Managing Forests for Climate Resiliency
IN RHODE ISLAND

Contents

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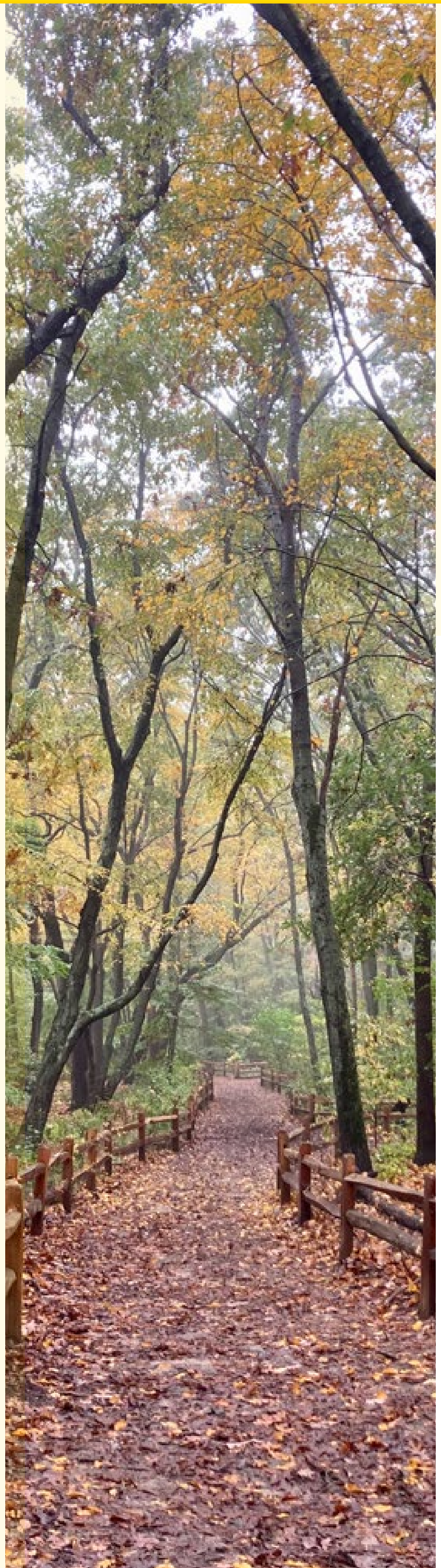


Introduction

Forest management activities are constantly changing to accommodate new challenges, and it is becoming increasingly important that forest and land management planning intentionally consider a changing and uncertain climate. This guide is designed to assist foresters and natural resource managers who are interested in integrating climate change information into the plans that they write and projects that they implement. The information presented here is intended to support the development of forest management and stewardship plans that address climate change impacts and identify management actions that support landowner goals in the face of changing conditions.

The first section of this guide summarizes the impacts of climate change on forests in Rhode Island. This summary is based on the results of several regional vulnerability assessments and published research papers; a list of more comprehensive resources is also available for those who wish to explore this topic more deeply.

The second section of this guide outlines how foresters and natural resource managers can integrate climate change considerations into forest management and stewardship plans. It highlights the key components of a climate-informed plan to enable users to start thinking about climate change impacts and adaptation actions. It draws on the Northern Institute of Applied Climate Science's Adaptation Workbook (adaptationworkbook.org**). The Workbook provides a comprehensive climate adaptation planning process, and it may be helpful as a supplement to this guide for larger or more complex forest management projects.**

Forest Management Options for Adaptation and Mitigation

This guide focuses on helping foresters and natural resource managers identify adaptation and mitigation actions in response to changing climate conditions. **Adaptation** actions actively address climate change impacts that are already occurring or are expected to occur in the future, such as more intense storms. **Mitigation** actions work to reduce the atmospheric carbon dioxide and other greenhouse gases responsible for climate change, either through emissions reductions or through carbon sequestration in vegetation. These "natural climate solutions" are conservation, restoration, and improved land management actions that increase carbon storage or avoid greenhouse gas emissions in landscapes; learn more at https://nature4climate.org. In forests, mitigation actions focus on reducing carbon losses from forests (such as when forest lands are converted to other uses) and increasing the amount of carbon dioxide that trees uptake and then store in forests and wood products. Adapting forests to changing conditions is a critical part of planning for mitigation.

Many adaptation actions create mitigation benefits because well-functioning ecosystems are more likely to persist as forests over the long-term, which can help to maintain their ability to uptake and store carbon. Stated another way, adapting forests to changing conditions reduces the risk of carbon losses from disturbances that are increasing due to climate change, which can result in carbon emissions. Forests that are not adapted to future conditions may be at greater risk of carbon losses. Adaptation projects can be designed to have mitigation benefits when carbon sequestration and storage are identified as goals at the outset of the adaptation planning process.

A wide range of forest management actions can be used to support climate adaptation and carbon mitigation. Climate adaptation actions span a continuum of options: resisting change, enhancing the resilience of ecosystems to change, and transitioning systems to better match expected future conditions. Actions to support carbon mitigation in forests can be described in terms of avoiding forest conversion, reducing the risk of carbon emissions from forests, and enhancing forest carbon sequestration. Multiple options are likely to be used across a property or landscape, and possibly even in the same stand.

Climate Adaptation Options

Adaptation actions intentionally address climate change impacts that are already occurring or are expected to occur in the future.

Resistance: Actions that are designed to defend against or prevent changes to ecosystems from climate change and other stressors.

Resilience: Actions that enhance the capacity of ecosystems to accommodate a temporary change in conditions as ecosystems respond to disturbances, and then "bounce back" and return to the same forest or ecosystem type.

Transition: Actions that intentionally facilitate ecosystem change in anticipation of or in response to changing conditions so that the ecosystem will be better adapted to the anticipated future conditions.

Carbon Mitigation Options

Mitigation actions reduce greenhouse gas emissions and maintain or increase rates of carbon sequestration in forests and natural ecosystems.

Avoid Forest Loss: Actions that reduce the conversion of forests to another land use or land cover type, such as development (e.g., residential housing, solar energy projects, etc.), agriculture, or other non-forest ecosystem types.

Reduce Carbon Emissions: Actions that reduce the risk of carbon emissions within forest ecosystems, such as those from insect pests, wildfire, drought, or other climate-related stressors, or forest harvest that reduce tree growth and increase tree mortality over the long term.

Enhance Sequestration: Actions that increase the rate of carbon uptake in the ecosystem, often through enhancing the rate of photosynthesis in trees and other vegetation.

Principles for Managing under Climate Change

Land managers have many tools available to begin to address climate change; however, management planning could be expanded to consider new issues, spatial scales, timing, and prioritization of efforts. The following principles can serve as a starting point for a new perspective:

Prioritization: It will be increasingly important to prioritize actions for adaptation based both on the vulnerability of resources and on the likelihood that actions to reduce vulnerability will be effective.

