Climate Change Field Guide for Northern Wisconsin Forests:

Site-level considerations and adaptation, 2nd edition

USDA

Forest Service U.S. Department of Agriculture

The Nature Conservancy
nature.org

AMERICAN FORESTS
- SINCE 1875 -

NIACS

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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. The CCRF has created numerous tools and resources for forest managers, as well as a growing network of real-world adaptation projects across the Midwest and Northeast.

USDA Northern Forests Climate Hub

The USDA Northern Forests Climate Hub is also led by NIACS, and was created to deliver locally-relevant information to natural resource 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 Wisconsin's forests. Foresters and landowners are considering how to prepare for future conditions and evaluate risks in the woods. This field guide is a quick reference on climate change for northern Wisconsin forests. We hope it will help foresters consider climate change risks together with local site characteristics, and also that it will help people design adaptation actions that help meet management goals.

This 2nd edition includes updated **tree species projections for northern Wisconsin Ecological Sections** (pg. 21), as well as a section on **Forest Carbon Management** (pg. 87).

This field guide will:

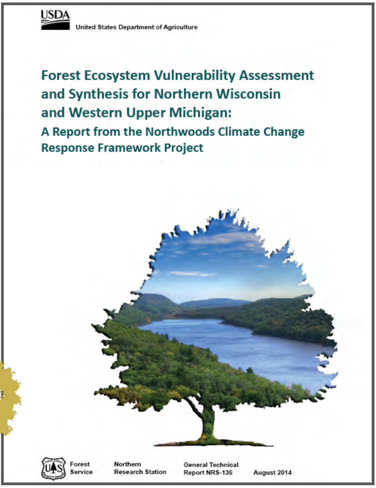
- **Summarize climate change effects on northern Wisconsin's forests**
- **Identify existing site conditions that could increase or reduce risk from climate change**
- **Help you start discussions about potential climate risks and management responses with co-workers, partners, and clients**

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**

Forest Ecosystem Vulnerability Assessment

Much of the information in this guide was drawn from the *Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan* (doi.org/10.2737/NRS-GTR-136). This report was a collaborative effort among dozens of authors from academia; forest industry; conservation groups; and federal, state, and tribal agencies. The assessment brought together the best available information on climate change from published research, ecosystem models, and manager expertise. Together, the team reached conclusions about major risks and vulnerabilities for forests in northern Wisconsin and Upper Michigan through the end of the century.


USDA United States Department of Agriculture

Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan:
A Report from the Northwoods Climate Change Response Framework Project

Forest Service | Northern Research Station | General Technical Report NRS-136 | August 2014

Climate Change Vulnerability: What does it mean?

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.

After identifying general climate impacts that are important to you, you'll need to **think about how your specific project area or property may be vulnerable to climate change**. The Site-Level Considerations pages in this field guide can help (See pages 41, 45, 49, 53, 57, 61, 65, 69, 73).

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

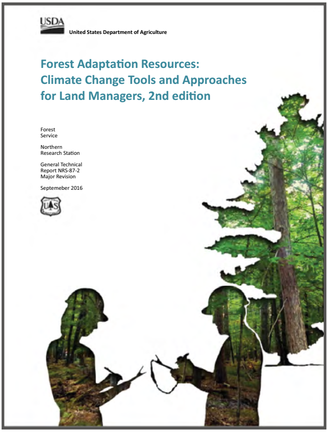
- Soils and topographic position
- Species diversity, age class diversity, and density
- Management history
- Presence of or susceptibility to pests, disease, or nonnative species
- The local rate or magnitude of climate change

5

Forest Adaptation Resources and the Adaptation Workbook

The final section of this field guide includes information from *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (FAR, doi.org/10.2737/NRS-GTR-87-2, adaptationworkbook.org). The FAR provides a structured process to help land managers incorporate climate change considerations into management. It includes an Adaptation Workbook and a "menu" of adaptation actions for managers to consider.

If you want to consider how climate change might affect your management objectives and brainstorm potential adaptation actions as you walk around a site, there's a summary version of the Adaptation Workbook and menu at the end of the field guide. (See page 74.)



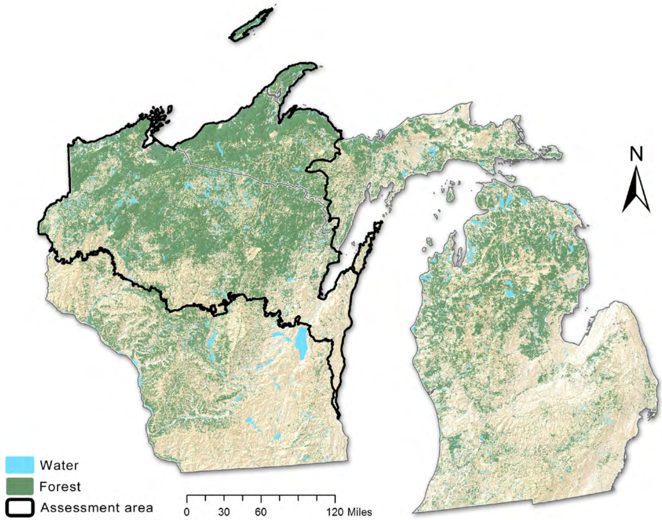
Adaptation: What does it mean?

Climate Change Adaptation includes all kinds of planned, ecosystem-based responses to 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 Systems in Northern Wisconsin

This field guide is organized around 9 common forest systems, listed below. These forest systems reflect a compromise between different ecosystem classifications used by different organizations in the region. Although the forest systems are labeled by dominant species or cover type, they are also designed to reflect the real-life diversity in landforms, soils, hydrology, disturbances, and management history that occurs in the woods.



The black boundary illustrates the area of northern Wisconsin and western Upper Michigan included in the full vulnerability assessment. The east-west boundary in Wisconsin is described by the Laurentian Mixed Forest Ecological Province. See the Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan (doi.org/10.2737/NRS-GTR-136).

