

Allen-Whitney Memorial Forest: Climate Change Adaptation Plan

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The goal of climate change adaptation in working forests is not to stop changes in climate or preserve the current composition of plants and animals as they exist today, but to safeguard the diverse benefits provided by forestlands.

Manomet Center for Conservation Sciences

Executive Summary

Alterations in temperature and precipitation patterns expected under climate change can impact forests in several ways. These changes may include shifting distributions of tree species and wildlife habitats, increases in the frequency and magnitude of disturbance events, introducing new and/or intensifying the impacts of invasive and non-native species, altering the economic contributions of forests to the economy, and changing the way the public uses and values forest lands. Forest managers need to be able to *adapt* management practices to these changing conditions to ensure that Maine's forests continue to provide benefits for future generations. Adaptation to climate change consists of developing strategies and management options that will help landowners plan and prepare for the changing climate. In this document we outline practical and cost-effective adaptation strategies for Allen-Whitney forest that can reduce a wide range of risks associated with a changing climate.

Adaptation Strategy #1: Maintain species, structural, and age class diversity. Sustainable management strategies that maintain species, structural, and age class diversity are important in the face of climate change because they can create a mosaic of habitats for existing wildlife species and new species that may shift into the area, diversify stands with species and age classes that are less vulnerable to climate impacts, protect against wide-spread damage and financial loss due to disturbance events, and create economic opportunities by managing for species that are well-suited to changing climatic conditions. Best Management Practices:

- 1. Create multi-aged stands
- 2. Plan to diversify species mix of red pine plantations
- 3. Retain areas with no or limited harvesting
- 4. Use short-rotation forestry when appropriate

Adaptation Strategy #2: Conduct sustainable timber harvests.

A shortened winter logging period, extended mud season, and increasingly frequent and severe storm events are likely to reduce the number of days with conditions favorable for low-impact logging, increase logging costs as machinery sits idle during marginal and unfavorable conditions, and increase pressure on managers to operate during marginal or unfavorable conditions, risking damage to soil and water quality.

Best Management Practices:

- 1. Continue to apply best management practices (BMPs) and sustainable forestry practices
- 2. Create infrastructure that can withstand a variety of weather conditions
- 3. Track and respond to changing soil and weather conditions

Manomet Center for Conservation Sciences 14 Maine Street, Suite 305 Brunswick, Maine 04011 Adaptation Strategy #3: Maintain and increase red oak and white pine on site. Red oak and white pine are well-suited for the warmer temperatures and altered precipitation patterns expected under climate change in Maine and are highly valued for forest products.

Best Management Practices:

1. Use shelterwood harvest systems to increase red oak and white pine

Adaptation Strategy #4: Be aware of and plan for threats facing hemlock stands. Infestations of Hemlock Wooly Adelgid (HWA) and Elongate Hemlock Scale (EHS) and temperature stress have profoundly negative implications for the long-term survival of hemlock in Allen-Whitney Forest.

Best Management Practices:

- 1. Track HWA and EHS in Maine and on-site
- 2. Reduce risk of introduction and spread of HWA and EHS
- 3. Be prepared to implement hemlock management options if HWA and/or EHS arrives

Adaptation Strategy #5: Promote regeneration of native tree species. Invasive plants are expected to thrive under a changing climate, allowing these species to outcompete native trees and quickly colonize forestland.

Best Management Practices:

- 1. Track existing and emerging threats of invasive species
- 2. Develop a modest but effective monitoring program for invasive species
- 3. Control invasive species at the early stages of infestation

Adaptation Strategy #6: Minimize negative impacts of disturbance events. The frequencies and intensities of widespread disturbances are predicted to increase due to climate change, resulting in injury or death of canopy trees and loss of economic value.

Best Management Practices:

- 1. Identify stands most vulnerable to disturbance events
- 2. Monitor regeneration and invasive species after stand-replacing events

Adaptation Strategy #7: Create a low-impact recreational trail system. Winter recreation is highly vulnerable to climate change. Decreases in the depth and duration of snow cover and increases in extreme precipitation events associated with climate change may degrade trail quality and become a significant source of sediment to water bodies. Best Management Practices:

1. Maintain low-impact and high quality trails

2. Clearly communicate permitted recreational uses

Adaptation Strategy #8: Encourage deer management. As winters warm and the depth and duration of snow cover decreases, herd size and deer density will increase. Increased deer herds can damage vegetation, interfere with forest regeneration, and increase the abundance of deer ticks and instances of Lyme disease.