Flexible and adaptive management: Adaptive management provides a science-based, experimental framework for decision-making that maintains flexibility and incorporates new knowledge and experience over time.

"No regrets" decisions: Actions that result in a wide variety of benefits under multiple scenarios and have little or no risk may be initial places to look for near-term implementation.

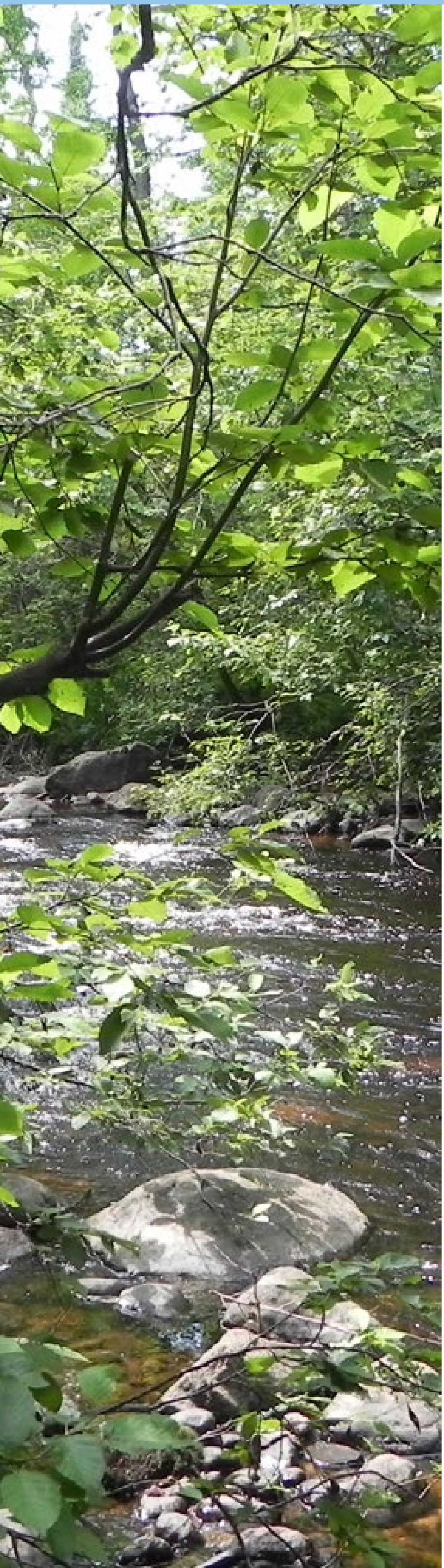
Precautionary actions: Where vulnerability is high, precautionary actions to reduce risk in the near term may be extremely important, even with existing uncertainty.

Variability and uncertainty: Climate change is much more than increasing temperatures; increasing climate variability will lead to equal or greater impacts that will need to be addressed.

Integrating mitigation: Many adaptation actions are complementary with goals to mitigate greenhouse gas emissions. Adapting forests to future conditions can help maintain and increase their ability to take up and store carbon, providing a foundation for mitigation.

Managing multiple stressors: Impacts from climate change are often first felt through their effects on ecological disturbances (wildfire, flood, insects and disease). Managing ecosystems for resilience to these forces is a wise place to focus management actions.

(*Adapted from Forest Adaptation Resources*[1])



Observed Climate Change

The average annual temperature in Rhode Island has risen more than 3°F since the late 1800s, with temperatures rising in all seasons.[2, 3] Historical records show that warming has accelerated in recent decades[2] (Figure 1).

Average annual precipitation also increased by about 4.75 inches in Rhode Island since recordkeeping began in the late 1800s.[2] (Figure 2). The greatest increase in precipitation has been in the fall, with moderate increases in the spring and smaller increases in the winter and summer. Extreme precipitation events have increased substantially, particularly over the past several decades.[4, 5, 6] Additionally, warmer temperatures have caused a greater proportion of precipitation to fall as rain rather than snow.[4]

While there is increasing and unequivocal evidence of these trends, it is important to note the high level of natural climate variability in the New England region. Temperature, precipitation levels, and the occurrence of extreme weather events fluctuate daily, annually, and over the course of many years. However, research has demonstrated that climate change has contributed to the increasingly extreme variability of these trends over the past several decades.

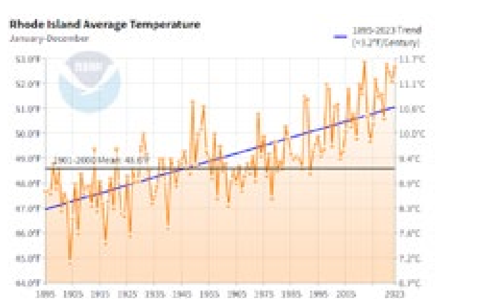


Figure 1. *Average annual temperature for Rhode Island during 1895-2023. The gray line reflects the average during 1901-2000, and the blue line shows the trend during the entire record. Average temperatures have risen more than 3.2°F since the late 1800s.* Source: NOAA National Centers for Environmental Information[2]

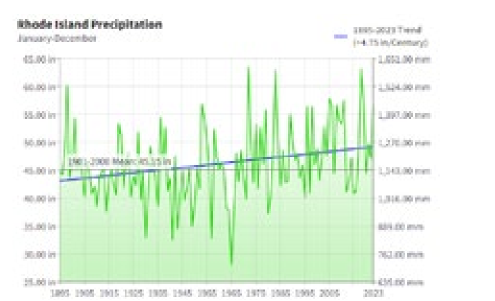


Figure 2. *Average annual precipitation for Rhode Island during 1895-2023. The gray line reflects the average during 1901-2000, and the blue line shows the trend during the entire record. Average precipitation has increased by about 4.7 inches since the late 1800s.* Source: NOAA National Centers for Environmental Information[2]

Future Climate Change

Global climate models can help us understand how conditions may change in the future and provide an opportunity to understand the range of potential changes that may occur depending on future greenhouse gas emissions (Figure 3).

All available climate models agree that temperatures will increase across all seasons in the region over the next century. The projected increase in annual temperature ranges from 5.0°F to 8.8°F by the end of the century, depending upon energy use and emissions[3] (Table 1). Growing seasons will continue to lengthen as a result of warmer temperatures.

It is harder to predict how future precipitation will change, but total annual precipitation is generally expected to increase through the end of the century[6]. The greatest precipitation increases are expected to occur during the winter, when warmer temperatures will result in more winter precipitation falling as rain instead of snow. There is greater uncertainty whether precipitation will increase or decrease during the growing season. Even with moderate precipitation increases, there may be greater moisture stress in summer or fall because higher temperatures lead to greater water loss from evaporation and transpiration[7].

