowland Conifer	• Conduct a sanitation cut with releases of spruce and fir species in a homogenous tamarack stand. Follow up with underplanting or seeding in canopy openings to introduce additional species. (2.1/9.1)
Lowland-Riparian Hardwoods	• Proactively underplant threatened ash with a variety of future-adapted shrub and tree species, such as red maple, silver maple, swamp white oak, and disease-resistant American elm. (2.1/9.2/10.1)
Oak	• Manage for a mix of red and white oak species to lessen the potential impact of oak wilt. (2.1/5.2) • Avoid harvesting or damaging oaks from March through October to be cautious about spreading oak wilt during milder shoulder seasons. (2.1) • Where oak stands are declining, regenerate the stand and establish a younger cohort of oak species. (2.1/5.1)
Red Pine	• Treat cut stumps with fungicide if cut from March through December if HRD occurs in the region. (2.1) • If shoot blights are present, avoid retaining overstory red pine and promote a diversity of species when regenerating stands. (2.1)

Access & Operability: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (sensitive or wet soils). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Upland Sites: Aspen-Birch; Northern Hardwoods; Oak	• Harvest during summer dry conditions if access is feasible. (1.1) • Upgrade access roads, use slash mats for travel in the woods, and use portable bridges to facilitate access. (1.1/1.2) • Be prepared to forego harvesting during winters where ground conditions do not allow access. (1.1) • Consider cost-efficient management tools such as non-commercial treatment or prescribed fire on sites with poor access for equipment. (1.5)
Lowland Sites: Lowland Conifer; Lowland-Riparian Hardwoods	• Consider removing stand from management if it is no longer possible to access stand in a sustainable manner. (1.2/6.2) • Harvest in dry conditions using high-floatation equipment or cable winches to avoid severe rutting. (1.1/1.2)

Regeneration Potential: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (limited regeneration potential). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Jack Pine	• Enhance the seedbed and reduce woody competition through roller chopping, trenching, widespread scarification, or prescribed fire. (1.4/1.5/10.1)
Lowland Conifer	• Use widespread scarification to enhance the seedbed and reduce woody competition. (1.4/10.2)
Lowland-Riparian Hardwoods	• Leave large branches and tree tops on site post-management or construct slash walls to deter deer browse. (2.3) • Use larger planting stock to enhance seedling survival during intense floods. (1.3)
Northern Hardwoods	• Install small deer exclosures to assess herbivory and tree regeneration potential. (2.3) • Leave large branches and tree tops on site post-management or construct slash walls to deter deer browse. (2.3)
Oak	• Remove mesic hardwood midstory to create light levels and conditions suitable for oak regeneration. (1.4/5.2) • Encourage suitable seedbeds through chemical, mechanical, or prescribed fire site preparation. (1.4/1.5)

Drought Risk: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (drought-prone site). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Aspen-Birch	• Promote more drought-tolerant species such as bigtooth aspen or white pine through appropriate silvicultural treatments or supplemental planting. (9.1/9.7)
Northern Hardwoods	• Reduce stand density to reduce competition for moisture. (1.4) • Plant with a mix of climate-adapted species, including Central Hardwoods, if consistent with landowner objectives. (9.2) • Maintain a more closed crown structure by thinning from below, to shield the soil from sun exposure and maintain ground-layer humidity. (1.4)
Red Pine	• Thin to reduce stand density, reduce competition for water and nutrients, and maintain a mix of large and small-diameter trees in a stand. (1.4/5.1)
Upland Spruce-Fir	• Create fuelbreaks to prepare for potential fire risk. (3.2)

Wildfire Risk: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (extreme or unacceptable wildfire). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Jack Pine **Red Pine** **Upland Spruce-Fir**	• Create fuelbreaks to mitigate potential spread around wildland-urban interface corridors or other sensitive areas. (3.2) • Thin stand to remove understory ladder fuels and increase spacing between overstory crowns. (3.1) • Use prescribed fire to mitigate hazardous fuels. (1.5)

