College of Food, Agricultural and Natural Resource Sciences
University of Minnesota

Climate Change Field Guide for Northern Minnesota Forests:

Site-level considerations and adaptation

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

NIACS
Northern Institute of Applied Climate Science

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Northern Institute of Applied Climate Science

Northern Institute of Applied Climate Science

The Northern Institute of Applied Climate Science (NIACS) is a multi-organization partnership focused on bridging the gap between research and management in the fields of climate adaptation and carbon science (www.nrs.fs.fed.us/niacs). NIACS leads a community effort called the Climate Change Response Framework (CCRF, www.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 (www.climatehubs.oce.usda.gov/hubs/northern-forests). This field guide is an example of how the national network of 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 forests across Minnesota. Foresters, land managers, and landowners are considering how to prepare for future conditions and how to evaluate risks for particular sites. This field guide is designed as a quick reference on climate change for northern Minnesota forests. The intent is to highlight key information that can be used during field visits or forest planning. We hope that this guide 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.

Using this Field Guide

This field guide is designed to put useful information at your fingertips as you walk through the woods.

This field guide will:

- **Provide summary information about the effects of climate change on northern Minnesota's forests**
- **Identify existing site conditions that could increase or reduce risk from climate change**
- **Help you start discussions about potential climate change impacts 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**

When you visit a stand, you should identify which forest system you are in and flip to the corresponding section in this guide:

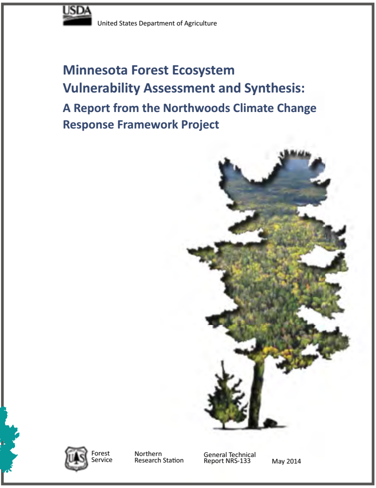
Fire-Dependent Forest	Forested Rich Peatland
Mesic Hardwood Forest	Acid Peatland
Wet Forest	Managed Aspen
Floodplain Forest	Managed Red Pine

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

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
Tree species projections	• Model results for species common to these forests
Site-level considerations	• Factors about a site that could increase or reduce risk from climate change

Minnesota Forest Vulnerability Assessment

Much of the information in this guide was drawn from the *Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis* (www.nrs.fs.fed.us/pubs/45939). 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 northern Minnesota forests through the end of the century.


USDA
United States Department of Agriculture

Minnesota Forest Ecosystem
Vulnerability Assessment and Synthesis:
A Report from the Northwoods Climate Change Response Framework Project

Forest Service
Northern Research Station
General Technical Report NRS-133
May 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 29, 34, 39, 44, 49, 54, 59, 64).

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

- Soils and topographic position
- Species or structural composition
- Management history
- Presence of or susceptibility to pests, disease, or nonnative species

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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, www.nrs.fs.fed.us/pubs/52760, www.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 66.)

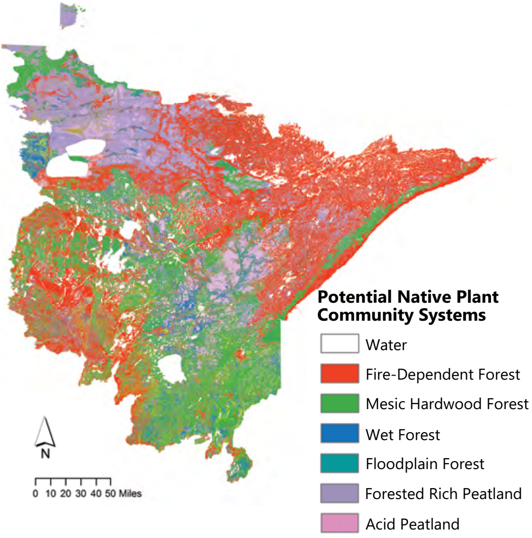
Adaptation: What does it mean?

Climate Change Adaptation includes all kinds of planned, ecosystem-based responses to climate change. The overarching purpose of 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!

Minnesota’s Native Plant Communities

This field guide is organized around six forested Native Plant Community (NPC) Systems in northern Minnesota and two managed forest types. NPCs are determined by vegetation, hydrology, landforms, soils, and natural disturbances. For complete NPC descriptions, see the *Field Guide to the Native Plant Communities of Minnesota: the Laurentian Mixed Forest Province* (www.dnr.state.mn.us/npc/index.html). Managed Aspen and Managed Red Pine are also included as separate forest types because they don’t align well with the NPCs.



Map of potential Native Plant Community Systems across the Laurentian Forest Province. Source: Natural Resources Research Institute, www.nrri.umn.edu/gis/default.htm

CLIMATE CHANGE AND NORTHERN MINNESOTA FORESTS

Climate change will continue to affect northern Minnesota 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 *Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis* (www.nrs.fs.fed.us/pubs/45939).

Key topics in this section include:

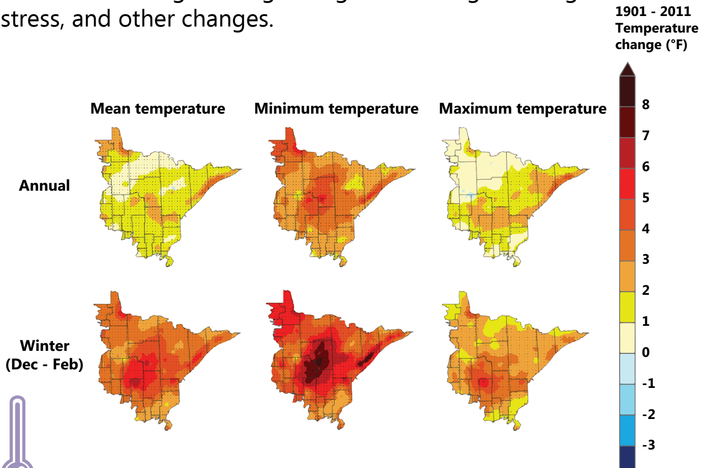
- Temperature increases
- Precipitation changes
- Longer growing season
- Soil moisture and drought stress
- Frozen ground duration
- Wildfire
- Invasive species
- Forest pests and diseases
- Deer browse damage

Temperature Increases

Temperatures have already warmed by about 2° F in northern Minnesota 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 Minnesota over the next century, depending on future greenhouse gas emissions and other factors.