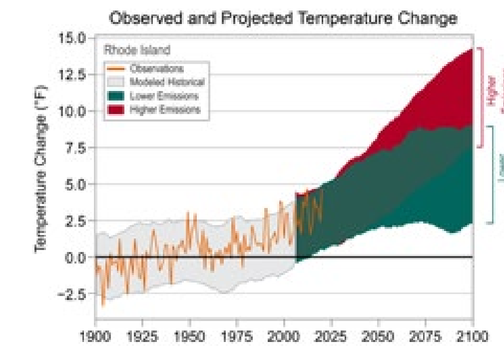


Figure 3. *Observed and projected changes in temperature for Rhode Island. Observed data are for 1900–2020. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Shading indicates the range of annual temperatures from the set of models. Historically unprecedented warming is projected during the 21st century. Less warming is expected under a lower emissions future (the coldest years being about 1°F warmer than the long-term historical average; green shading) and more warming under a higher emissions future (the hottest years being about 10°F warmer than the hottest year in the historical record; red shading).* Source: NOAA National Centers for Environmental Information[3]

CLIMATE INDICATOR		OBSERVED 1971-2010	MID-CENTURY Projected Change (2040-2069)	END OF CENTURY Projected Change (2070-2099)
Average Temperature	Annual	50.6°F	Increase by 4.2 - 5.5°F	Increase by 5.0 - 8.8°F
Maximum Temperature	Summer	78.9°F	Increase by 4.2 - 6.0°F	Increase by 5.0 - 8.9°F
	Fall	62.3°F	Increase by 4.5 - 5.6°F	Increase by 5.1 - 9.1°F
Minimum Temperature	Winter	17.1°F	Increase by 4.7 - 6.1°F	Increase by 5.5 - 9.9°F
	Fall	39.4°F	Increase by 4.3 - 5.6°F	Increase by 5.1 - 9.3°F
Days with Maximum Temperature > 86°F		11 days	Increase by 20 - 32 days	Increase by 26 - 56 days
Days with Minimum Temperature ≤ 32°F		111 days	Decrease by 32 - 42 days	Decrease by 38 - 64 days

Table 1. *Observed and projected change in climate in Rhode Island (median values). Future changes in temperature variables highlight the total change that is expected to occur by middle (2040-2069) and end of century (2070-2099) based on 21 climate models and the "low" (RCP 4.5) and "high" (RCP 8.5) pathways of future greenhouse gas emissions.* Source: MACAv2 dataset, Climate Toolbox (https://climatetoolbox.org)[8]

Climate Impacts on Forests

Forests experience both direct and indirect impacts from a changing climate. Although it is hard to anticipate all of the ways that forests may change, there is a growing amount of information about how forests in southern New England are likely to change.[9] This information can be combined with professional expertise to better understand how a particular forest may respond to changing environmental conditions, including climate, land use, management, and biological invasions. The following paragraphs provide a short summary of climate change impacts on Rhode Island's forests. See the Resources and References sections of this document for additional details.

Extreme precipitation and more frequent and intense weather events are expected in the Northeast throughout the next century. Extreme rain events are occurring more often, and this trend is expected to continue.[4, 5, 6] Heavy rain events can lead to increased erosion, flooding, soil loss and sedimentation in nearby streams that reduces water quality and can affect aquatic organisms. These impacts can change the economic viability of forest management by altering when lands can be accessed or when operations can take place and by also increasing the costs of maintaining or improving forest infrastructure. Where forests are used for recreation, damage from extreme precipitation and weather events can create hazards and increase the need for costly safety interventions.

Soil moisture patterns will change, with greater risk of drier soil conditions or drought later in the growing season. Seasonal changes in precipitation are expected across Rhode Island, with a greater proportion of total rainfall coming in heavy precipitation events. Warmer winters are already leading to earlier snowmelt in the spring,[4, 10] and longer growing seasons combined with altered patterns of precipitation and warmer temperatures may lead to more frequent moisture stress in summer and fall. Drought conditions have been linked to the decline of oak and ash species in the Northeast and can generally hinder seed germination and establishment. Warmer and drier weather conditions may also increase the potential for wildfire.

Forest insect pest and pathogen outbreaks are expected to increase in occurrence and inflict more damage within Northeastern forests. These events contribute to tree stress and mortality, difficult management scenarios for landowners and managers, and potentially dangerous recreation conditions. Some of the non-native insect pests of greatest concern within Northeastern forests include spongy moth, hemlock woolly adelgid, emerald ash borer, Asian long-horned beetle, and southern pine beetle. In particular, hemlock woolly adelgid and southern pine beetle are expanding northward because warmer winters have reduced the occurrence of extremely low temperatures that cause insect mortality.

Deer populations will be affected and impact herbivory patterns. Warmer winter temperatures and reduced snow depth are expected to reduce the energy requirements for white-tailed deer and increase access to forage during winter months, enabling them to expand the size and range of their populations. This is likely to impact plant regeneration, structure, and species diversity. Expanded deer herbivory could disproportionately affect regeneration and recruitment of preferred species like oak, especially where snowpack and winter severity are reduced.

Many non-native, invasive species are expected to increase. Invasive species can exploit unstable conditions resulting from the combined stress of multiple climate-related disturbances, and novel invasive species may expand their range into the Northeast under future climate conditions. These factors will vary geographically and by forest community, and will likely depend heavily on human influence both in terms of introduction and treatment.

Many Northeastern tree species will face increasing stress from climate change. Northern tree species such as Eastern white pine, sweet birch, and pitch pine are projected to have reduced suitable habitat across Rhode Island at the end of the century[11, 12] (Table 2, Appendix 1). These species may be less able to take advantage of longer growing seasons and rising temperatures than tree species that are able to tolerate warmer conditions, especially if temperatures increase substantially. Regeneration failure may become increasingly common for some species. Although habitat suitability is expected to decrease over time, trees that are already established may respond favorably to slightly warmer and more favorable conditions during the next several decades.

Conditions may become more favorable for some tree species. Temperate or southern tree species are generally expected to have increased suitable habitat[12, 13] (Table 2, Appendix 1). This includes many oak and hickory species that are currently found in Rhode Island, as well as other species that are more common farther south. Several other minor species currently found in places like New Jersey, Pennsylvania, and Maryland are projected to increase, but fragmentation may limit the natural migration of these species.

Species and forest types that are more tolerant of disturbance have less risk of declining across the landscape. Climate change is generally expected to increase disturbances over the next century.[13] As hurricanes, storms, floods, pest outbreaks, or other events become more frequent or damaging, tree species and forest types that are better able to tolerate these disturbances may be favored, such as red maple. Although disturbance-adapted ecosystems have a higher threshold for disruption, these ecosystems may also show declines in response to substantially increased disturbance frequency or intensity.

Low-diversity systems are at greater risk. Studies have consistently shown that more diverse systems are more resilient to disturbance, and low-diversity systems have fewer options to respond to change. There are many aspects to forest diversity—species composition, structural characteristics, and genetics—and increases in each of these can generally help reduce risk and increase adaptability.