Best Management Practices:

1. Continue to provide hunting opportunities

Adaptation Strategy #9: Be aware of the need for cross-sector adaptation planning at landscape, state, and regional scales. Climate change impacts multiple economic sectors (e.g. natural resources, transportation, and public health), requiring coordination among government agencies, non-profits, and other stakeholders to effectively prepare for these changes. In addition, climate change adaptation must include regional and state-wide approaches to fully protect forestland.

- 1. Be aware of landscape-scale adaptation planning efforts
- 2. Be aware of interdisciplinary adaptation efforts



Introduction

Working forests are a prominent and important feature of Maine's natural landscapes. These forests are critical to maintaining the state's natural resources, economy, and local traditions. Successful forest management has long included strategies that minimize the effects of stressors such as disturbance events, invasive species, and pests. A new and important stressor, global climate change, has recently begun to exert its effects on New England's landscapes, and is having local impacts on how Maine's forests grow, change, and need to be managed. To manage these resources successfully, we need to be able to *adapt* our management practices to the changing conditions. Adaptation to climate change consists of developing strategies and management options that will help landowners and forest managers plan and prepare for the changing climate to ensure that Maine's forests continue to provide economic, ecological, and societal benefits for future generations.

Climate change will alter many aspects of forests and forest management, and although managers and landowners cannot control the changes in climate (e.g., warmer temperatures, altered precipitation), we are not helpless in shaping the future condition of our forestland. Managing forests under climate change is a complicated undertaking as the timing and severity of anticipated changes are somewhat difficult to predict, and can vary across the landscape. The goal of climate change adaptation in working forests is not to stop changes in climate or preserve the current composition of plant and animal species as they exist today, but to safeguard the economic value, ecological functions and other diverse benefits provided by forestland.

Site-specific adaptation plans can help landowners ensure that forests continue to provide valuable habitat, a sustainable supply of forest products, and a safe and enjoyable place for people to recreate. Such plans will evaluate how we expect the changing climate to impact valued resources, and provide strategies and tactics to best manage these resources as the climate changes. This report presents a climate change adaptation plan for the Allen-Whitney Forest in central Maine. It summarizes the predicted changes in climate expected at this site over the next 100 years, discusses how these changes may alter the landowner's existing management goals and practices, and identifies adaptation strategies for safeguarding the many benefits this forest provides. We focus on "no-regret" adaptation strategies that are practical and costeffective ways for addressing the wide range of risks associated with a changing climate. While this adaptation plan is intended for a specific site, the strategies can be applied to similar forestland throughout northern New England.

Allen-Whitney Forest

Site History. The Allen-Whitney Forest (AWF) is a 700-acre parcel located in Manchester, Maine (Figure 1). It was donated by Edward Allen Whitney to the New England Forestry Foundation (NEFF) in the mid-1950s. NEFF has sustainably managed the AWF over the past 60 years for timber products, while also maintaining and creating wildlife habitat and providing opportunities for public recreation and education about forests and forest management.

Species Composition and Habitats. The forest composition and topography are typical of central Maine. AWF comprises approximately 700 acres of rolling terrain, between 250-640 feet in elevation. The predominant forest type is a mix of hardwoods and softwoods comprising 277 acres. Hardwood stands (sugar maple, beech, ash, red oak) occupy 171 acres and softwoods (white pine, hemlock, and spruce-fir) make up approximately 187 acres. Approximately 61,000 red and white pines were planted in the 1950s and 1960s under the federal government's Soil Bank Program, resulting in 66 acres of pine plantations. The forest has a large proportion of mid-sized trees (40% pole size [10-13" dbh] and 31% saw log size [14-17" dbh]). There is a small proportion of small, younger trees (17% sapling [6-9" dbh]) and very few (6%) large, old trees on the property.



Figure 1. Location of Allen-Whitney Forest



The New England Forestry Foundation (NEFF) is dedicated to providing for the conservation and ecologically sound management of privately owned forestlands. NEFF manages over 130 demonstration forests, totaling more than 23,000 acres and holds 137 conservation easements protecting 1,138,000 acres. More Information: www.newenglandforestry.org The property includes the eastern shore of Shed Pond, a 50-acre shallow pond with an undeveloped shoreline. There are small complexes of forested wetlands associated with Shed Pond and approximately four acres of non-forested wetland on the property. Since there are only a few small drainages, stream habitat is limited.