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



Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis, 2014

Precipitation Changes

Many areas in northern Minnesota are receiving about 4 inches more rainfall across the year than they did in the early 1900s. Spring, summer, and fall have experienced the most increases in precipitation, but the trend is variable across the state.

Perhaps more importantly, **Minnesota is getting a larger share of total precipitation from heavy rainfall events.** 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 has severe consequences for ecosystems, infrastructure, and local communities.** These events can also disrupt and delay forest management operations.


Patrick Hampston, Superior NF

Longer Growing Season

Northern Minnesota's growing season has already extended earlier by about a week over the past 60 years. This trend is expected to continue, as **some studies have projected that growing seasons across the Midwest could increase by 30 to 70 days by the end of the century.**

A longer growing season could be a good thing for some tree species in northern Minnesota, 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.

Eli Sagor, Univ. of MN

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 Minnesota have been slightly less common and less severe. Elevated carbon dioxide in the atmosphere may also 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 Minnesota's forests.

Joseph O'Brien, USFS

Frozen Ground Duration

Over the 20th century, frozen ground conditions declined by 12 to 24 days per winter across northern Minnesota. Frozen ground is necessary to conduct forest management in much of northern Minnesota to protect sensitive soils, cross wet areas, and haul on unpaved roads. 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 shrink by another 30 days per winter by the end of the century. Minnesota is also expected to receive less snow and more winter rain.

Charlie Blinn, Univ. of MN

Wildfire

Wildfire is an important driver for many forests across northern Minnesota. Many aspects of Minnesota'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 northern Minnesota, such as jack pine and other Fire-Dependent Forests.

Land use and management decisions will heavily influence whether there is actually an increase in wildfire in Minnesota. 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.


USFS

Invasive Species

Invasive species are already a major threat to some forests in northern Minnesota. 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 Minnesota may lose some of the protection offered by a traditionally cold climate and short growing season. European buckthorn, garlic mustard, Pennsylvania sedge, and reed canarygrass are some invasive species of concern in northern Minnesota.

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 Minnesota'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.

Additionally, we expect mild winters to increase winter survival for insect pests, and longer growing seasons could allow some insects to complete multiple life cycles. These factors can allow populations to grow rapidly, as we are currently seeing with the ongoing outbreak of eastern larch beetles. Furthermore, new pests or pathogens may enter northern Minnesota during the 21st century.


Steven Valley, ODA, bugwood.org


Steven Katovich, USFS, bugwood.org

Deer Browse Damage

Climate change is expected to favor white-tailed deer and continue to reduce populations of moose. Warmer winters and reduced snow depth reduce energy requirements for deer and increase access to forage during winter months. Milder winters may also 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 Minnesota. Deer browsing pressure may limit the ability of forests to respond to climate change, because species anticipated to expand their ranges northward, such as sugar maple, white oak, and northern red oak, are browsed much more heavily than boreal conifers such as balsam fir and white spruce. 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.

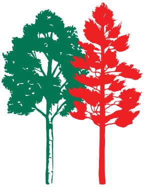

Casey Mcquiston, USFS

TREE SPECIES PROJECTIONS

The *Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis* used two climate scenarios to "bracket" a range of plausible futures. These future climate projections were used with two forest impact models (Tree Atlas and LANDIS) to provide information about individual tree species. **The following pages show future projections for individual tree species in northern Minnesota by the end of the century.** The full report contains more information on the climate and forest impact models.

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 activity, and invasive species. These factors could cause a particular species to perform better or worse than a model projects. Management choices will also continue to influence forest distribution, such as whether to intentionally plant species that are projected to increase.

Despite these limits, models provide useful information about future expectations. It's probably best to think of these projections as indicators of potential change and direction. Get a 2-page handout of this information at: www.forestadaptation.org/northwoods_treehandouts.



Using the Tree Species Table

Data for the end of the century (2100) are summarized for two forest impact models under two climate change scenarios (Low=PCM B1, High=GFDL A1FI). The Climate Change Tree Atlas (www.fs.fed.us/nrs/atlas) models future suitable habitat, while LANDIS models changes in forest growth over time (future biomass presented in this table).

▲ **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

ADAPTABILITY
Factors not included in the models, such as the ability to respond favorably to disturbance, may make a species more or less able to adapt to future stressors.

\+ **HIGH**
Species may perform better than modeled

· **MEDIUM**

– **LOW**
Species may perform worse than modeled

Species	Low Climate Change: Tree Atlas	Low Climate Change: LANDIS	High Climate Change: Tree Atlas	High Climate Change: LANDIS	Adapt
American basswood	●	▲	▲	▲	·
American beech	★		★		·
American elm	▲	▲	▲	▲	·
American hornbeam	▲		▲		·
Balsam fir	▼	▼	▼	▼	–
Balsam poplar	▼		▼		·
Bigtooth aspen	●	▲	▼	▲	·
Bitternut hickory	▲		▲		+
Black ash	●	▲	▼	▼	–
Black cherry	▲	▲	▲	▲	–
Black hickory			★		·
Black locust	★		★		·
Black oak	▲		▲		·
Black spruce	▼	▼	▼	▼	·
Black walnut	▲		▲		·
Black willow	▲		▲		–
Blackgum			★		+
Blackjack oak			★		+
Boxelder	▲		▲		+
Bur oak	●	●	▲	●	+
Butternut	●		▼		–
Chestnut oak			★		+
Chinkapin oak	★		★		·
Chokecherry	●		●		·
Eastern cottonwood	▲		▲		·
Eastern hemlock	★		★		–
Eastern red cedar	▲		▲		·