Using this Field Guide

This field guide is designed to put useful information at your fingertips. As you walk through the woods, you should identify which forest system you are in and flip to the corresponding section in this guide:

- Aspen-Birch
- Jack Pine
- Lowland Conifer
- Lowland Hardwood (inc. Riparian)
- Northern Hardwood-Hemlock
- Oak
- Red Pine
- Upland Spruce-Fir
- White Pine

In the section for each forest system, you'll find this information:

Page	What's Included?
Forest system characteristics	• Background information on typical soils, disturbance regimes, and vegetation
Climate change vulnerability and impacts	• Overall rankings for vulnerability and confidence • Expected climate change impacts for these forests
Adaptive capacity factors	• Factors that might help this system tolerate change
Site-level considerations	• Factors about a site that could increase or reduce risk from climate change

CLIMATE CHANGE AND NORTHERN WISCONSIN FORESTS

Climate change will continue to affect northern Wisconsin 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 the *Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan* (doi.org/10.2737/NRS-GTR-136).

Key topics in this section include:

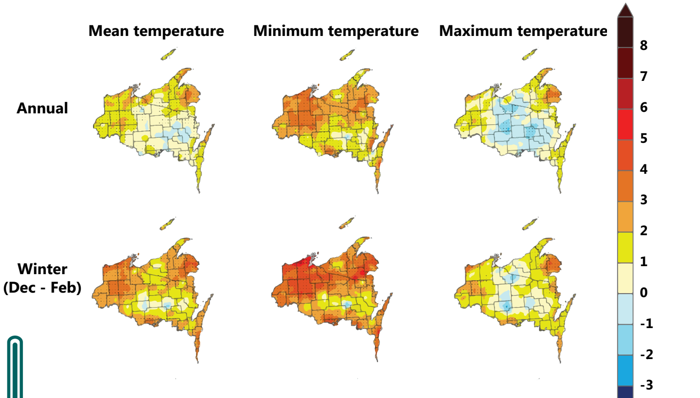
- Temperature increases
- Precipitation changes
- Longer growing season
- Soil moisture and drought stress
- Frozen ground duration
- Changing hydrology
- Wildfire
- Invasive species
- Forest pests and diseases
- Deer browse damage

Temperature Increases

Temperatures have already warmed by about 2° F in northern Wisconsin over the past century. **Winters have warmed about twice as much as other seasons,** and minimum temperatures are increasing faster than maximum temperatures.

Temperatures are projected to continue to increase by 3 to 9° F in northern Wisconsin over the next century, depending on future greenhouse gas emissions and other factors, with as many as 24 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.



[Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan, 2014]

Precipitation Changes

Most of northern Wisconsin now receives about 2 inches more annual precipitation than in the early 1900s, but the trend is highly variable across the state. Late fall and winter have experienced the most increases in precipitation over the last century. Mean annual precipitation is projected to continue to increase across most of the area by another 1 – 3 inches by the end of the century, with most of the increases coming 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, depth of snowpack, frozen ground duration, flooding, and surface runoff.

Longer Growing Season

Wisconsin'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 growing seasons across northern Wisconsin could increase by 14 to 49 days by the end of the century.**

A longer growing season could be a good thing for some tree species in northern Wisconsin, 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 also raise the risk of frost damage if trees break bud before the last frost.

Soil Moisture and Drought Stress

Droughts are major stressors on forests, and they can make trees more vulnerable to insect outbreaks and other impacts. As rainfall has increased over the past century, droughts in northern Wisconsin have been slightly less common and less severe, but northeastern Wisconsin has been drier than average. 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:

- More water will be lost from evapotranspiration with longer growing seasons and warmer conditions.
- Warmer winters 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 rain events.

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

Joseph O'Brien, USFS

Frozen Ground Duration

Frozen ground is necessary to conduct forest management in much of northern Wisconsin to protect sensitive soils, cross wet areas, and haul on unpaved roads. **Over the 20th century, frozen ground conditions declined across northern Wisconsin.** As winter temperatures have increased, snow conditions have also become more variable. Some places have seen an increase in snowfall (such as lake-effect snow belts), while warm periods also lead to more melting between snowfalls. Snow acts as an insulator and protector for the soil during winter, so a change in snow levels has consequences for management and the duration and depth of frozen ground.

Frozen ground duration is expected to shrink by another 1–2 months by the end of the century. The exception may be those areas that currently have deep snowpack, where snow reductions may expose soils to sufficiently cold temperatures and allow for a deeper frost.

Changing Hydrology

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

Longer growing seasons also mean that the timing of snowmelt, runoff, and peak streamflow will be earlier in the year. Peak flow amounts in winter and spring could more than double, depending on ground conditions, timing, and amount of rainfall.

Wildfire

Wildfire is an important driver for many forests across northern Wisconsin. Many aspects of the area's fire regime may be affected by changes in climate, such as growing season length, snowmelt dates, temperature, 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 and other fire-dependent systems.

Land use and management decisions will heavily influence whether there is actually an increase in wildfire in northern Wisconsin. Future policies on fire suppression and prescribed fire are uncertain, but it is reasonable to expect that larger, less managed forest areas may be the first to experience any changes to the fire regime.

Invasive Species

Invasive species are already a major threat to some forests in northern Wisconsin. We don't have a great understanding of the ecology of many invasive species, and ecological models generally don't focus on invasive species. **It is generally expected that invasive plants will "disproportionally benefit" under climate change, because they have traits that allow them to exploit changed environments and aggressively colonize disturbed areas.** Woody invasive species may also benefit from elevated carbon dioxide in the atmosphere. Northern Wisconsin may lose some of the protection offered by a traditionally cold climate and short growing season. Japanese barberry, European buckthorn, European earthworms, garlic mustard, and reed canary grass may benefit from ongoing climate change, and other invasive species may emerge in the years ahead.