Tree Species Change

One tool used to estimate changes in habitat suitability for tree species is the USDA Forest Service Climate Change *Tree Atlas* (https://www.fs.usda.gov/nrs/atlas/tree/). The *Tree Atlas* uses climate models to assess future habitat suitability and capability of individual species to cope or persist with climate change.[13] The *Tree Atlas* is useful for understanding the trends projected for a species in a particular region, which can be informed by local expertise about how a species may perform at a given site. Projected trends are available for most tree species in Rhode Island under low and high emissions scenarios.

Model projections can't account for all factors that influence future species success. Human choices will continue to influence forest distribution, especially for tree species that are projected to increase. Exotic pests and diseases are likely to impact the health of Rhode Island forests, but the *Tree Atlas* doesn't include these kinds of variables. Despite these limitations, the models provide useful information about future expectations. It's best to think of these projections as indicators of possibility and potential change.

Climate Change Projections for Individual Tree Species in Rhode Island.
Tree species are sorted by the projected capability of the species' ability to cope or persist with climate change. Species with low model reliability are excluded from the table.

Good Capability	Good Capability	Poor Capability	Mixed Capability
American beech	Red maple	Balsam fir	American elm
American holly	Shagbark hickory	Balsam poplar	Eastern white pine
American hornbeam	Sugar maple	Eastern hemlock	Pitch pine
Bigtooth aspen	Yellow birch	Hackberry	Scarlet oak
Black oak	Yellow-poplar	Paper birch	
Black gum		Quaking aspen	
Chestnut oak		Red pine	
Eastern red cedar		Sweet birch	
Mockernut hickory			
Northern red oak		**Fair Capability**	
Pignut hickory		Black cherry	

Table 2. *Climate Change Projections for Individual Tree Species in future climate conditions (end of the 21st century). Capability is a rating of the species' ability to cope or persist with climate change in this region based on suitable habitat change (statistical modeling), adaptability (literature review and expert opinion), and abundance (USDA FS FIA data).* ***Good Capability*** *indicates a projected increase in capability of species to thrive in Rhode Island by 2100,* ***Poor Capability*** *indicates a projected decrease in capability by 2100.*

Capability projections can help identify species that may be at risk from climate change. This information can be integrated into decision-making that also considers how local site conditions and other factors (that are not included in the model) may affect a species response to changing conditions. More information on capability, suitable habitat, adaptability, and migration potential are included at the end of this guide (Appendix 1) and at https://doi.org/10.2737/Climate-Change-Tree-Atlas-v4[11]

Forest Vulnerability

Climate change will not affect all forest species, communities, and parts of the landscape in the same way. Tree species tend to grow with common associations called forest types, forest systems, or natural communities. As the climate changes, forest composition, structure, and function will shift. There will not likely be a simple direct relationship between climate and forest condition because climate is not the only set of factors influencing forests, and climate change will affect different forests in different ways.

Impacts to individual forest types are summarized at right. See the Climate Change and New England and New York Forest Ecosystem Vulnerability Assessment and Synthesis[9] for more details.

Central hardwood-pine forests, typically dominated by oak, have relatively low vulnerability to climate change. This ecosystem supports a high number of tree species and occurs over a wide range of habitats. Many species are tolerant of dry soil conditions and fire, although young trees may be sensitive to severe drought and fire. Several oak and hickory species are likely to benefit from projected changes in climate.

Transition hardwood forests, which include a diverse mix of species such as sugar maple, red maple, yellow birch, black cherry, and red oak, are moderately vulnerable to climate change. Because these forests vary widely, there is a wide variety of potential outcomes depending upon the interaction of climate impacts and local conditions. Over the next several decades, change in these forests is expected to be driven primarily by a number of current stressors, such as insect pests and invasive species, more than climate change.

Northern hardwood forests are sensitive to reduced soil moisture that will occur on some sites under warmer and drier conditions. Eastern hemlock, yellow birch, and to a lesser extent, sugar maple, are projected to decline under scenarios of greater warming. Not all areas are expected to be affected equally because this forest type is widespread across many different areas. Locations that face north, at higher elevations, or farther north in the region are generally expected to be less vulnerable. Some hardwood species from farther south could see new habitat in the region as their ranges expand northward.

Pitch pine-scrub oak forests are a fire dependent community that occurs on particularly warm and dry sites. Habitat for pitch pine may decrease slightly under climate change, but these forests are generally considered to have lower vulnerability to climate change than other types because the dominant species are at the northern extent of their ranges and have greater tolerance to hotter and drier conditions. Insect pest species such as southern pine beetle have been observed expanding northward, and these movements are expected to continue due to higher temperatures.

Lowland and riparian hardwood forests are also moderately vulnerable to climate change. Climate change is expected to alter the hydrologic regimes in riparian and lowland systems, which may amplify the effects of insect pests and invasive species. High diversity and the presence of southern species raise the adaptability of these forests. There is high uncertainty regarding future precipitation patterns and how flooding or other hydrologic changes may affect these forests, and many impacts will be strongly influenced by local conditions.

Addressing Climate Change in Forest Management

Climate change can be integrated into Forest Stewardship Plans and other management plans by taking extra time to consider how climate change may affect a particular location and what management actions can help meet landowner goals given changing conditions. Many sustainable forestry practices that you may already be doing, such as controlling invasive species and improving forest health, become even more important for improving forest resilience to climate change. In other situations, it may be necessary to alter management activities to proactively address current or anticipated stressors or disturbances.

Climate-informed forest management plans intentionally consider climate change and make linkages between potential climate change impacts and the associated management actions. There is not a single prescription for responding to climate change, and you can draw upon your experience and knowledge of your local ecosystem and management context in order to develop a customized plan for a particular landowner.

This guide outlines five steps to adaptation planning, which can be incorporated into Forest Stewardship Plans. These steps summarize an adaptation planning process outlined in the Adaptation Workbook.[1] The complete Workbook may be useful for reference material or when developing plans for larger and more complex projects, such as a large property or multiple parcels scattered across a community or landscape.

More information on Rhode Island's Forest Stewardship Program is available online: https://dem.ri.gov/natural-resources-bureau/agriculture-and-forest-environment/forest-environment/forest-stewardship

1. Management Goals

Landowners have different values associated with their lands, and so the first step of developing a management plan is to work with the landowner to understand and clarify the goals, interests, and hopes that they have for their woods. Clearly stated goals and objectives are important for helping landowners and managers describe what they are trying to achieve.

Climate change is an emerging issue, and some landowners may be more interested or aware of climate change than others. At the same time, climate change poses risks to many forests that can be addressed as part of long-term stewardship. Having a broad discussion about a variety of management goals can help determine whether a landowner wants to include climate adaptation or carbon mitigation as a primary management objective, or if climate change can be integrated as a more general topic. The *Caring for Rhode Island's Woods: Increasing Resiliency and Adapting to Changing Conditions* booklet (available at https://web.uri.edu/rhodeislandwoods/climate-smart-forestry/climate-smart-forestry-resources) can be used to help formulate a conversation on the topics that may be of interest to a landowner. Often, talking about recent or notable weather events or other forest stressors (such as the arrival of new insect pests) can be useful to understanding how a landowner is thinking about changing conditions and what concerns they may have.