Species	Low Climate Change: Tree Atlas	Low Climate Change: LANDIS	High Climate Change: Tree Atlas	High Climate Change: LANDIS	Adapt
Eastern redbud			★		·
Eastern white pine	▲	▲	▲	▲	·
Flowering dogwood			★		·
Green ash	●	▲	▲	▲	·
Hackberry	▲		▲		+
Honeylocust	★		★		+
Ironwood	▲		▲		+
Jack pine	●	▲	▼	▼	·
Mockernut hickory			★		+
Mountain maple	▼		▼		+
Northern catalpa			★		·
Northern pin oak	▲		▲		+
Northern red oak	▲	▲	●	▼	+
Northern white-cedar	▼	▲	▼	▼	·
Ohio buckeye			★		·
Osage-orange	★		★		+
Paper birch	●	▼	▼	▼	·
Peachleaf willow	▼		▲		·
Pignut hickory	★		★		·
Pin cherry	▼		●		·
Pin oak	★		★		–
Post oak			★		+
Quaking aspen	▼	▼	▼	▼	·
Red maple	▲	▲	▲	▲	+
Red mulberry	★		★		·
Red pine	●	▲	▲	▼	·
River birch	▲		▲		·

Species	Low Climate Change Tree Atlas	Low Climate Change LANDIS	High Climate Change Tree Atlas	High Climate Change LANDIS	Adapt
Rock elm	●		▲		–
Sassafras	★		★		·
Scarlet oak	★		★		·
Shagbark hickory	★		★		·
Shingle oak			★		·
Silver maple	▲		▲		+
Slippery elm	▲		▲		·
Striped maple	●		●		·
Sugar maple	▲	▲	▲	▲	+
Sugarberry			★		·
Swamp white oak	▲		▲		·
Sweet birch			★		–
Sweetgum			★		·
Tamarack	▼		▼		–
White ash	▲		▲		–
White oak	▲	▲	▲	▲	+
White spruce	▼	▼	▼	▼	·
Wild plum	▲		▲		·
Yellow birch	▲	▲	▼	▼	·
Yellow-poplar			★		+

FIRE-DEPENDENT FOREST

System Characteristics

Fires help tree reproduction by exposing mineral soil, triggering seed dispersal, and increasing sunlight on the ground.

Fires periodically remove litter, duff, and other organic material from the soil.

Species are adapted to survive repeated fires or to regenerate following fire; pines, other conifers, and pioneer species like aspen and birch are common.

Fire-Dependent Forests occur on drought-prone sites with sandy or gravelly soils, or thin soils over bedrock.

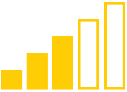
Nutrient availability in these forests is tied to fires, so it is episodic and unpredictable.

Climate Change Vulnerability

Overall Vulnerability:

Moderate

Confidence:



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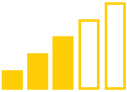

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Climate Change Impacts: Negative

Greater wildfire activity could be a benefit, but too much fire could hamper regeneration.

- Wildfires may burn larger areas in northern Minnesota under climate change.
- The fire season could shift later into the growing season with warmer, drier summers. Early-season fires could also become more common with earlier snowmelt.
- Severe wind events or pest and disease outbreaks could create more fuel for large fires.

Insect pests and diseases may become more damaging under a warmer climate. New pests could arrive in northern Minnesota, such as western bark beetles.

Broadleaf species are increasing within Fire-Dependent Forests and may be further encouraged by climate change.

Deer populations are expected to increase with warmer winters, which may increase herbivory on preferred species.

Adaptive Capacity: Moderate-High

- Fire-Dependent Forests are generally tolerant of drought and disturbances, which are expected to increase in the future.
- These forests can contain a diversity of species, so some species will likely be available if others decline.
- Fire-Dependent Forests can persist on poor soils, so they could “retreat” to favorable locations on the landscape if conditions change.
- These forests may be more likely to shift to Mesic Hardwoods if fragmentation and broadleaf species limit fire activity.


John Almendinger, MN DNR

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100, under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species are presented roughly in order of importance for Fire-Dependent Forests. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	Tree Atlas	LANDIS	Tree Atlas	LANDIS
Red pine*	●	▲	▲	▼
Jack pine	●	▲	▼	▼
Quaking aspen	▼	▼	▼	▼
Paper birch	●	▼	▼	▼
Eastern white pine	▲	▲	▲	▲
Balsam fir -	▼	▼	▼	▼
Black spruce	▼	▼	▼	▼
Northern red oak +	▲	▲	●	▼
Red maple +	▲	▲	▲	▲
Bigtooth aspen	●	▲	▼	▲
Bur oak +	●	●	▲	●
White spruce	▼	▼	▼	▼
Northern pin oak +	▲		▲	
Northern white-cedar*	▼	▲	▼	▼

*Projected to increase in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

Site-level factors could make a Fire-Dependent Forest 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	←	**Regeneration**	→	Tree regeneration is not limited
Shade-tolerant species are encroaching	←	**Disturbance regime**	→	Natural conditions maintained by management or wildfire
Hazardous fuel loads or ladder fuels are present	←	**Hazardous fuels**	→	Fuel loads are within acceptable levels
Ongoing damage or looming threats	←	**Pests and diseases**	→	No current or imminent threats
Drought-prone soils, south-facing aspect, or high stocking level	←	**Drought risk**	→	Mesic soils, north-facing aspect, or moderate stocking
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

MESIC HARDWOOD FOREST

System Characteristics

Mesic Hardwood Forests generally occur on fine-textured soils or in areas with dense subsoil layers that retain water. These moist sites are generally protected from fire.

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

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

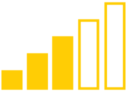
Common disturbances are individual canopy gaps or small patches created by wind, disease, or other fine-scale events.

Climate Change Vulnerability

Overall Vulnerability:

Moderate

Confidence:



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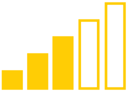


Medium agreement

Climate Change Impacts: Moderate

Droughts could increase stress in Mesic Hardwood Forests, and also raise the risk of pests, diseases and wildfire on drier sites.

Forest tent caterpillar and other pests may cause more frequent and severe damage in climate-stressed forests. New pests such as gypsy moth and Asian longhorned beetle present unknown risks.

Deer populations may increase with warmer winters, which may limit regeneration and the northward expansion of Mesic Hardwood species.

Deciduous forest types may have increased productivity with longer growing seasons and elevated carbon dioxide.

Earthworm activity may make these forests more susceptible to drought stress.