AWF primarily provides habitat for forest generalist species. Shed Pond provides nesting habitat for waterfowl including common loon (*Gavia immer*). A comprehensive species inventory has not been completed but there are no known rare species or species of special conservation concern on the property. Several non-native invasive plant species grow on the parcel including Japanese barberry (*Berberis thunbergii* DC.), multiflora rose (*Rosa multiflora* Thunb.), and shrub honeysuckles (Amur: *Lonicera maackii*, Morrow's: *L. morrowii*, Tartarian: *L. tatarica*). These species are concentrated along old roads that transect the property but barberry has expanded beyond roadbeds into a recently harvested stand. There is currently no formal strategy for monitoring or managing for invasive species.

Timber Management. AWF has a timber management plan that serves as an inventory and planning document. Based on the abundance and size distribution of tree species on the site, the plan evaluates and recommends the prescription (i.e., target species and products, size of harvest block, and harvest techniques) and timing of future timber harvests. This plan was developed by NEFF staff in consultation with a certified consulting forester and it is updated periodically. An independent logging contractor conducts harvests with oversight from NEFF staff and the consulting forester. Forest management activities at AWF are certified by the Forest Stewardship Council (FSC) and American Tree Farm (ATF) and these organizations periodically review harvest operations on NEFF properties to ensure properties are being managed according to their sustainability criteria.

A timber survey completed in 2001 estimated the timber value of the parcel to be approximately \$695,000. Recent management methods are primarily uneven-aged management (selected canopy trees are harvested, allowing younger, smaller trees more growing space and a future supply of economically valuable larger trees). Many trees (primarily hardwoods and red pines) sustained severe damage in the 1998 ice storm. Severely damaged trees were salvaged following the storm and harvests were scheduled to minimize mortality due to ice storm damage.

In Maine, 90% of sawtimber volume comes from white pine, sugar maple, red maple, yellow birch, white birch, and red oak (McWilliams et al. 2005). The most abundant commercially valuable species in AWF is white pine (18% of forest composition, 58% of timber value; Table 1) and red oak (4% of forest, 20% of timber value; Table 1). Sugar maple, red maple, yellow birch, and white birch are economically valuable but uncommon at the site, making up less than 1% of the forest. Trees suitable for pulp markets are 24% softwood, 34% hardwood, and 10% hemlock (Table 1). Despite pulpwood being common at the site, the economic value is low with pulp contributing only 9% of the timber value (softwood 3%, hardwood 5%, and hemlock 1%).

Management Objectives/Property Goals. NEFF manages the property to meet the following objectives: (1) to protect and maintain natural resources, (2) to provide a source of forest products that generate timber income, and (3) to provide public education and recreation activities (e.g., hiking, snowmobiling, hunting). We used these objectives to guide the selection of climate change adaptation strategies.

Objective 1: Protect and Maintain Natural Resources. AWF is a

large block of forest that provides a mix of native trees and associated wildlife habitat, and contributes to clean air and water and a myriad of other ecosystem services provided by forestland. The property is protected from future development and, therefore, will remain as forest into the foreseeable future. Maintaining a diverse mix of native species in a variety of age classes will help ensure the site continues to provide habitat for deer, moose, loons, and a diverse assemblage of breeding and migratory birds.

Objective 2: Sustainable Source of Timber Products. NEFF manages the property for forest products including lumber, pulp wood, and biomass energy. NEFF employs sustainable timber harvesting practices approved by

Tree species	Species/Product composition (% of volume)	Economic value (% of value)
Softwood		
White Pine	18	58
Red pine	4	2
Hemlock	4	4
Hemlock Pulp	10	1
Spruce-Fir	0	0
Spruce-Fir		
Pulp	0	0
SW Pulp	24	3
Hardwood		
Red Oak	4	20
Sugar Maple	1	3
W. Ash	1	2
W. Birch	1	1
Yellow birch	0	0
Red Maple	0	0
Beech	0	0
Other HW	0	0
HW pulp	34	5

Table 1. Species composition and contribution to

timber value of species in the AWF

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FSC and ATF. These organizations provide third-party verification that harvesting operations are conducted in a manner that is consistent with maintaining the current and future biological, economic, and societal benefits of healthy forests.

Objective 3: Provide Education and Recreation Opportunities. Recreation and public education are key parts of NEFF's mission. Passive recreation (wildlife viewing, hiking, snowshoeing, skiing, etc.), as well as hunting (deer, waterfowl, small mammals) are allowed. AWF has trails for hiking, cross-country skiing, and snowshoeing and is part of a larger snowmobile trail system. NEFF sponsors periodic educational walks on a variety of topics, including timber management, forest ecology, and birding. A volunteer steward who lives nearby conducts day-to-day oversight and management of the property and the local snowmobile club is responsible for maintenance and safety of the trails.