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

Forest Pests and Diseases

Unfortunately, we lack basic information on the climatic thresholds for many forest pests, and we aren't able to 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 Wisconsin'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 natural defenses to natural pest outbreaks, while pests such as gypsy moth and hemlock wooly 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 Wisconsin 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 months. Milder winters reduce the need for deer to yard up in sheltered areas. Conversely, warmer temperatures lead to greater physiological stress and parasite loads in moose.

As deer benefit from climate change over the 21st century, they could have even greater impacts on forests across Wisconsin. Deer browsing pressure may limit the ability of forests to respond to climate change, because species anticipated to gain suitable habitat in northern Wisconsin, 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.

USFS Photo by Ryan Pennesi

TREE SPECIES PROJECTIONS

This section shows future projections of suitable habitat for tree species in northern Wisconsin 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 35 species in each Ecological Section. Learn more about the Tree Atlas and get complete results at: fs.usda.gov/nrs/atlas/tree.

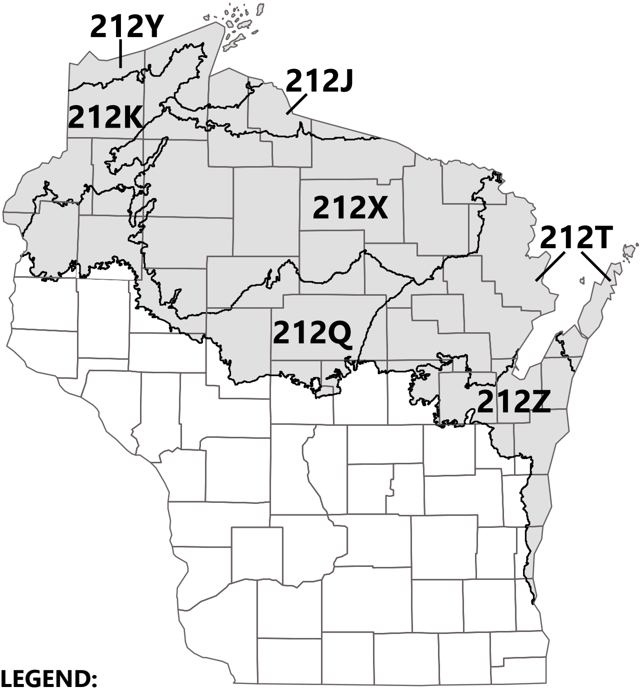
Remember that models are just tools, and they're not perfect. Models don't account for some factors that could be modified by climate change, like droughts, wildfire, and invasive species. These factors could cause a species to perform better or worse than the model projects. Management choices, such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

Ecological Sections

In this section, you'll find Tree Atlas results for individual Ecological Sections in northern Wisconsin. 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 (lit. 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

212J Southern Superior Uplands

- Lake Superior affects local climate (mild temperatures, more precipitation and snow)
- Glacial moraines, lake plains, and hilly uplands with escarpments
- Local cities: Hurley, Mellen

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low					▽	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	–	▼	○	▼	○
Bigtooth aspen	·	▲	△	▲	△
Bitternut hickory	+	★		★	
Black ash	–	●	○	●	○
Black cherry	–	▲	△	▲	△
Black oak	·	★		★	
Black spruce	·	▼	▽	▼	▽
Black walnut	·	★		★	
Bur oak	+	★		★	
Eastern cottonwood	·	★		★	

212J Southern Superior Uplands

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

212K Western Superior Uplands

- Glacial drift plains, moraines, and drumlins
- Areas of deep sands along eastern edge (Moquah Barrens)
- Local cities: Solon Springs, Iron River

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
–	low					▽	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 spruce	·	▼	▽	▼	▽
Black walnut	·	▲	△	▲	△
Boxelder	+	▲	△	▲	△
Bur oak	+	●	△	●	△

212K Western Superior Uplands

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	–	▲	△	▲	○
Green ash	·	▲	△	▲	△
Hackberry	+	▲	△	▲	△
Ironwood	+	▲	△	▲	△
Jack pine	+	▼	○	▼	○
Northern pin oak	+	▲	△	●	△
Northern red oak	+	●	△	●	△
Northern white-cedar	·	▲	○	▲	△
Paper birch	·	●	△	▼	○
Quaking aspen	·	▼	○	▼	○
Red maple	+	●	△	●	△
Red pine	–	●	○	●	○
Shagbark hickory	·	★		★	
Silver maple	+	●	△	●	△
Sugar maple	+	▲	△	▲	△
Swamp white oak	·	▲	△	▲	△
Tamarack	–	▲	○	▲	○
White oak	+	▲	△	▲	△
White spruce	·	▼	▽	●	○
Yellow birch	·	▲	○	▲	○

212Q North Central Wisconsin Uplands

- Glacial till plain with portions of moraines
- Transition area along Tension Zone
- Local cities: Rice Lake, Marshfield, Wausau

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

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

212Q North Central Wisconsin Uplands

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

212T Northern Green Bay Lobe

- Lake Michigan affects local climate (mild temperatures, more precipitation and snow)
- Ground moraines and areas of lake plains, sand dunes, glacial outwash to the west
- Local cities: Shawano, Florence, Marinette

+	high	▲	increase	▼	decrease	△	good
·	medium	●	no change	★	new habitat	○	fair
−	low					▽	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	·	▲	△	●	○
Black ash	–	▼	▽	▼	▽
Black cherry	–	▲	△	▲	△
Black oak	·	▲	△	▲	△
Black spruce	·	▼	▽	▼	▽
Black walnut	·	★		★	
Boxelder	+	●	△	●	△