Adaptive Capacity: Moderate-High

- Mesic Hardwood Forests can contain many species, so some species may available if others decline.
- Stands with low species and structural diversity may have lower adaptive capacity.
- Species at their northern range limits, such as sugar maple and northern red oak, may fare well under climate change.
- These forests could gain territory lost by other forest types under either wetter or drier future conditions.
- Warmer temperatures may also allow these forests to expand into previously unsuitable areas.
- Increased carbon dioxide may increase the water-use efficiency of broadleaf species, reducing the risk of drought stress.
- Mesic Hardwood Forests on moist, rich soils may be buffered from short-term or seasonal droughts.


John Almendinger, MN DNR

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100, under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species are presented roughly in order of importance for Mesic Hardwood Forests. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	**Tree Atlas**	**LANDIS**	**Tree Atlas**	**LANDIS**
Sugar maple +	▲	▲	▲	▲
American basswood	●	▲	▲	▲
Paper birch	●	▼	▼	▼
Quaking aspen	▼	▼	▼	▼
Northern red oak +	▲	▲	●	▼
Red maple +	▲	▲	▲	▲
Bur oak +	●	●	▲	●
Ironwood +	▲		▲	
Green ash	●	▲	▲	▲
Black ash -	●	▲	▼	▼
Yellow birch	▲	▲	▼	▼
White spruce	▼	▼	▼	▼
Northern white-cedar*	▼	▲	▼	▼
Eastern white pine	▲	▲	▲	▲
White oak +	▲	▲	▲	▲

*Projected to increase in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

Site-level factors could make a Mesic Hardwood Forest 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	←	**Regeneration**	→	Tree regeneration is not limited
Ongoing damage or looming threats	←	**Pests and diseases**	→	No current or imminent threats
Earthworms have intensely altered litter and soil conditions	←	**Earthworms**	→	Earthworm impacts are mild or non-existent
Drought-prone soils, south facing aspect, or high stocking level	←	**Drought risk**	→	Mesic soils, north-facing aspect, or moderate stocking
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

WET FOREST

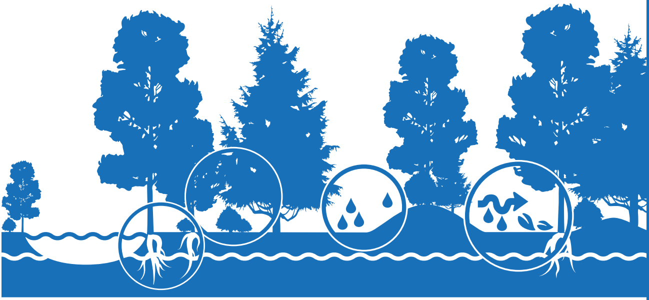
System Characteristics

Wet Forests occur where tree roots can reach the water table, but water does not remain above ground during the growing season (shallow depressions or the edges of lakes, rivers, and peatlands).

Black ash or northern white-cedar are usually dominant, with understories of shrubs like speckled alder.

Variations in topography and groundwater can result in alternating saturated and dry soils.

Soil moisture variability over space and time controls oxygen availability for root respiration, litter decomposition, and nutrient availability.

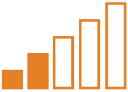


Climate Change Vulnerability

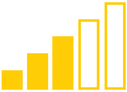
Overall Vulnerability:

High

Confidence:



Limited-medium evidence



Medium agreement

Climate Change Impacts: Negative

Changes in the timing or amount of precipitation could disrupt how Wet Forests function. For example, regeneration of several species is linked to the timing of intermittent wet and dry periods.

Extended droughts would cause significant damage to these shallow-rooted forests.

Black ash is already declining in some places in northern Minnesota.

Invasive species such as reed canarygrass and European buckthorn may increase under climate change.

Where emerald ash borer kills ash, sites may become inundated or colonized by invasive plant, shrub, or tree species.

Deer populations are expected to increase with warmer winters, which may hinder regeneration of northern white-cedar.

Adaptive Capacity: Low

- Many species in Wet Forests can tolerate intermittent wet and dry conditions, so they could survive short-term floods and droughts.
- Increased winter and spring precipitation could buffer summer drought stress if excess water is retained in low-lying areas.
- Wet Forests often exist as large complexes of a single species or a few species, which increases risk if dominant species decline.
- Isolated Wet Forests may be disconnected in terms of migration and gene flow across the landscape.
- Dutch elm disease is expected to limit the potential increase in American elm, and EAB is expected to reduce ash.


John Almendinger, MN DNR

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100, under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species are presented roughly in order of importance for Wet Forests. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	**Tree Atlas**	**LANDIS**	**Tree Atlas**	**LANDIS**
Black ash -	●	▲	▼	▼
Northern white-cedar*	▼	▲	▼	▼
Balsam fir -	▼	▼	▼	▼
Balsam poplar	▼		▼	
Red maple +	▲	▲	▲	▲
Black spruce	▼	▼	▼	▼
Paper birch	●	▼	▼	▼
Yellow birch	▲	▲	▼	▼
Quaking aspen	▼	▼	▼	▼
American elm	▲	▲	▲	▲
White spruce	▼	▼	▼	▼
Green ash	●	▲	▲	▲
American basswood	●	▲	▲	▲
Tamarack ~	▼		▼	

~ Projected to have mixed results across climate scenarios in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

*Projected to increase in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

Site-level factors could make a Wet Forest 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
Ditches, roads, or other changes have altered local hydrology	←	**Local hydrology**	→	Natural hydrology has been maintained
Regeneration limited by deer or non-native species	←	**Regeneration**	→	Tree regeneration is not limited
Ongoing ash decline or emerald ash borer in area	←	**Pests and diseases**	→	No current or looming threats
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
Simple structure and a single age class	←	**Structural diversity**	→	Diverse age classes and a complex structure

FLOODPLAIN FOREST

System Characteristics

Floodplain Forests occur in floodplains and on terraces next to streams and rivers.

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

Dominant tree species can tolerate saturated soils, prolonged inundation, and frequent erosion or deposition.

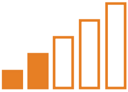
The understory often is open, with few shrubs or saplings.