It is important that management goals reflect the landowners' interests and hopes for their property. They do not have to explicitly include managing for climate change adaptation or resilience, but climate management objectives can easily be associated with typical management goals and provide a more explicit connection between good management practices and resilience. The impact of climate change on these goals and objectives will be considered on the following pages.

Examples of Management Goals and Objectives

Management Goals describe the broad outcomes you are trying to accomplish. Goals outline the big picture and set the long-term vision for where you want to go.	**Management Objectives** are more specific actions that support the completion of a goal. These are typically addressed in stand descriptions and management objectives portions of a management or stewardship plan.
• Enhance the quality and quantity of forest products.	• Enhance the overall health and productivity of an overstocked stand by reducing the abundance of high-risk trees (likely to die or lose value between now and the next entry).
• Enhance habitat for birds and other wildlife.	• Increase the structural diversity of forests by increasing understory and midstory vegetation. • Maintain and increase downed dead wood, snags, and legacy trees.
• Protect water quality in streams, ponds, and other wetlands.	• Increase canopy cover along stream to increase shade and cooling. • Create opportunities for regeneration of long-lived species in the stream buffer.
• Conserve biodiversity and protect vulnerable ecosystems.	• Identify mature stands with the potential to enhance old growth characteristics.
• Optimize high rates of carbon sequestration and amount of carbon stores in older forest stands.	• Identify mature stands with the potential to enhance old growth characteristics. • Enhance growth rates of the residual forest through ecologically based silviculture.
• Provide safe access for recreation.	• Develop and maintain a trail network on the property to support walking and other outdoor activities.

2. Climate Change Impacts and Vulnerabilities

Climate change will affect our natural landscapes and the human communities that depend upon them in many ways. The first section of this guide describes climate change impacts across Rhode Island, but every location will experience impacts differently based on local conditions and the unique characteristics of that place. Foresters and natural resource managers can use their local knowledge and experience to identify the greatest climate risks for a particular property or stand.

Some examples of factors that will influence vulnerability are:

- Site conditions, such as topographic position, soils, or hydrology
- Past and current management that has affected the condition of the land
- Ecosystem composition and structure
- Susceptibility to pests, diseases, or other stressors that may become more frequent and severe

Identify the climate change impacts that are most likely to affect a particular stand, property, or location. These will be important to consider when thinking about the landowner's management goals and how to achieve them. Examples of potential impacts to consider are:

- Elevated drought risk
- Increases in extreme precipitation events and storms
- Increases in insect pests and forest pathogens
- Elevated risk of wildfire
- Increasing impact of herbivory
- Increases in invasive plants
- Reduced habitat for some northern tree species
- Increased habitat for some southern tree species
- Higher sea levels
- Shorter duration of frozen ground conditions
- Altered hydrology in streams or wetlands

See the earlier climate change section of this Guide (pages 4-9) for additional details and resources.

3. Management Considerations for Climate Change

After considering the climate change impacts and vulnerabilities for a particular area, additional thought can be given to how these impacts may affect the landowners' goals and objectives.

These questions can be useful to help you evaluate goals and objectives in the context of climate change:

- What new or different challenges resulting from climate change or related stressors need to be considered in future management planning?
- What new opportunities might be available as a result of anticipated changes?
- How can existing management practices be changed to support forest resiliency while continuing to meet the desired management goals and objectives?
- Do any of the goals or objectives need to change?

Climate change is expected to create challenges for forest management in ways we cannot fully anticipate. Traditional management practices and decisions may need to be reconsidered. This may require a forester or natural resource manager to work together with the landowner to identify the site-specific effects of climate change and adjust their management goals, objectives, or expectations. Taking the time to do this can help determine a suitable path forward for managing the forest for the near and long term.

Examples of Climate Change-Related Challenges and Opportunities

Management Objectives	Climate Change-related Challenges to Goals	Climate Change-related Opportunities for Meeting Goals
• Enhance the overall health and vigor of an overstocked stand and reduce the abundance of high-risk trees (likely to die or lose value between now and the next entry).	• Warmer winter climate conditions may limit window of harvest operations on stable soil.	• Climate-driven tree mortality might increase forest structural diversity, enhancing habitat for wildlife.
• Protect water quality and aquatic habitat in streams, ponds, and other wetlands.	• Vernal pools could be affected by changes in precipitation and hydrology, especially where conditions become drier. This could negatively affect amphibians and other organisms.	• There are a wide range of tree species on the site, including species that thrive on either wetter or drier sites.
• Retain the current mix of hardwood and conifer species on site.	• Warmer conditions will make hemlock more susceptible to hemlock woolly adelgid.	• The warming temperature will aid in promoting oak, hickory, and cherry species in the project area.
• Identify stands with abundant large-diameter trees to maintain healthy forest conditions and optimize carbon storage and sequestration.	• Insect pests such as emerald ash borer and hemlock woolly adelgid can increase mortality of large ash and eastern hemlock that are components of mature stands.	• Climate-driven tree mortality might increase forest structural diversity, and enhance carbon stored in coarse woody material.
• Develop and maintain a trail network on the property to support walking and other outdoor activities.	• Increases in extreme rain events can flood low-lying areas and block trails. Extreme weather events may cause safety hazards from damaged trees.	• Increasing length of shoulder seasons could allow more time for trail building and trail use.

4. Management Actions for Climate Change

Management practices may be altered to address new or increased challenges from climate change, as well as to take advantage of potential opportunities. Depending on landowner goals and anticipated impacts, management may focus on resisting climate stressors, building resilience, transitioning forests to new conditions—or combination of these across a property or landscape. Clearly articulating the connection between management objectives, climate change impacts, and management actions will help landowners understand the rationale for the management actions outlined in their plan.

While some management actions may be evident, it may take some brainstorming to determine how to address new or complex situations. Because climate change creates unprecedented conditions, there isn't a single "right" answer—it is okay to try new things, take educated guesses, and experiment with different actions within a stand or throughout the property. Monitoring (discussed in the next step) can help you practice adaptive management and learn from your actions.

The following questions can be useful for evaluating different actions:

Time Frames: When would this action be implemented? Some actions may occur in the short term, while others may not occur for a long time or will occur only in certain situations (such as after a large disturbance). Although a plan may be written for the next 10 years, consider how actions may unfold over longer time spans so that you can set the forest up for success.

Benefits: What benefits does the action provide? For example, note if a tactic addresses your biggest challenge, addresses multiple challenges, or has co-benefits like improving carbon mitigation and visitor experiences.

Drawbacks and Barriers: What drawbacks are associated with this action? Note any negative effects or potential barriers (e.g., landowner interest or resources) that are likely to arise.