212T Northern Green Bay Lobe

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
Bur oak	+	▲	△	▲	△
Eastern cottonwood	·	●	▽	▲	○
Eastern hemlock	–	▼	▽	▼	▽
Eastern white pine	–	●	▽	●	▽
Green ash	·	▲	△	▲	△
Ironwood	+	▲	△	▲	△
Jack pine	+	▼	○	▼	○
Northern pin oak	+	▲	△	▲	△
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	▼	○	▼	○
Paper birch	·	▲	△	●	○
Quaking aspen	·	●	△	●	△
Red maple	+	●	△	●	△
Red pine	–	●	○	●	○
Silver maple	+	▲	△	▲	△
Sugar maple	+	▼	△	▼	△
Swamp white oak	·	▲	△	▲	△
Sycamore	·	★		★	
Tamarack	–	●	▽	●	▽
White ash	–	▲	○	▲	○
White oak	+	▲	△	▲	△
White spruce	·	▼	▽	▼	▽
Yellow birch	·	▼	▽	▼	▽

212X Northern Highlands

- Glacial outwash plain, end and ground moraines, and smaller areas of hilly terrain
- Kettle lakes and depressions are common in the north
- Local cities: Rhinelander, Minocqua, Hayward

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

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

212X Northern Highlands

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

212Y Southwest Lake Superior Clay Plain

- Lake Superior affects local climate (mild temperatures, more precipitation and snow)
- Level topography, clay soils and moraines
- Local cities: Ashland, Bayfield, Superior

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

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

212Y Southwest Lake Superior Clay Plain

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

212Z Green Bay Manitowac Upland

- Lake Michigan affects local climate (mild temperatures, more precipitation and snow)
- Transition area along Tension Zone
- Level lake plains and rolling ground moraines
- Local cities: Green Bay, Appleton, Sheboygan

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

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

212Z Green Bay Manitowac Upland

Species	Adapt	LOW CHANGE Habitat Change Class	LOW CHANGE Species Capability	HIGH CHANGE Habitat Change Class	HIGH CHANGE Species Capability
Eastern cottonwood	·	▲	△	▲	△
Eastern white pine	–	▼	▽	▼	▽
Green ash	·	▼	○	▼	○
Hackberry	+	▲	△	▲	△
Ironwood	+	▲	△	▲	△
Northern pin oak	+	●	○	●	○
Northern red oak	+	▲	△	▲	△
Northern white-cedar	·	▼	○	▼	○
Osage-orange	+	★		★	
Paper birch	·	●	○	●	○
Post oak	+	★		★	
Quaking aspen	·	▼	▽	▼	▽
Red maple	+	▼	△	▼	△
Red pine	–	▼	▽	▼	▽
Shagbark hickory	·	▲	△	▲	△
Silver maple	+	▲	△	▲	△
Sugar maple	+	▲	△	▲	△
Swamp white oak	·	▲	△	▲	△
Sycamore	·	★		★	
Tamarack	–	▼	▽	▼	▽
White ash	–	●	▽	●	▽
White oak	+	▲	△	▲	△
Yellow birch	·	▼	▽	▼	▽

ASPEN-BIRCH

System Characteristics

Early-successional species require openings from management or disturbance such as fire or wind events.

Aspen species reproduce heavily from root suckers.

Birch and other early-successional species require a mineral soil seedbed to regenerate.

A wide range of soil, nutrient, and moisture tolerance.

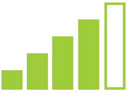
Quaking aspen and paper birch have upper temperature or drought limits based on their physiology.

Climate Change Vulnerability

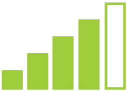
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-high

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



Medium-high evidence



Medium-high agreement

Climate Change Impacts: Negative

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

Projected temperatures may be beyond the physiological limits of aspen and birch by the end of the century. Quaking aspen and paper birch are near their southern range limits in Wisconsin.

Insect pests such as forest tent caterpillar and gypsy 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.
- Wind-dispersed seed and vegetative reproduction help these species tolerate many forms of disturbance.
- These forests occur on a wide variety of soils and landforms.
- Paper birch-dominated forests may be at greater risk than aspen-dominated forests, because paper birch is already less common and faces challenges for regeneration.

Site-level Considerations

Site-level factors could make an aspen-birch 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
Drought-prone soils or south-facing aspect	←	**Drought risk**	→	Mesic soils or north-facing aspect
On-going pest damage, or earthworms have altered soil conditions	←	**Pests and earthworms**	→	Site is free of pests and earthworms
On-going diseases like hypoxylon canker or Armillaria	←	**Declines and diseases**	→	No looming threats; stand is vigorous and healthy
Deer, health issues, or other factors may limit regeneration	←	**Regeneration potential**	→	Conditions are suitable for good regeneration
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

JACK PINE

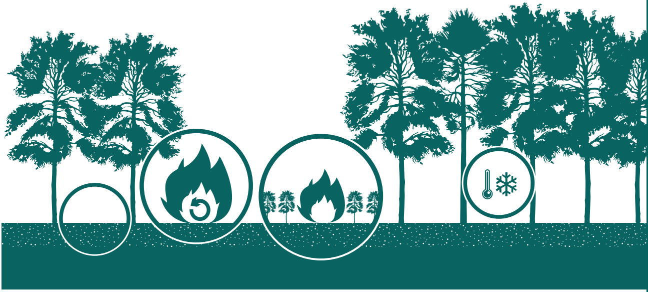
System Characteristics

Occurs on the most drought-prone sites with low nutrient availability, typically upland landscape positions or outwash plains.

Stand-replacing fire naturally occurs every 30-80 years for serotinous jack pine, and surface fires occur more frequently in barrens.

Serotinous jack pine stands require stand-replacing fire for regeneration, or management practices that mimic fire.

Favored by cold temperatures and tolerates growing-season frost.

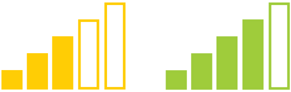


Climate Change Vulnerability

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-high agreement

Climate Change Impacts: Moderate

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

Too much change to the fire regime might hamper regeneration and cause these forests to shift to barrens.