Size & Connectivity: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (isolated or fragmented site). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Jack Pine	• Consider prescribed fire as a management tool if a small timber harvest is impractical. (1.5)
Lowland-Riparian Hardwoods	• Establish native tree and shrub corridors for connectivity. (7.2) • Limit runoff of water and nutrients from adjacent lands with filter strips or other means. (1.1/1.3) • Reconnect natural floodplains and native habitats (such as floodplain forest and sedge meadow). (1.3)
Pine and Oak Barrens	• Restore adjacent lands to natural vegetation. (7.1) • Manage competition from invasive species. (2.2)

Planting Success: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (limited planting success). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Jack Pine	• Conduct aerial or targeted spraying of microbial pesticides to reduce the impacts of jack pine budworm. (2.1)
Red Pine	• Use paper bud caps to prevent deer browse damage on planted seedlings. (2.3) • Plant in the fall rather than the spring. (1.4) • Plant stock from seed sources that might have heat or drought-tolerant genotypes, informed by the Seedlot Selection Tool. (8.2/9.1)

Thermal Conditions: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (warming area).

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Upland Spruce-Fir	• Gradually introduce species that are adapted to warmer conditions, such as white pine. (9.7/10.2) • Following a natural disturbance or harvest, intentionally alter forest composition to a mix of future-adapted species. (10.1/10.3)

Prescribed Fire: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (limited potential for prescribed fire). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

<table>
<tr><th>Forest Type</th><th>Example Adaptation Actions
(Strategy/Approach # from Forest Adaptation Menu)</th></tr>
<tr><td>Jack Pine
Oak
Pine and Oak Barrens</td><td>If prescribed fire is suitable for the site and landowner goals:
• Adjust burn unit size to incorporate defensible fire breaks, capture adjacent fire-dependent communities, and increase efficiency. (1.5)
• Use silvicultural tools to enhance fire breaks. (3.2)
• Consider night-time or growing season burns to expand potential burn windows and reduce fire hazards. (1.5)
If prescribed burns are not suitable:
• Mimic fire effects with mechanical fuel removal (dozer, skidder blading of advance regeneration or forest mulching equipment. (1.4)
• Use soil scarification to expose mineral soil for regeneration, particularly for oaks. (1.4)
• Create expanding gaps to slow the introduction of shade-tolerant species. (5.1)
• Manage for a different target community or cover type. (9.2/10.3)</td></tr>
</table>

Natural Hydrology: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (disrupted hydrology). Use these ideas as a starting point for your own brainstorming and review the Forest Adaptation Menu (p. 75) for more ideas.

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Lowland Conifer **Lowland-Riparian Hardwoods**	• Repair road/stream crossings to restore hydrology, especially where culverts are preventing natural water flow. (1.2/1.3) • If an area is persistently dry due to hydrologic alteration, manage to favor species able to thrive on drier sites. (9.1/9.2) • Upgrade culverts or stream crossings to accommodate increased flows from heavy rain events. (1.2/1.3/10.3)

Water Table Fluctuation: Example Adaptation Actions

Here are some example adaptation actions to address this high-risk condition (water table change).

Forest Type	Example Adaptation Actions (Strategy/Approach # from Forest Adaptation Menu)
Lowland Conifer **Lowland-Riparian Hardwoods**	• Introduce tip-up mounds to introduce more microtopography in the stand. (4.1/6.1) • Use large woody debris or other materials to dissipate streamflow energy and enhance bank stability during large storms. (1.3) • Remove adjacent drain tile and fill ditches to restore hydrology. (1.2)

FOREST CARBON MANAGEMENT

This guide mostly covers adaptation, or helping forests cope with climate change impacts. **But forests also play a critical role in climate change mitigation, because they remove carbon dioxide from the atmosphere through photosynthesis and store carbon in soils and vegetation.**

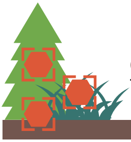
A growing number of forest managers feel it is important to maintain and enhance carbon storage and sequestration, while also boosting carbon stored in wood products and wood-based fossil fuel substitutes. Many practices to enhance forest carbon can align with other benefits, such as managing for wildlife habitat, so the decision may depend on the priorities of your organization and the characteristics of the forest in question. There are usually win-win opportunities where climate adaptation and mitigation can work together. Typically, things that keep forests healthy and prevent large-scale disturbances fulfill both goals.