Effectiveness: Does the action meet its desired intent and help achieve the management objectives?

Feasibility: Can the action be implemented?

The preferred actions will likely be those that overcome the greatest challenges, have major benefits, and can be implemented given available resources.

Examples of Adaptation Actions

Management Goals or Objectives	Adaptation Action	Benefits, Drawbacks, and Barriers
• Enhance the overall health of an overstocked stand and reduce the abundance of high-risk trees (likely to die or lose value between now and the next entry).	• Reduce forest density to an appropriate level, while retaining under-represented species to enhance overall diversity.	• Reducing stand density can reduce risks from drought, storms, and some pests. The ability to increase species diversity may be limited (without planting) in less diverse stands.
• Increase canopy cover along stream to increase shade and cooling. • Create opportunities for regeneration of long-lived species in the stream buffer.	• Plant native species that are expected to be adapted to future conditions in areas of hemlock mortality.	• Tree planting can be expensive and labor intensive, particularly in areas with high levels of invasive plants or deer browse.
• Enhance growth rates of the residual forest through ecologically-based silviculture.	• Thin from below to reduce competition for soil moisture while maintaining large, healthy trees.	• Reducing stand density can reduce risks from drought, storms, and some pests. Retention of large, healthy trees helps develop late-successional forest characteristics.
• Develop and maintain a trail network on the property to support walking and other outdoor activities.	• Layout new trail segments with weather and climate considerations in mind.	• There may be increased time or cost associated with trail layout and creation.

Identifying Adaptation Actions

The *Caring for Rhode Island's Woods: Increasing Resiliency and Adapting to Changing Conditions* booklet for landowners (https://web.uri.edu/rhodeislandwoods/wp-content/uploads/sites/2078/RI_Landowner_Booklet_Climate_Resiliency_and_Adaptation.pdf) provides a general description of how forest management activities can help support climate adaptation. The items below are described in greater detail in the booklet, providing a starting point for talking to woodland owners about climate change and their woods.

Actions to Protect Ecosystem Functions

- Keep forest land in forest use.
- Protect rare or sensitive plant and animal communities.
- Protect water and soils.

Actions to Reduce Stressors

- Improve ability of trees to resist insect pests and disease.
- Prevent and control invasive plants.
- Manage damage to young trees from excessive deer browsing.

Actions to Build Resilience

- Promote a diversity of tree species.
- Promote a diversity of tree ages and sizes.
- Promote strong, healthy trees to prepare for big weather events.

Actions to Facilitate Transition

- Respond quickly after big disturbance events to help the woods bounce back.
- Proactively manage forest for future conditions.

Monitoring

- Monitor the woods and the effect of different management tactics.

A Guide to Forest Carbon in the Northeast (https://web.uri.edu/rhodeislandwoods/climate-smart-forestry/climate-smart-forestry-resouces) provides additional information for landowners who are interested in increasing the carbon benefits associated with their management activities.

Additionally, the Northern Institute of Applied Climate Science and partners have compiled several "menus" of potential climate change adaptation actions for a variety of topics, including forestry, wildlife management, and recreation. These menus can be browsed online at https://adaptationworkbook.org/strategies.

5. Monitoring and Adaptive Management

Monitoring is about asking the right questions that can help ensure desired outcomes over time (Figure 5). When developing plans, monitoring can be used to evaluate whether management is achieving its intended goals and objectives, as well as to what extent specific management actions were effective in helping to meet those goals.

Practice adaptive management. It has always been impossible to predict the future, and climate change makes that uncertainty even more apparent. Adaptive management supports decision-making in the face of uncertain future conditions by adopting a flexible approach that allows you to adjust your management as new information becomes available.

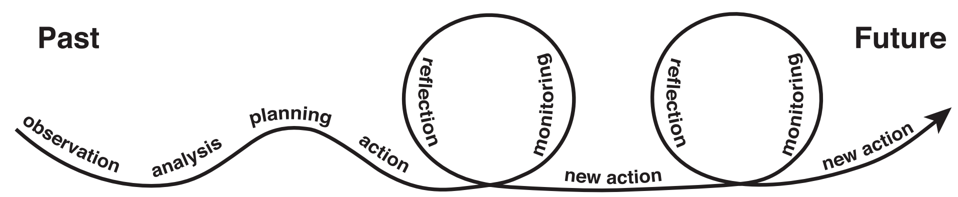


Figure 5. *Adaptation is an iterative process where monitoring can inform future actions.*[14]

Examples of Monitoring Items

Objectives and Management Actions	Monitoring Items
• Enhance the overall health of an overstocked stand and reduce the abundance of high-risk trees (likely to die or lose value between now and the next entry).	• Species diversity in the overstory, midstory, and understory. • Proportion trees that are at high-risk from climate change or other stressors. • Tree vigor and productivity. • Evidence of damage from pests or pathogens.
• Increase the structural diversity of forests by regenerating a new cohort of trees.	• Abundance and survival of seedlings and saplings of a desired species. • Evidence of browse impact on regeneration. • Presence or abundance of invasive or competing vegetation.
• Maintain and increase downed dead wood, snags, and wildlife trees.	• Presence or abundance of standing dead trees and downed dead wood.
• Protect water quality along stream with steep banks.	• Evidence of erosion and soil disturbance, particularly after extreme rain events.
• Maintain healthy forest conditions and optimize carbon storage and sequestration in older stands.	• Evidence of damage for pests or pathogens. • Tree size diversity, vigor, and productivity.

GLOSSARY

Adaptation
Adjustments, both planned and unplanned, in natural and human systems in response to climatic changes and subsequent effects. Ecosystem-based adaptation activities use a range of opportunities for sustainable management, conservation, and restoration.

Adaptive capacity
The general ability of institutions, systems, and individuals to moderate the risks of climate change, or to realize benefits, through changes in their characteristics or behavior. Adaptive capacity can be an inherent characteristic, or it could have been developed as a result of previous policy, planning, or design decisions.

Adaptive management
A dynamic approach to forest management in which the effects of treatments and decisions are continually monitored and used, along with research results, to modify management on a continuing basis to ensure that objectives are being met.

Biomass
The mass of living organic matter (plant and animal) in an ecosystem. Biomass also refers to organic matter (living and dead) available on a renewable basis for use as a fuel; biomass includes trees and plants (both terrestrial and aquatic), agricultural crops and wastes, wood and wood wastes, forest and mill residues, animal wastes, livestock operation residues, and some municipal and industrial wastes.

Carbon pool
Different types of biomass found within forests. The amount of carbon stored in pools changes over time and in response to various factors. Pools can be defined in several ways, but generally include the following: live aboveground biomass (trees, shrubs, herbs, grasses), live belowground biomass (roots), dead wood (standing dead trees, stumps, logs), forest floor (leaves, small branches), and soil (mineral soil, decaying organic matter).