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

Insect pests like jack pine budworm and diseases like *Scleroderris* 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

- Jack pine may be able to tolerate the projected decreases in soil moisture during the summer. Jack pine seedlings are more susceptible to drought stress than are established trees, however, and regeneration failure may occur more frequently.
- These forests can persist on dry and poor soils and in the future may be able to colonize relatively mesic sites that become drier as a result of climate change. Sites currently dominated by red pine or white pine may become more suitable for jack pine.
- The potential for increased fire frequency or intensity under warmer and drier conditions would favor jack pine relative to many other forest types.
- Low tree species diversity in this forest type also provides few options if conditions shift beyond the physiological limits of jack pine.

Site-level Considerations

Site-level factors could make a jack pine 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
Fire-intolerant species are encroaching	←	**Disturbance regime**	→	Natural conditions maintained by management or wildfire
Regeneration limited by unsuitable seedbed conditions or competition	←	**Natural regeneration**	→	Conditions are suitable for good regeneration
Deer, health issues, or competition may limit planting success	←	**Planting success**	→	Planting is likely to be successful
Hazardous fuels or ladder fuels create extreme or elevated fire risk	←	**Wildfire risk**	→	Fuel loads are within acceptable levels
On-going damage or looming threats such as jack pine budworm or Armillaria	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy

LOWLAND CONIFER

System Characteristics

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.

Systems that are fed by groundwater have higher nutrient availability and may be acidic or alkaline.

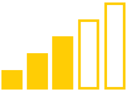
Microtopography is undulating with hummocks and mounds from wind events.

Climate Change Vulnerability

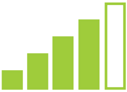
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

High

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



Medium evidence



Medium-high agreement

Climate Change Impacts: Negative

Hydrologic and soil conditions could change in a variety of ways, through flood, drought, or the relative influence of precipitation versus groundwater.

Water table changes may be more likely where roads, drainage ditches, or beaver dams have altered local hydrology.

Sphagnum moss may not tolerate warmer conditions. 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 subsequently increase fire risk.

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

Adaptive Capacity: Moderate-Low

- 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.
- These forests are unlikely to expand to new territory or outcompete other forest types.
- Acidic or alkaline soil conditions may make these areas less susceptible to encroachment by invasive species or competing forest types.


Scott Pearson

Site-level Considerations

Site-level factors could make a lowland conifer 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
Ditches, roads, dams, or other changes have altered local hydrology	←	**Natural processes**	→	Natural hydrology has been maintained
Damage from forest pests or diseases such as tamarack sawfly or mistletoe	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Small site that relies on precipitation inputs, prone to extreme water table changes	←	**Water table fluctuation**	→	Large wetland with groundwater inputs and a stable water table
Regeneration limited by deer or non-native species	←	**Regeneration**	→	Tree regeneration is not limited
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

LOWLAND HARDWOOD
(INC. RIPARIAN)

System Characteristics

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

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

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

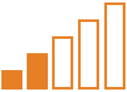
Flooding often happens over frozen or saturated ground in the spring, but the timing, duration, and intensity of flooding varies annually.

Climate Change Vulnerability

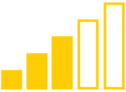
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-high

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



Limited-medium evidence



Medium agreement

Climate Change Impacts: Moderate-Negative

Emerald ash borer will severely reduce or eliminate ash species in most stands. Gypsy 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 canarygrass, Japanese barberry, and buckthorn may increase 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 excessive waterlogging or prolonged droughts.

Adaptive Capacity: 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.

Site-level Considerations

Site-level factors could make a lowland hardwood or riparian 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
A single age class or simple topography	←	**Structural diversity**	→	A diversity of age classes or microsites from tip-up mounds and hummocks
Ditches, roads, dams, or floodplain alterations have affected local hydrology	←	**Natural hydrology**	→	Natural hydrology has been maintained
Regeneration limited by deer or understory competition from native or non-native species	←	**Regeneration**	→	Tree regeneration is not limited
On-going ash decline or emerald ash borer in the area	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Site is small and isolated, prone to extreme water table changes	←	**Size and connectivity**	→	Site is part of a large lowland complex, so water table changes may be buffered
Droughty soils and less reliable access to water table	←	**Drought risk**	→	Mesic soils and consistently available groundwater

NORTHERN HARDWOOD-HEMLOCK

System Characteristics

Occurs on fine-textured soils or in areas with dense subsoil layers that retain water.

Water and nutrient availability follows a relatively predictable annual or seasonal pattern.

Occurs on moist sites or dry-mesic sites where fire has been excluded for an extended period of time.

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

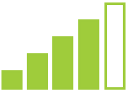
These forests develop dense, continuous canopies of shade-tolerant trees and shade-tolerant understory plants.

Climate Change Vulnerability

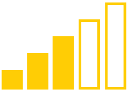
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate

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



Medium-high evidence



Medium agreement

Climate Change Impacts: Moderate-Negative

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

Increases in extreme weather events may lead to more frequent or widespread windthrow, which could affect the gap-phase dynamics that foster regeneration of shade-tolerant species.

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

Forest tent caterpillar, gypsy moth, and other pests may cause more damage in climate-stressed forests. New pests such as hemlock wooly adelgid may be able to persist if introduced.

Deer populations will likely increase with warmer winters, which may further 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.

Site-level Considerations

Site-level factors could make a northern hardwood 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
Regeneration limited by deer or understory competition from native or non-native species	←	**Regeneration**	→	Tree regeneration is not limited
Drought-prone soils, south-facing aspect, or high stocking level	←	**Drought risk**	→	Mesic soils, north-facing aspect, or moderate stocking
On-going damage or looming threats	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Earthworms have severely altered litter and soil conditions	←	**Earthworms**	→	Earthworm impacts are mild or non-existent
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

OAK

System Characteristics

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

Requires disturbance to limit competition - surface fire return intervals of 50-250 years.

Tolerant of drought and episodic, unpredictable nutrient availability.

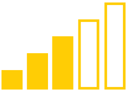
Limited by cold temperatures and growing-season frost.