Climate Change Vulnerability

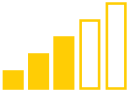
Overall Vulnerability:

Low-moderate

Confidence:



Limited-medium evidence



Medium agreement

Climate Change Impacts: Moderate-Positive

Changes in flood timing or intensity could impair regeneration because the regeneration requirements of several tree species are linked to these events.

Intense precipitation and extreme floods could cause excessive waterlogging and downcutting of riverbanks.

Dams and river channelization have already disrupted natural processes in many Floodplain Forests. Climate change could intensify these changes by increasing both high- and low-flow periods.

Invasive species such as reed canarygrass and European buckthorn may increase in northern Minnesota under climate change.

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

Adaptive Capacity: Moderate

- Floodplain Forests can withstand periodic flooding and drought, so they might be capable of tolerating some hydrologic changes.
- Many dominant and common tree species in Floodplain Forests are expected to remain highly competitive, so these forests are less likely to transition to other forest types.
- These forests are confined to floodplains and are not expected to expand to new territory in the future.

John Almendinger, MN DNR

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100, under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species are presented roughly in order of importance for Floodplain Forests. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	**Tree Atlas**	**Landis**	**Tree Atlas**	**Landis**
Silver maple +	▲		▲	
Black ash -	●	▲	▼	▼
Green ash	●	▲	▲	▲
American elm	▲	▲	▲	▲
American basswood	●	▲	▲	▲
Black willow -	▲		▲	
Eastern cottonwood	▲		▲	
Boxelder +	▲		▲	
Bur oak* +	●	●	▲	●

*Bur oak is projected to increase in LANDIS model results for the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

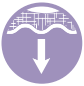
Site-level factors could make a Floodplain Forest more or less vulnerable to climate change. Here are some factors to consider as you visit a particular site.

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
Disconnected from natural floodplain or flow regime has been altered	←	**Local hydrology**	→	Natural hydrology has been maintained
Regeneration limited by deer or non-native species	←	**Regeneration**	→	Tree regeneration is not limited
Ongoing damage or looming threats	←	**Pests and diseases**	→	No current or looming threats
Topography and landscape position make the site prone to excessive flooding	←	**Flood risk**	→	Topography and landscape position reduce risk form excessive flooding
Droughty soils and high topographic position	←	**Drought risk**	→	Mesic soils and low topographic position
Simple structure and a single age class	←	**Structural diversity**	→	Diverse age classes and a complex structure

FORESTED RICH PEATLAND

System Characteristics

Forested Rich Peatlands are conifer-dominated wetlands on deep peat (>15 inches).



These systems exist on large, flat, poorly drained landscapes where the water table is typically below the peat surface and drops during the summer.

Topography is undulating, and hummocks remain dry and aerated enough to support trees and shrubs.

Peat accumulation requires saturated soils, cool conditions, and low oxygen levels to inhibit plant decomposition.

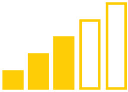
These systems are nutrient-poor, where nutrients typically come from rainfall, runoff from adjacent uplands, and groundwater.

Climate Change Vulnerability

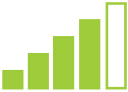
Overall Vulnerability:

High

Confidence:



Medium evidence



Medium-high agreement

Climate Change Impacts: Negative

Forested Rich Peatlands function in a narrow range of water table conditions.

If water tables rise due to intense rainfall or increased precipitation, these systems could convert to open peatlands.

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

Longer, warmer growing seasons could cause peat to dry and decompose, allowing other forest species to invade.

Sphagnum moss may not tolerate warmer conditions.

Milder winters may increase winterburn or promote more frequent outbreaks of pests like tamarack sawfly and eastern larch beetle.

These systems sometimes occur within a matrix of Fire-Dependent Forests (such as jack pine), increasing wildfire risk if northern Minnesota has a more active wildfire regime in the future.

Adaptive Capacity: Low

- Forested Rich Peatlands typically receive water through groundwater as well as precipitation, so they may be buffered from short-term droughts.
- Increased winter and spring precipitation could be retained in low-lying areas on the landscape and compensate for summer droughts.
- These systems require particular water regimes and peat soils, making it unlikely that they would expand to new territory.
- Isolated peatlands on the landscape may be disconnected in terms of migration and gene flow.

Casey Mcquiston, USFS

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100, under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species are presented roughly in order of importance for Forested Rich Peatlands. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See [Handler et al. (2014)] for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	**Tree Atlas**	**Landis**	**Tree Atlas**	**Landis**
Tamarack ~	▼		▼	
Black spruce	▼	▼	▼	▼
Northern white-cedar*	▼	▲	▼	▼
Balsam fir -	▼	▼	▼	▼
Speckled alder	Unknown - species hasn't been modeled			
Red maple +	▲	▲	▲	▲
Paper birch	●	▼	▼	▼
Eastern white pine	▲	▲	▲	▲
White spruce	▼	▼	▼	▼

~ Projected to have mixed results across climate scenarios in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).
*Projected to increase in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

Site-level factors could make a Forested Rich Peatland 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
Ditches, roads, or other changes have altered local hydrology	←	**Local hydrology**	→	Natural hydrology has been maintained
Ongoing damage from forest pests or diseases	←	**Pests and diseases**	→	No current or looming threats
Small site with low groundwater inputs, prone to extreme water table changes	←	**Size and connectivity**	→	Large wetland with groundwater inputs and a stable water table
Adjacent to fire-prone forest types, and wildfires would be hard to suppress	←	**Wildfire susceptibility**	→	Wildfire risk is low due to neighboring lands and access
Simple structure and a single age class	←	**Structural diversity**	→	A diversity of age classes on the site or across the landscape

ACID PEATLAND

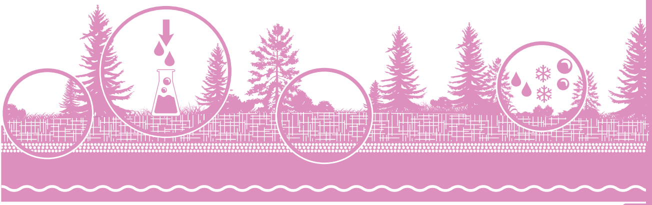
System Characteristics

Acid Peatlands are dominated by conifers, low shrubs, or graminoids. Trees are sparse and stunted.