Carbon sequestration
The process of plants using sunlight to capture CO2 from the air and convert it into plant biomass, including wood, leaves, and roots.

Carbon storage
The amount of carbon retained long-term within the forest, stored in "carbon pools" (see definition below).

Climate
The statistical description of the weather in terms of the mean and variability of relevant quantities (usually temperature, precipitation, and wind) over periods of several decades (typically three decades). In a wider sense, the "climate" is the description of the state of the climate system.

Climate change
A change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external factors, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate projection
A projection of the response of the climate system to emission scenarios of greenhouse gases based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the scenario used, which is based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Coarse woody material
Any piece(s) of dead woody material, including dead boles, limbs, and large root masses, that are on the ground in forest stands or in streams.

Disturbance
Stresses and destructive agents such as invasive species, diseases, and fire; changes in climate and serious weather events such as hurricanes and ice storms; pollution of the air, water, and soil; real estate development of forest lands; and timber harvest. Some of these are caused by humans, in part or entirely; others are not.

Diversity
The variety and abundance of life forms, processes, functions, and structures of plants, animals, and other living organisms, including the relative complexity of species, communities, gene pools, and ecosystems at spatial scales that range from local through regional to global. There are commonly five levels of biodiversity: (a) genetic diversity, referring to the genetic variation within a species; (b) species diversity, referring to the variety of species in an area; (c) community or ecosystem diversity, referring to the variety of communities or ecosystems in an area; (d) landscape diversity, referring to the variety of ecosystems across a landscape; and (e) regional diversity, referring to the variety of species, communities, ecosystems, or landscapes within a specific geographic region.

Ecological community
An assemblage of plants and animals living together and occupying a given area.

Ecosystem
A system of living organisms interacting with each other and their physical environment. The boundaries of an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

Emissions scenario
A plausible representation of the future development of emissions of greenhouse gases and aerosols that are potentially radiatively active, based on demographic, technological, or environmental developments.

Forest type
A classification of forest vegetation based on the dominant and commonly occurring associated tree species.

Greenhouse gases
Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.

Global warming
The observed increase in average temperature near the Earth's surface and in the lowest layer of the atmosphere. In common usage, "global warming" often refers to the warming that has occurred as a result of increased emissions of greenhouse gases from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns.

Management goal
Broad statements, usually not quantifiable, that express a desired state or process to be achieved. Goals are often not attainable in the short term and provide the context for more specific objectives.

Management objective
Concise, time-specific statements of measurable planned results that correspond to preestablished goals in achieving a desired outcome.

Mitigation
In the context of climate change, actions that reduce the amount of heat-trapping greenhouse gases, such as CO2, in the atmosphere to minimize changes in the Earth's climate. Actions can include avoiding or reducing emissions of greenhouse gases into the atmosphere, as well as removing greenhouse gases that are already present in the atmosphere.

Monitoring
The collection of information over time, generally on a sample basis by measuring change in an indicator or variable, to determine the effects of resource management treatments in the long term.

Projection
An estimate of something in the future, based on data or trends. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Resilience
The capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly.

Suitable habitat
An area in which a species could potentially occur based on favorable climatic and environmental conditions.

Silviculture
Silviculture is the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society such as wildlife habitat, timber, water resources, restoration, and recreation on a sustainable basis.

Structural diversity
The amount of three-dimensional variation within a forest stand. This is influenced by a combination of plant species diversity and height classes (vertical structure), and is often used as an indicator for biodiversity of forest ecosystems.

Vulnerability
The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the impacts and adaptive capacity of a system. A system may be considered to be vulnerable if it is at risk of a compositional change leading to a new identity, or if the system is anticipated to suffer substantial declines in health or productivity.

Rhode Island

Rhode Island Department of Environmental Management, Forest Stewardship Program https://dem.ri.gov/natural-resources-bureau/agriculture-and-forest-environment/forest-environment/forest-stewardship

Rhode Island Woods: Climate Change and Forests https://web.uri.edu/rhodeislandwoods/climate-smart-forestry

NOAA National Centers for Environmental Information. State Climate Summaries 2022: Rhode Island https://statesummaries.ncics.org/chapter/ri

Climate Change Impacts and Vulnerability

New England and Northern New York Forest Ecosystem Vulnerability Assessment and Synthesis https://doi.org/10.2737/nrs-gtr-173

Adaptation Resources

Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd Edition https://doi.org/10.2737/NRS-GTR-87-2

Adaptation Workbook https://adaptationworkbook.org

Adaptation Strategies and Approaches for Different Topics https://adaptationworkbook.org/strategies

Healthy Forests for our Future: A Management Guide to Increase Carbon Storage in Northeast Forests https://research.fs.usda. gov/treesearch/63533

Other

Climate Change Response Framework https://forestadaptation.org/

A Guide to Forest Carbon in the Northeast https://web.uri.edu/rhodeislandwoods/climate-smart-forestry/climate-smart-forestry-resources

Recommendations for Communicating about Climate Change https://tinyurl.com/LTA-Climate-Communications

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

Climate Change Projections for Individual Tree Species

Rhode Island

Rhode Island's forests will be affected by a changing climate and other stressors during this century. Researchers and managers created an assessment that describes the vulnerability of forests in the New England region (Janowiak et al. 2018: doi.org/10.2737/nrs-gtr-173). This report includes information on the current landscape, observed climate trends, and a range of projected future climates. It also describes many potential climate change impacts to forests and summarizes key vulnerabilities for major forest ecosystems. This handout summarizes data from the U.S. Forest Service's Climate Change Tree Atlas (doi.org/10.2737/Climate-Change-Tree-Atlas-v4). Two climate scenarios are presented to "bracket" a range of possible futures. These future climate projections (2070 to 2099) provide information about how individual tree species may respond to a changing climate. Results for "low" and "high" emissions scenarios can be compared on the reverse side of this handout.

The Tree Atlas provides information to interpret tree species changes:

- **SUITABLE HABITAT** - calculated based on 45 variables that explain where conditions exist for a species, including soils, landforms, and climate variables.
- **ADAPTABILITY** - based on life-history traits that might increase or decrease tolerance of expected changes, such as the ability to withstand different forms of disturbance.
- **CAPABILITY** - a rating of the species' ability to cope or persist with climate change in this region based on suitable habitat change (statistical modeling), adaptability (literature review and expert opinion), and abundance (inventory data). The capability rating is modified by abundance information; ratings are downgraded for rare species and upgraded for abundant species. See the table to the right for ratings.
- **MIGRATION POTENTIAL MODEL** - when combined with habitat suitability, an estimate of a species' colonization likelihood for new habitats. This rating can be helpful for assisted migration or focused management.