NIACS has released a menu of adaptation actions for Forest Carbon Management. Like the Forest Adaptation Menu, it is organized into Strategies and Approaches and is designed to be used with the Adaptation Workbook. Review all the ideas and pick those that seem most appropriate to your situation!
See: forestadaptation.org/carbon

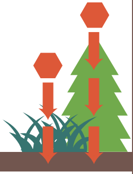
Considerations for Carbon Management

Forest soils and live tree biomass are the two largest carbon pools in Michigan's forests. Standing dead trees and down dead wood are two other substantial pools. Management can maintain carbon storage by reducing the disturbance risk for these carbon pools, or it can increase the rate of sequestration through improved forest health and productivity.

Site-level risks can help determine some of the actions you can take to manage forests for carbon value. In forests with increasing risk from climate change, carbon removal from harvest or other actions may ultimately provide long-term benefits compared to no action. For example, delaying a harvest or designating a stand as a reserve can provide significant carbon benefits. **In forests with increasing risk from climate change, carbon removal from harvest or other actions may ultimately provide long-term increases in carbon from enhanced sequestration or storage compared to no action.** Where disturbances such as fire are critical for forest health, it might actually be necessary to reduce carbon storage in the near-term in order to maintain a healthy forest that can act as a carbon sink in the future.



Carbon Storage:
The amount of carbon that is retained in a carbon pool within the forest.



Carbon Sequestration:
The process of removing carbon from the atmosphere for use in photosynthesis, resulting in the maintenance and growth of plants and trees.

Actions to Increase Carbon in Managed Stands

Soil Carbon

Under climate change, best management practices that protect soils and their large carbon stocks are more important than ever. If site conditions indicate potential risks to soils, you may opt to take additional actions to protect soils.

Topic:	Actions that increase carbon:
Soil Damage: Warmer winter conditions could lead to unreliable frozen ground in the winter, increasing the risk of rutting and compaction. **Flooding and Erosion:** Extreme rainfall could strongly affect some locations, such as a floodplain or steep, highly erodible slopes.	• Time harvest operations to match site conditions and minimize risk to stands. • Use temporary bridges at stream crossings or timber mats to limit soil impacts during wet conditions. • Limit management-related disturbance or widen buffers in areas that may be at risk of erosion, such as steep slopes, riparian zones, and wetlands. • Use mastication or biochar application to increase soil carbon on infertile or dry sites.


Todd Ontl, NIACS

Live Trees

Older forests that contain abundant large-diameter trees store substantial amounts of carbon in live biomass, while young forest stands with rapidly growing trees have a high rate of carbon sequestration. Consider risks to existing carbon stocks as well as opportunities for enhancing carbon sequestration.

Topic:	Actions that increase carbon:
Tree Health: Damage from insect pests or diseases, or looming threats from pests or diseases could reduce carbon stocks from tree mortality. **Species Diversity and Suitability:** Stands with lower species diversity than expected for the cover type, as well as stands dominated by species near the southern extent of their species range, could have greater impacts from climate stressors. **Structural Diversity:** Mature stands that contain trees that are primarily a single age or size with a simple canopy structure could be more susceptible to disturbance. **Tree Crowns and Spacing:** Trees that are too crowded and competing for growing space may be more impacted by drought.	• Retain healthy, large-diameter trees when harvesting to maintain greater carbon stocks in tree biomass. • Thin around crop trees, retaining carbon in existing healthy trees while improving the ability to sequester additional carbon through enhanced growth. • Enhance future sequestration in young forest stands through harvesting to promote a greater diversity of tree species and promote regeneration. • Plant a variety of native species expected to do well under future conditions to generate resilient sequestration capacity.