Acid Peatlands are highly acidic (pH < 5.5) and very nutrient poor, with water inputs mostly from rainfall.

These forests occur in basins with non-calcareous soils and on lake plains with impermeable clayey and loamy soils, which block groundwater movement through the overlying peat.

Peat accumulation requires saturated soils, cool conditions, and low oxygen levels to inhibit plant decomposition.

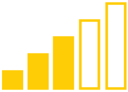


Climate Change Vulnerability

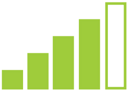
Overall Vulnerability:

High

Confidence:



Medium evidence



Medium-high agreement

Climate Change Impacts: Negative

If water tables rise due to intense rainfall or increased precipitation, these systems could convert to open peatlands.

- Acid Peatlands are more vulnerable to water level changes than Forested Rich Peatlands because they have limited groundwater connection.

Acid Peatlands may be more vulnerable to water table changes where roads, drainage ditches, or beaver dams have altered local hydrology.

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

Sphagnum moss may not tolerate warmer conditions.

Milder winters may increase winterburn or promote more frequent outbreaks of pests like tamarack sawfly and eastern larch beetle.

Acid Peatlands could be exposed to more fire from neighboring Fire-Dependent Forests, especially if northern Minnesota has a more active wildfire regime in the future.

Adaptive Capacity: Low

- Acid Peatlands receive water only through precipitation, so they may not tolerate short-term droughts.
- Increased winter and spring precipitation could be retained in low-lying areas on the landscape and compensate for summer droughts.
- Acid Peatlands require particular water regimes and peat soils, so it is unlikely they would expand to new territory.
- Acid Peatlands are more widely distributed on the landscape than Forested Rich Peatlands.
- Acidic conditions may limit competition from encroaching forest types in the future.
- These forests are very slow to recover following disturbance.


John Almendinger, MN DNR

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100 under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species are presented roughly in order of importance for Acid Peatlands. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	**Tree Atlas**	**Landis**	**Tree Atlas**	**Landis**
Tamarack ~	▼		▼	
Black spruce	▼	▼	▼	▼
Bog birch	Unknown - species hasn't been modeled			

~ Projected to have mixed results across climate scenarios in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

Site-level factors could make an Acid Peatland 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
Ditches, roads, or other changes have altered local hydrology	**Local hydrology**	Natural hydrology has been maintained
Ongoing damage from forest pests or diseases	**Pests and diseases**	No current or looming threats
Small site without groundwater inputs, prone to extreme water table changes	**Size and connectivity**	Large wetland with groundwater inputs and a stable water table
Adjacent to fire-prone forest types, and wildfires would be hard to suppress	**Wildfire susceptibility**	Wildfire risk is low due to neighboring lands and access
Simple structure and a single age class	**Structural diversity**	A diversity of age classes on the site or across the landscape

MANAGED ASPEN

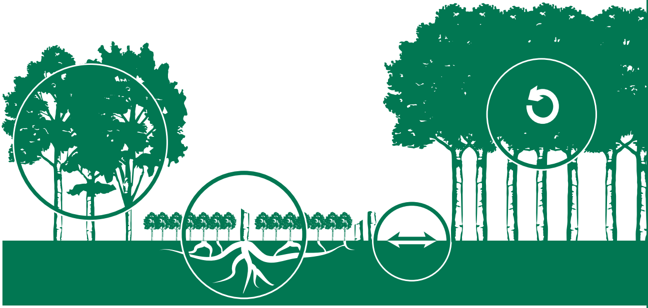
System Characteristics

Quaking aspen, bigtooth aspen, and balsam poplar are collectively referred to as “aspen” in this system.

These early-successional, shade-intolerant species reproduce heavily from root suckers and will succeed to other forest types in the absence of disturbance.

Aspen grows on a wide range of soil types and landforms.

Aspen is typically managed in even-aged rotations from 35 to 60 years, depending on site conditions and management objectives.

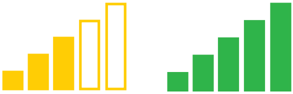


Climate Change Vulnerability

Overall Vulnerability:

Moderate-high

Confidence:



Medium evidence

High agreement

Climate Change Impacts: Moderate-Negative

Drought stress during the growing season could cause stress and mortality for aspen on drier sites.

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

Earthworm activity may make these forests more susceptible to drought stress.

Deer populations are expected to increase with warmer winters, so herbivory may increase.

Multiple harvests in Managed Aspen forests may lead to a decline of nutrient status or productivity over time, which might make these sites more susceptible to climate-related stress.

Aspen may have increased productivity with longer growing seasons and elevated carbon dioxide.

Adaptive Capacity: Moderate

- Managed Aspen stands on mesic soils or low landscape positions may be less vulnerable to drought.
- Warmer growing-season temperatures might encourage more suckering after harvests.
- Increased wildfire activity could help maintain aspen on the landscape.
- Clonal reproduction is an advantage, particularly for aspen clones better adapted to future conditions.
- Short-rotation, even-aged systems tend to have low species and structural diversity, lowering the adaptive capacity of Managed Aspen across the landscape.
- There is a limited history of repeated, short-rotation aspen management, and many questions remain about how these systems will respond over time.


Eli Sagor, Univ. of MN

Tree Species Projections

Projected changes for individual tree species across the Laurentian Mixed Forest Province by 2100 under low and high climate scenarios, as modeled by Tree Atlas and LANDIS. Species marked with (+) or (-) have traits that might make them more or less adaptable to future change than indicated by the Tree Atlas model. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	Tree Atlas	Landis	Tree Atlas	Landis
Quaking aspen	▼	▼	▼	▼
Bigtooth aspen	●	▲	▼	▲
Balsam poplar	▼		▼	

Site-level Considerations

Site-level factors could make a Managed Aspen 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 dominates the site and other species are absent	←	**Species diversity**	→	Site has a diverse mix of native tree species suitable to its NPC
Simple structure and a single age class	←	**Structural diversity**	→	A diversity of age classes on the site or across the landscape
Ongoing pest damage and earthworms have altered soil conditions	←	**Pests and earthworms**	→	Site is free of pests and earthworms
Ongoing aspen decline or diseases like *Hypoxylon* canker	←	**Decline 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
Deer, health issues, or stand age may limit regeneration	←	**Regeneration potential**	→	Regeneration is likely to be good
Requires frozen ground or deep snow	←	**Access and operability**	→	Can occur in seasons other than winter

MANAGED RED PINE

System Characteristics

Red pine seedlings are planted at 400 to 800 trees per acre in single-species, even-aged plantations with extensive site preparation.