Remember that models are just tools, and they're not perfect. Model projections can't account for all factors that influence future species success. If a species is rare or confined to a small area, model results may be less reliable. These factors, and others, could cause a particular species to perform better or worse than a model projects. Human choices will also continue to influence forest distribution, especially for tree species that are projected to increase. Planting programs may assist the movement of future-adapted species, but this will depend on management decisions. Despite these limits, models provide useful information about future expectations. It's perhaps best to think of these projections as indicators of possibility and potential change.

CLIMATE CHANGE CAPABILITY TABLE.
Capability is a rating of the species' ability to cope or persist with climate change. Species have been organized into poor, fair, good, and mixed capability ratings. New habitat species and species with low model reliability are excluded from this table. See the Tree Species Projections table legend on the following page for more information on ratings.

POOR CAPABILITY	
Balsam fir	Paper birch
Balsam poplar	Quaking aspen
Eastern hemlock	Red pine
Hackberry	Sweet birch
FAIR CAPABILITY	
Black cherry	
GOOD CAPABILITY	
American beech	Northern red oak
American holly	Pignut hickory
American hornbeam	Red maple
Bigtooth aspen	Shagbark hickory
Black oak	Sugar maple
Blackgum	White ash
Chestnut oak	White oak
Eastern redcedar	Yellow birch
Mockernut hickory	Yellow-poplar
MIXED CAPABILITY	
American elm	Pitch pine
Eastern white pine	Scarlet oak

CREDIT: *This handout summarizes the full model results for the State of Rhode Island. Data provided by the USDA Forest Service (M.P. Peters, A.M. Prasad, S.N. Matthews, & L.R. Iverson) as part of the Climate Change Tree Atlas (doi.org/10.2737/Climate-Change-Tree-Atlas-v4). Models and variables are described in Iverson et al. 2019 and Peters et al. 2019 (available at fs.usda.gov/nrs/atlas/products/pubs). More information on vulnerability and adaptation in the region can be found at forestadaptation.org/new-england.*

This handout is a product of the USDA Northern Forests Climate Hub and the Northern Institute of Applied Climate Science, a collaborative partnership led by the USDA Forest Service. Funding was provided by the USDA Forest Service.

Tree Species Projections Table

Information presented in the table is from the Climate Change Tree Atlas regional summaries, more details at fs.usda.gov/nrs/atlas/combined/resources/summaries.

ADAPTABILITY: Life-history factors, such as the ability to respond favorably to disturbance, that are not included in the Tree Atlas model and 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*

HABITAT CHANGE: Projected change in suitable habitat between current and potential future conditions.

- ▲ **INCREASE** *Projected increase of >20% by 2100*
- ▼ **DECREASE** *Projected decrease of >20% by 2100*
- ● **NO CHANGE** *Projected change of <20% by 2100*
- ★ **NEW HABITAT** *Tree Atlas projects new habitat for species not currently present*

ABUNDANCE: Based on Forest Inventory Analysis (FIA) summed Importance Value data, calibrated to a standard geographic area.

- \+ **ABUNDANT**
- · **COMMON**
- – **RARE**

CAPABILITY: An overall rating that describes a species' ability to cope or persist with climate change based on suitable habitat change class, adaptability, and abundance within this region.

- △ **GOOD** *Increasing suitable habitat, medium or high adaptability, and common or abundant*
- ○ **FAIR** *Mixed combinations, such as a rare species with increasing suitable habitat and medium adaptability*
- ▽ **POOR** *Decreasing suitable habitat, medium or low adaptability, and uncommon or rare*

			LOW CLIMATE CHANGE (RCP 4.5)		HIGH CLIMATE CHANGE (RCP 8.5)	
SPECIES	**ADAPT**	**ABUN**	**HABITAT CHANGE**	**CAPABILITY**	**HABITAT CHANGE**	**CAPABILITY**
American basswood	·	–	★		★	
American beech	·	–	▲	△	▲	△
American elm	·	–	●	▽	▲	△
American holly	·	–	▲	△	▲	△
American hornbeam	·	–	▲	△	▲	△
American mountain-ash*	–	–	●	▽	●	▽
Atlantic white-cedar*	–	–	▼	▽	▼	▽
Bald cypress	·	–	★		★	
Balsam fir	–	–	▼	▽	▼	▽
Balsam poplar	·	–	▼	▽	▼	▽
Bigtooth aspen	·	–	▲	△	▲	△
Bitternut hickory*	+	–	★		★	
Black cherry	–	·	▲	○	▲	○
Black hickory	·	–	★		★	
Black locust*	·	–	▲	△	▲	△
Black oak	·	+	●	△	●	△
Blackgum	+	·	▲	△	▲	△
Blackjack oak	+	–	★		★	
Boxelder*	+	–	▼	▽	▼	▽
Chestnut oak	+	·	▲	△	▲	△
Common persimmon*	+	–	★		★	
Eastern hemlock	–	·	▼	▽	▼	▽
Eastern redcedar	·	·	▲	△	▲	△
Eastern white pine	–	+	▼	○	▼	▽
Flowering dogwood	·	–	★		★	
Gray birch*	·	·	●	○	▲	△
Green ash*	·	·	▲	△	▲	△
Hackberry	+	–	▼	▽	▼	▽
Ironwood*	+	–	●	○	▲	△
Loblolly pine	·	–	★		★	
Mockernut hickory	+	·	▲	△	▲	△
Northern red oak	+	+	▼	△	▼	△
Paper birch	·	–	▼	▽	▼	▽
Pignut hickory	·	·	▲	△	▲	△
Pin cherry*	·	·	▼	▽	▼	▽
Pitch pine	·	·	●	○	▼	▽
Post oak	+	–	★		★	
Quaking aspen	·	·	▼	▽	▼	▽
Red maple	+	+	▼	△	▼	△
Red pine	–	–	▼	▽	▼	▽
Sassafras*	·	·	▲	△	▲	△
Scarlet oak	·	+	●	△	▼	○
Shagbark hickory	·	–	▲	△	▲	△
Shortleaf pine	·	–	★		★	
Silver maple*	+	–	▼	▽	●	○
Sourwood	+	–	★		★	
Southern red oak	+	–	★		★	
Sugar maple	+	·	▲	△	▲	△
Sugarberry	·	–	★		★	
Swamp chestnut oak*	·	–	★		★	
Swamp white oak*	·	–	▼	▽	▼	▽
Sweet birch	–	·	●	▽	●	▽
Sweetgum	·	–	★		★	
Sycamore*	·	–	★		★	
Virginia pine	·	–	★		★	
Water oak	·	–	★		★	
White ash	–	·	▲	△	▲	△
White oak	+	+	●	△	●	△
Willow oak*	·	–	★		★	
Winged elm	·	–	★		★	
Yellow birch	·	·	▲	△	▲	△
Yellow-poplar	+	–	▲	△	▲	△

**Species with low model reliability based on five statistical metrics of the habitat models that affect change class.*

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THE UNIVERSITY OF RHODE ISLAND COLLEGE OF THE ENVIRONMENT AND LIFE SCIENCES

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