Dead Wood

Forests can store significant quantities of carbon in dead biomass, including snags and coarse woody debris that can take decades to decompose. As dead wood decomposes, nutrients are returned to soils to maintain site fertility and future tree productivity. This carbon pool may not be as susceptible to climate stressors as soils and live trees, but foresters can still consider opportunities to enhance carbon storage through accumulation of dead wood.

Topic:	Actions that increase carbon:
Standing Dead Trees and Down Dead Wood: Carbon stocks can be increased with dead wood additions in some situations. For example, foresters can identify stands with few large standing dead trees or stands without coarse woody debris, such as branches and boles.	• Identify several legacy trees per acre, such as trees in declining condition (as long as no serious diseases or pathogens are present), to retain as eventual snags. • Retain low-quality timber on site for down dead wood (e.g., chop-and-drop). • Retain slash, tree tops, and existing snags when present.


Todd Ontl, NIACS

RESOURCES AND LINKS

Michigan DNR Forestry: A central landing page for state agency information on forest management, tree planting, forest stewardship, and other topics. michigan.gov/dnr/managing-resources/forestry

Michigan State University Forest Carbon and Climate Program: A collection of professional development courses and useful resources for natural resources managers. canr.msu.edu/fccp

Climate Change Atlas: Projected suitable habitat for individual tree species under climate change. fs.usda.gov/nrs/atlas/

Climate Change Response Framework: A collection of NIACS vulnerability assessments, adaptation tools, and real-world adaptation demonstration projects. forestadaptation.org

Online Adaptation Workbook: An interactive, self-guided version of the Adaptation Workbook. adaptationworkbook.org

Climate Change Resource Center: A national-level website with topic-specific information and a library of online tools. fs.usda.gov/ccrc/

Great Lakes Silviculture Library: A collection of real-world silviculture case studies, searchable by forest type and keywords. silvlib.cfans.umn.edu/silviculture-library

ACKNOWLEDGMENTS

Authors

Stephen Handler, Northern Institute of Applied Climate Science, USDA Forest Service

Todd Bishop, Compass Land Consultants

Lauren Cooper, Michigan State University Forest Carbon and Climate Program

Julie Crick, Michigan State University Extension

Michelle Felde, Michigan Forest Products Council

Daphna Gadoth-Goodman, Michigan State University Forest Carbon and Climate Program

Jason Hartman, Michigan Department of Natural Resources

Alex Helman, The Nature Conservancy

Andy Henriksen, USDA Natural Resources Conservation Service

Trevor Hobbs, Huron-Manistee National Forest

Rexx Janowiak, Green Timber Consulting Foresters

Keith Konen, Huron-Manistee National Forest

Bill O'Brion, Lyme Great Lakes Timberland

Todd Ontl, Northern Institute of Applied Climate Science, Michigan Technological University

Matt Peters, USDA Forest Service

Georgia Peterson, Michigan State University Extension

Kailey Marcinkowski, Northern Institute of Applied Climate Science, Michigan Technological University

Kama Ross, Leelanau Conservation District (retired)

Ben Schram, Michigan Association of Conservation Districts

Authors (cont.)

Mike Smalligan, Michigan Department of Natural Resources

Mike Streiter, Ottawa National Forest

Carol Young, Huron-Manistee National Forest

Maria Janowiak, USDA Northern Forests Climate Hub and Northern Institute of Applied Climate Science, USDA Forest Service

Reviewers

Katie Armstrong (Michigan Department of Natural Resources), **Brandon Bal** (American Forest Management), **Winona Grieshop** (Gogebic Conservation District), and **Jerry Grossman** (Grossman Forestry) reviewed this field guide and provided valuable suggestions.

Graphics and Layout

Kailey Marcinkowski (Northern Institute of Applied Climate Science and Michigan Technological University) designed the graphics and layout. The Minnesota Department of Natural Resources provided tree species graphics.

Printing

The Nature Conservancy, Michigan Forest Stewardship Program, and Michigan State University Forest Carbon and Climate Program provided financial support to print this field guide. This field guide was printed by University of Minnesota Printing Services.