Climate Change Vulnerability

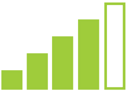
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-low

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



Medium evidence



Medium-high agreement

Climate Change Impacts: Moderate

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

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

Forest tent caterpillar, gypsy moth, two-lined chestnut borer and other insect pests may cause more frequent and severe damage under climate change.

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

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

White-tailed deer populations may also increase with warmer winters, which could hinder regeneration and reduce the potential for oak forests to expand.

Adaptive Capacity: Moderate-High

- Oak-dominated forests are relatively drought-tolerant and may tolerate some degree of greater precipitation variability under climate change.
- Oaks are limited by cold temperatures in northern Wisconsin, so warming may allow this forest type to expand into previously unsuitable areas.
- High species and genetic diversity of oak forests provides for many possible future trajectories.
- These forests could gain territory lost by other forest types under drier future conditions.


Wisconsin Department of Natural Resources

Site-level Considerations

Site-level factors could make an oak 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 the site or across the landscape
Mesic species are encroaching or out-competing oak	←	**Competition**	→	Oak has a competitive advantage maintained by management, wildfire, or dry conditions
Regeneration limited by deer, poor seedbed conditions, or non-native species such as garlic mustard	←	**Regeneration**	→	Conditions are suitable for good oak regeneration
Damage from forest pests or diseases such as forest tent caterpillar or oak wilt	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

RED PINE

System Characteristics

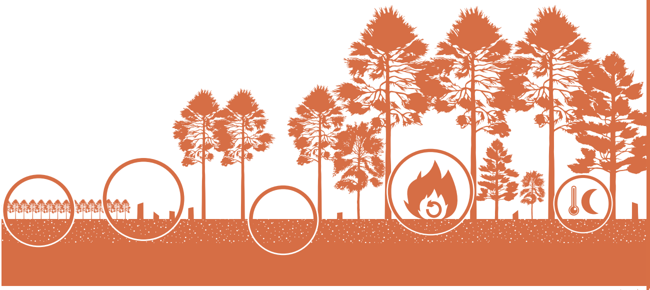
Most red pine stands in northern Wisconsin are single-species plantations.

Red pine is shade-intolerant. Seedlings are planted after canopy removal or in large gaps.

Occurs on sites with a range of soil types – coarse-textured or shallow soils over bedrock, and also mesic soils.

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

Limited by warm nights at the southern extent of the range.

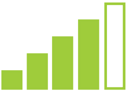


Climate Change Vulnerability

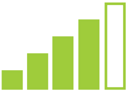
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-high

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



Medium-high evidence



Medium-high agreement

Climate Change Impacts: Moderate-Negative

Drier summers or droughts may reduce survival of planted seedlings.

Diseases and insect pests may become more damaging under warmer conditions. Dense, overstocked stands are at greatest risk from droughts and associated pests and diseases.

Red pine is sometimes browsed by deer, and deer populations are anticipated to increase with warmer winters.

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

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

Adaptive Capacity: Moderate-Low

- 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.
- Natural regeneration of red pine is sometimes limited following harvest, particularly further south in Wisconsin.

Site-level Considerations

Site-level factors could make a red pine 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**	→	A diversity of age classes on the site or across the landscape
On-going damage or looming threats such as shoot blight or Armillaria	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
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
Deer, health issues, or competition may limit planting success	←	**Planting success**	→	Conditions favor seedling survival
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

UPLAND SPRUCE-FIR

System Characteristics

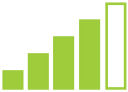
- Occurs on dunes, glacial lake plains, or areas with thin soil over bedrock.
- Competitive on nutrient-poor sites with sandy, loamy sand, or sandy loam soils.
- Many species limited by high summer temperatures.
- Adapted to infrequent catastrophic wildfire linked to periodic cycles of pest outbreaks such as spruce budworm.
- Tolerates frequent windthrow.

Climate Change Vulnerability

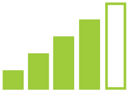
Overall Vulnerability: Will this community experience declining health, reduced extent, or identity changes by 2100?

High

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



Medium-high evidence



Medium-high agreement

Climate Change Impacts: Negative

Several species in this system are near their southern range limits in Wisconsin, and are limited by high growing-season temperatures.

Spruce budworm and other insect pests may become more active and damaging under a warmer climate, especially where forests are already stressed by drought or other changes.

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

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

Adaptive Capacity: Moderate-Low

- Increases in stand-replacing wildfire could provide opportunities for regeneration where conditions remain suitable for the dominant species. Several of these species produce seed 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, so they may be able to tolerate short-term moisture stress.
- These forests have relatively low diversity or contain primarily boreal species, which leads to fewer possible trajectories in the future.

Site-level Considerations

Site-level factors could make an upland spruce-fir 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
Drought-prone soils, south-facing aspect, or high stocking level	←	**Drought risk**	→	Mesic soils, north-facing aspect, or moderate stocking
In a location prone to future warming	←	**Thermal conditions**	→	Located in a "frost pocket" or cold-air drainage
Hazardous fuels or ladder fuels create extreme or elevated fire risk	←	**Wildfire risk**	→	Fuel loads are within acceptable levels
On-going damage from spruce budworm or other pests and diseases	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

WHITE PINE

System Characteristics

Occurs on sites with a range of soil types – coarse-textured or shallow soils over bedrock, and also mesic soils.

Competitive on dry or dry-mesic sites.

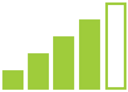
Historical fire return intervals were 50 to 250+ years, with more frequent surface fires.

Climate Change Vulnerability

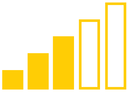
Overall Vulnerability:
Will this community experience declining health, reduced extent, or identity changes by 2100?

Moderate-low

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



Medium-high evidence



Medium agreement

Climate Change Impacts: Moderate-Positive

Increased storm or wind events may kill mature trees, while also creating opportunities for regeneration.