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

Thinning treatments ideally begin 20 to 30 years after planting and continue every 15 years.

Final harvest occurs at 60 to 70 years in intensively managed stands, or 120 years or more in long-rotation systems.

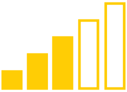
Most red pine plantations in Minnesota have been planted on suitable sites with sandy, nutrient-poor soils.

Climate Change Vulnerability

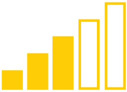
Overall Vulnerability:

Moderate-high

Confidence:



Medium evidence



Medium agreement

Climate Change Impacts: Moderate-Negative

- Drier summers or droughts may reduce survival of planted seedlings.
- Dense, overstocked stands are at greatest risk from droughts and associated pests and diseases.
- Diseases and insect pests may become more damaging under warmer conditions.
- New agents such as Heterobasidion root disease or western bark beetles may become problematic in northern Minnesota.
- Red pine is sometimes browsed by deer, and deer populations are anticipated to increase with warmer winters.
- Competition from hazel and European buckthorn could intensify under climate change.
- Understory ladder fuels like balsam fir could make red pine forests more vulnerable to crown fires.

Adaptive Capacity: Moderate-Low

- Red pine is generally drought-tolerant, and thinning can reduce drought stress in managed stands.
- Low structural and species diversity reduces options for red pine stands to respond to future disturbances or 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 climate conditions.
- Managed Red Pine occurs across a range of soil types, from dry to mesic.
- Red pine has typically been planted in suitable locations in Minnesota.


Eli Sagor, Univ. of MN

Tree Species Projections

Modeling results are mixed for red pine across northern Minnesota. Tree Atlas projects that red pine may maintain or increase overall suitable habitat, although suitable habitat may shift from north-central Minnesota to northeast Minnesota. LANDIS-II projects that red pine will generally increase in under a low climate scenario and decrease under a high climate scenario.

Projected changes in suitable habitat (Tree Atlas) and biomass (LANDIS) for red pine across the Laurentian Mixed Forest Province by 2100, under low and high climate scenarios. See Handler et al. (2014) for more detail. The legend for this table is on page 21.

	Low Climate Change (PCM B1)		High Climate Change (GFDL A1FI)	
Species	**Tree Atlas**	**LANDIS**	**Tree Atlas**	**LANDIS**
Red pine*	●	▲	▲	▼

*Projected to increase in the Northern Minnesota Drift & Lake Plains Ecological Section (Lucash et al. 2017).

Site-level Considerations

Site-level factors could make a Managed 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 suitable to its NPC
Simple structure and a single age class	←	**Structural diversity**	→	Diverse age classes and complex structure
Ongoing damage or looming threats	←	**Pests and diseases**	→	No looming threats; stand is vigorous and healthy
Site is unmanaged and overstocked	←	**Management history**	→	Site has been thinned regularly
Drought-prone soils, south-facing aspect, or high stocking level	←	**Drought risk**	→	Mesic soils, north-facing aspect, or moderate stocking
Deer, health issues, or competition may limit planting success	←	**Planting success**	→	Planting is likely to be successful
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, www.nrs.fs.fed.us/pubs/52760). 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.

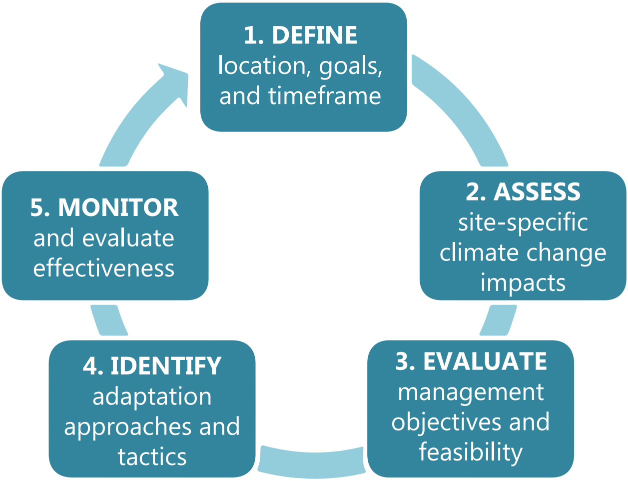
CHANGE

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

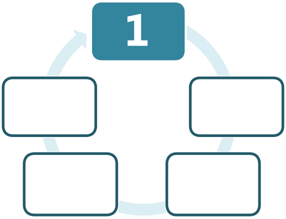
Adaptation Workbook

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: www.nrs.fs.fed.us/pubs/52760, or use the online version at: www.adaptationworkbook.org.

There are five steps in the Adaptation Workbook, which are explained in the following pages. **Use these pages to take notes and brainstorm for your own projects!**



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?

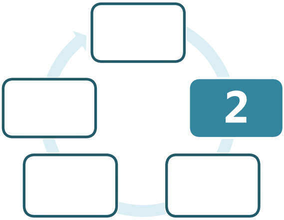
Step 1: Define location, management goals, and time frames

Project Area and Location:

Ecosystems or Management Areas:	Management Goals and Objectives: (list separately and number)

Where are you working and what are your goals?

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



This step emphasizes how climate change may affect your site based on local conditions. You can use the summary information in this guide as a starting point for broad trends, or review the *Minnesota Forest Ecosystem Vulnerability Assessment* (www.nrs.fs.fed.us/pubs/45939).