Drought could also favor red pine, jack pine, or northern pin oak on marginal white pine sites, especially if fire also becomes more frequent or severe.

Insect pests and diseases such as white pine weevil may become more damaging under a warmer climate, especially under increased drought stress.

White-tailed deer populations are also anticipated to increase with warmer winters, so herbivory on white pine seedlings may hinder regeneration.

Adaptive Capacity: High

- White pine forests are relatively drought tolerant.
- White pine can grow in many soil and moisture conditions, and drier northern hardwood sites may provide new habitat for this system.
- This species can disperse seed and be a pioneer in gaps and open areas, so it may be able to colonize new suitable habitat.
- Increases in periodic fire may be beneficial by reducing ladder fuels and competition.
- White pine forest occupies much less area than its historical distribution, but it has been increasing in northern Wisconsin in recent decades.

Site-level Considerations

Site-level factors could make a white pine 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
Regeneration limited by deer or understory competition	←	**Regeneration**	→	Tree regeneration isn't limited
Mesic species are encroaching and out-competing white pine	←	**Competition**	→	White pine has a competitive advantage maintained by management, wildfire, or dry conditions
On-going damage from pests and diseases such as white pine tip weevil or blister rust	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

ADAPTATION WORKBOOK

This section includes information from the second edition of *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (FAR, doi.org/10.2737/NRS-GTR-87-2). Adaptation will work best if you generate your own ideas and actions based on local site conditions and management experience, rather than following boilerplate guidance or recommendations. Therefore, this section is designed to help you make your own climate-informed decisions for forest management and conservation.

Adaptation: What does it mean?

Climate change adaptation means taking action to prepare for the likely effects of climate change. Adaptation will mean different things to different people, because we're all working with different management goals, risk tolerance, and forest conditions. The overall purpose of adaptation is to **give yourself the best chance for success**, considering the range of plausible future risks. This means not only identifying new and different management actions to address climate impacts, but also recognizing how your current management actions might already help address climate change.

Adaptation Options

Adaptation Options are large concepts that describe the general focus of land managers toward climate change adaptation. Think about how each Option might apply to your particular values and situation – this can help you judge what kind of adaptation choices will be most appropriate for your situation.

There are three basic Adaptation Options:

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 normal conditions after disturbance. Useful with systems and species that can tolerate a wide range of environmental conditions and disturbance.

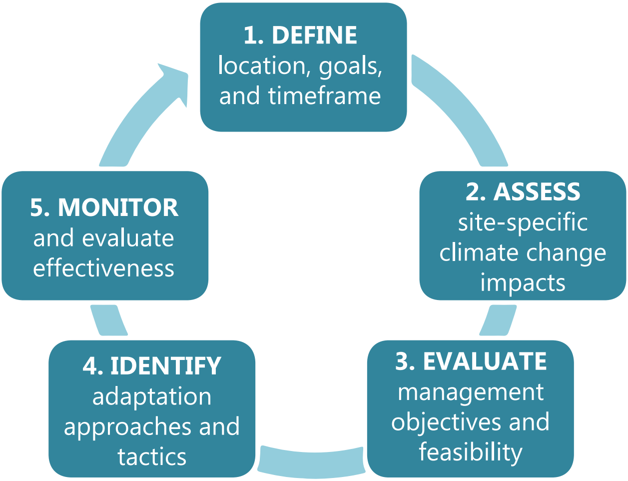
CHANGE

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

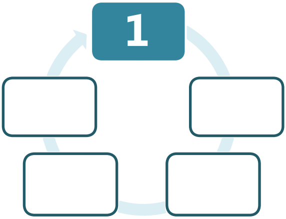
Adaptation Workbook

The Adaptation Workbook is a structured process to help land managers incorporate climate change considerations into management. Download a complete version of the Adaptation Workbook at: doi.org/10.2737/NRS-GTR-87-2, or use the online version at: adaptationworkbook.org.

There are five steps in the Adaptation Workbook, which are explained in the following pages. **Use these pages to brainstorm your own adaptation actions.**



Step 1: Define location, management goals, and time frames



This step is about clearly recording your **management goals and objectives.** Being specific now will help in subsequent steps, so try to be detailed. You might be able to get this information from a management plan or other planning document.

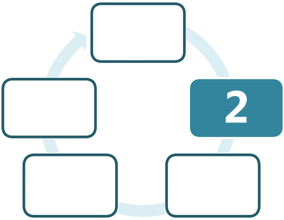
Management goals are general statements, usually not quantifiable, that express a desired state or process to be achieved. Goals could be future ecosystem conditions, habitat features, or forest products.

Management objectives are concise statements of measurable, planned results that help to achieve a desired outcome.

Key Questions:

- Where are you working?
- What are your management goals and objectives for this area?

Step 2: Assess site-specific climate change impacts and vulnerabilities



This step emphasizes how climate change may affect your site based on local conditions. Use the information in this guide as a starting point, or review the *Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan* (doi.org/10.2737/NRS-GTR-136).

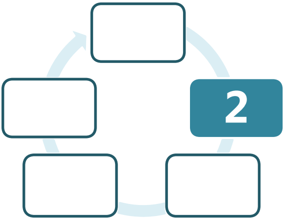
After identifying general impacts that are important to you, **evaluate how your specific project area or property may be uniquely affected by climate change impacts.** The Site-Level Considerations pages in this guide can help.