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

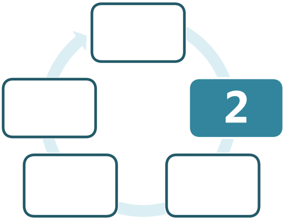
Your property may be more or less vulnerable to broad-scale climate impacts. Factors that may influence risk for a specific location include:

- 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

Regional Climate Impacts: (mark all that apply)	Site-Specific Impacts:
☐ Warmer temps, especially in winter	
☐ Increased winter and spring precip	
☐ Drier summer conditions	
☐ More heavy precip	
☐ Shorter winters and more variable snowpack	
☐ More high streamflow days in winter and spring	
☐ More low streamflow days in summer and fall	
☐ Longer growing seasons	
☐ Changes in phenology	
☐ Declines in boreal species	
☐ Increases in southern species	
☐ More wildfire activity	
☐ More damage from pests and pathogens	
☐ Increases in nonnative species	
☐ Others?	

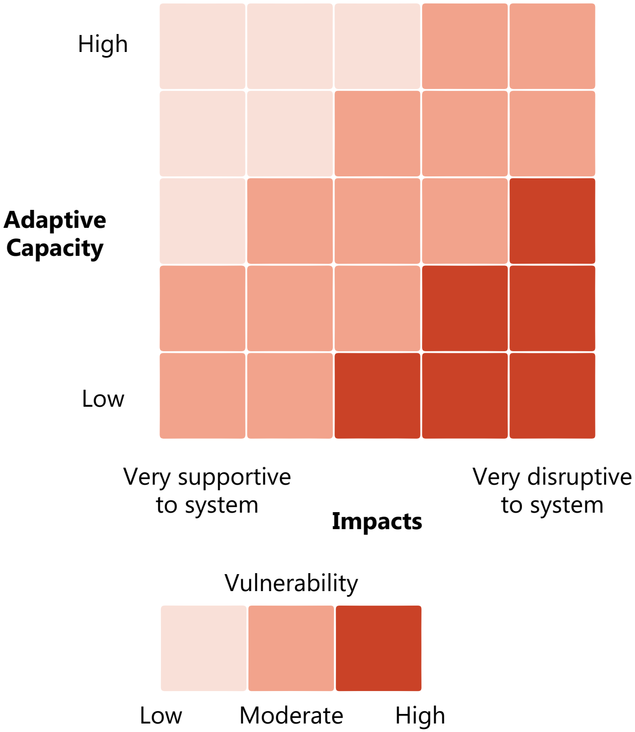
Step 2: Assess site-specific climate change impacts and vulnerabilities (continued)



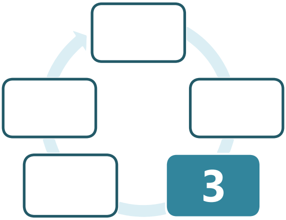
This step also asks you to consider the overall vulnerability of your site to climate change. **Vulnerability** is the susceptibility of a system to adverse effects from climate change. Vulnerability depends on the potential impacts from climate change, as well as the ability of the system to tolerate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

After thinking about the unique site conditions on your property or project area, you'll determine an overall rating of vulnerability for your site. You can make separate vulnerability determinations for different forest types, management areas, or specific topics, depending on how you've organized your management goals and objectives.

Use this chart to consider vulnerability for your site. Take notes for individual forest types or management areas, or the project area as a whole.

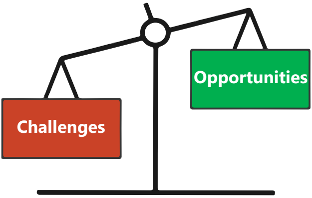


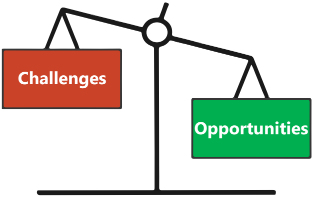
Step 3: Evaluate management objectives and feasibility



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:





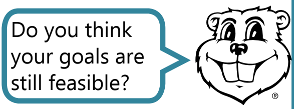
Feasibility Rating

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

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

Step 3: Evaluate management objectives and feasibility

Management Objectives: (list #s from Step 1)	Feasibility (High/Med/Low) and Notes: (explain feasibility rank)



Step 4: Identify adaptation approaches and tactics

This step helps you identify and evaluate specific management actions that can help prepare for changing conditions. You'll generate a custom set of adaptation tactics—prescriptive actions 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 in the Midwest and Northeast. The menu can help you brainstorm management tactics for your particular needs, and it helps connect the dots between your management actions and your broader adaptation intentions. For more complete descriptions of the Adaptation Strategies and Approaches listed in the menu, see the full version of the FAR (www.nrs.fs.fed.us/pubs/52760).

The 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.

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.

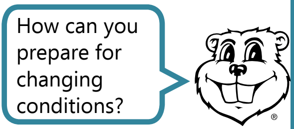
10.1. Promptly revegetate sites after disturbance.

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 4: Identify adaptation approaches and tactics

Adaptation Approach: (list #s from Menu on pages 79–81)	Management Tactics: (specific notes about how you'll implement each idea)



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?

Step 5: Monitor and evaluate effectiveness

Monitoring Variable: (what will you monitor?)	Implementation and Criteria: (how will you conduct the monitoring, and what is your threshold for success?)

What do you need to pay attention to over time?

RESOURCES AND LINKS

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

Minnesota-Specific Information

All of these resources are available at:
www.ForestAdaptation.org/MN_Resources

Handouts of Individual Tree Species Projections: 1-page summaries of climate change projections for tree species across several large landscapes in Minnesota and other states.*

Minnesota Native Plant Communities: Descriptions and classification of NPCs.

Minnesota DNR Tree Species Suitability Tables: Tool to help decide which species to favor in different NPCs.

Minnesota DNR Climate Change Information: A collection of useful links and reports.

Adapting to a Changing Climate: The Minnesota Pollution Control Agency leads the Minnesota Interagency Adaptation Team and collects examples of adaptation across the state.

*See the following reference for a more detailed assessment for the Minnesota Drift and Lake Plains: Lucash, M.S., R.M. Scheller, E. J. Gustafson, B. R. Sturtevant. 2017. LANDIS-II Visualization for North Central MN (212N).

National-Scale Information

Climate Change Atlas: Projected suitable habitat for individual tree species under climate change. www.fs.fed.us/nrs/atlas/

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

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

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

U.S. Global Change Research Program: A national-level program that produces comprehensive reports on observed and projected climate trends. www.globalchange.gov

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

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