Climate Change and Your Property

Your property may be more or less vulnerable to broad-scale climate impacts. Factors that may influence risk for a specific location include:

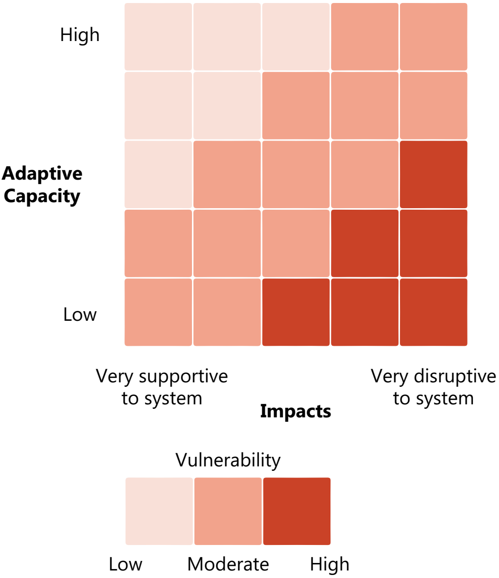
- Soils and topographic position
- Management history
- Species or structural diversity
- Presence of or susceptibility to pests, disease, or nonnative species
- Surrounding landscape features

Step 2: Assess site-specific climate change impacts and vulnerabilities (continued)

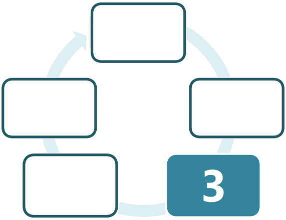


This step also asks you to consider the overall vulnerability of your site to climate change. **Vulnerability** is the susceptibility of a system to adverse effects from climate change. Vulnerability depends on the potential impacts from climate change, as well as the ability of the system to tolerate those impacts without significantly changing (adaptive capacity).

This chart illustrates how to consider vulnerability for your site, based on impacts and adaptive capacity.

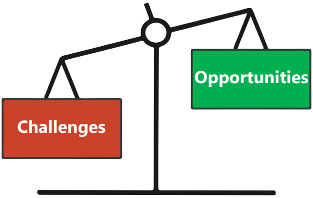


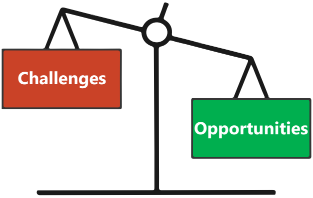
Step 3: Evaluate management objectives and feasibility



This step identifies **challenges and opportunities associated with climate change** for each of your management objectives. You'll also evaluate whether it's feasible to meet your management objectives under current management.

Thinking about how the potential challenges and opportunities stack up against each other will help you decide how feasible your management objectives are:





Feasibility Rating

Low: Current management can't overcome challenges, or few opportunities exist.

High: Current management can overcome challenges, or opportunities outweigh challenges.

Step 4: Identify adaptation approaches and tactics

This step helps you identify and evaluate specific management actions that can help prepare for changing conditions. Your adaptation plan will be unique and specifically designed for your site and your management objectives.

If you need help brainstorming adaptation tactics, you can use the Menu of Adaptation Strategies and Approaches as a springboard (see next page). Making connections between adaptation actions and the menu will provide important context and rationale to justify your choices.

As you identify a list of tactics, consider how they might work together. The goal is to identify a set of actions that are complementary and help to overcome the challenges you identified in Step 3.

Menu of Adaptation Options

The FAR includes a “menu” of adaptation actions for forest management. The 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 (doi.org/10.2737/NRS-GTR-87-2). See NIACS adaptation menus for other topics, including watershed management, wildlife, tribal perspectives, wetlands, and more! (forestadaptation.org/adapt/adaptation-strategies).

The Forestry menu contains 10 general Adaptation 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.

Forestry Adaptation Menu

Strategy 1: Sustain fundamental ecological functions.

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.

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.

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.

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.

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.

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.

7.1. Reduce landscape fragmentation.

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

Strategy 8: Maintain and enhance genetic diversity.

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.

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.

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.

Step 5: Monitor and evaluate effectiveness

Finally, you'll identify monitoring items to evaluate whether your management goals are achieved in the future and whether the recommended adaptation tactics were effective. The outcome of this step is a **realistic and feasible monitoring scheme** that can help determine whether management should be altered in the future.

Key Questions:

- How will you know if the selected actions are effective?
- What can you learn from these actions to inform future management?

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.**

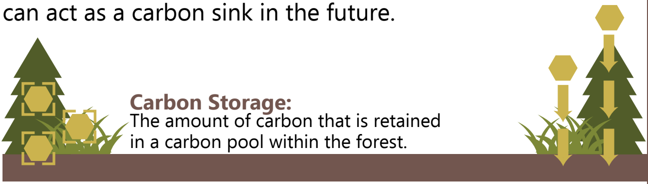
A growing number of forest managers feel it is important to maintain and enhance carbon storage and sequestration, while also boosting carbon stored in wood products and wood-based fossil fuel substitutes. Many practices to enhance forest carbon align with other benefits, such as managing for wildlife 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 Forestry 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/focus/forest-carbon-management.

Considerations for Carbon Management

Forests store carbon primarily in soils and in live tree biomass. Along with standing dead trees and down dead wood, these total ~96% of the carbon in Wisconsin's forests. Management can enhance carbon storage by reducing the risk of disturbance to these carbon pools, or increase the rate of sequestration by improving 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 low risk from climate impacts and other stressors, management can help store more carbon in larger trees and forest soils, or increase stocking in understocked stands. For example, delaying a harvest or designating a stand 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.	• Time harvest operations to match site conditions and minimize risk to stands.
Flooding and Erosion: Extreme rainfall could strongly affect some locations, such as a floodplain or steep, highly erodible slopes.	• 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.


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

Many resources exist to help people consider climate change impacts and make adaptation decisions.

Wisconsin-Specific Information

Handouts of Individual Tree Species Projections: 2-page summaries of climate change projections for tree species across several large landscapes.
forestadaptation.org/northwoods_treehandouts

Wisconsin Initiative on Climate Change Impacts (WICCI): WICCI is the hub of climate adaptation activity in the state. There is a WICCI Forestry Working Group, as well as a Plants and Natural Communities Working Group.
wicci.wisc.edu

Regional and National Information

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

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

National Climate Assessment: A national-level report with the best available information on observed and projected climate trends. nca2018.globalchange.gov

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

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