Observed and Predicted Changes in Climate*

Climate change may be one of the largest environmental, economic, and social challenges that society has encountered. It is not a problem reserved for the distant future—changes in climate are already being observed. In the Northeast, average temperatures have increased >1.5°F since 1970, with winters having rapidly warmed 4°F between 1970 and 2000 (NECIA 2006). Average yearly precipitation and the number of large rain events (>1″) in central Maine increased between the years 1948 and 2007 (Spierre and Wake 2010). Over the last 150 years, the length of the growing season in Maine has increased >40 days (Jacobson et al. 2009), the onset of first tree leaf out at Hubbard Brook in central New Hampshire has shifted 5-10 days earlier over the last 50 years (Richardson et al. 2006), and the number of days in Maine with snow cover has decreased an average of between 4 to 24 days since 1965 (Frumhoff 2007). Forest Inventory and Analysis (FIA) data from over 65,000 inventory plots in the eastern U.S. detected a northern migration of 70% of tree species (defined as increased germination and seedling survival at the northern edge of species range compared to southern edge of range) (USFS 2010).

Predictions about future climate conditions are available using climate models (IPCC Fourth Assessment 2007). While these models may not agree about all the details of climatic futures, they do allow managers to prepare for a range of expected changes. In the next 100 years Maine is projected to become warmer and wetter in all four seasons (Jacobson et al. 2009); average temperatures in central Maine are projected to increase 6.7°F in winter and approximately 5.7°F during the spring, summer, and fall (Jacobson et al. 2009); and precipitation is predicted to increase 10% in winter, 10% in spring, and 6% in fall (Jacobson et al. 2009, Hayhoe et al. 2007).



*More details about climate models and predicted changes in Maine's climate are detailed in Maine's Climate Future (Jacobson et al. 2009).

Climate Change & Forests

Alterations in temperature and precipitation patterns can impact forests in 5 important ways: 1. Shift the distributions of tree species and wildlife habitats

2. Increase the frequency and magnitude of disturbance events (e.g., thunderstorms, ice storms, wind events)

3. Introduce new invasive, nonnative, or pest species and/or increase the threat of infestations of these species

4. Alter economic value of forests (e.g., timber harvesting, infrastructure investments, timber markets, land value)

5. Change the way the public uses and values forestland (e.g., recreational activities, public health and safety, ecosystem functions and values)

Climate Change and Forests

Changes in climate will have significant implications for forests and how forests are managed in Maine. Alterations in temperature and precipitation patterns may: 1) shift distributions of tree species and wildlife habitats northward or upslope, 2) increase the frequency and magnitude of disturbance events, 3) introduce new invasive species and/or intensify the impacts of invasive and non-native plant and pest species, 4) alter the economic contributions of forests to the economy, and 5) change the way the public uses and values forest lands. We have briefly outlined below how each of these categories will impact forest lands in Maine. Details regarding specific changes and projected impacts of climate change at AWF are compiled in Appendix A.

Shifting distributions of species and habitats: Changing temperature and precipitation may shift the distributions of species at both global and local scales (McLaughlin et al. 2002). Forest types in the Northeast are predicted to significantly change in the next 100 years under every modeled atmospheric emissions scenario (Prasad et al. 2007). Habitat for several important species in Maine are projected to decline including: sugar maple (Acer saccharum), red maple (Acer rubrum), black cherry (Prunus serotina), balsam fir (Abies balsamea), red spruce (Picea rubens), yellow birch (Betula alleghaniensis), paper birch (Betula papyrifera), quaking aspen (Populus tremuloides), eastern hemlock (Tsuga canadensis), American beech (Fagus grandifolia), and white ash (Fraxinus americana) (Iverson et al. 2008). A few "southern" species are expected to extend their ranges northward and upslope, including: red oak (Quercus rubra) and white oak (Quercus alba) (Iverson et al. 2008). The distribution of white pine (Pinus strobus) is expected to contract across New England (Iverson et al. 2008), primarily in the southern portion of the range. Maine is at the northern edge of the current distribution and white pine will likely grow and thrive for at least the next 100 years.

Increased frequency and severity of disturbance events: The distribution of forest habitats is expected to change slowly in response to climate change because canopy trees are long lived, slow to extend or contract their ranges, and can tolerate environmental stress. However, more rapid change could occur due to changes in disturbance regimes (Aber et al. 2001, Dale et al 2001). The frequency and magnitude of storms, droughts, periods of extreme heat, fires, and insect or disease outbreaks may increase under a changing climate (Baker 1995, Union of Concerned Scientists 2006). These disturbance events can damage canopy trees resulting in injury or death and loss of economic value. Each year in the United States ice and wind storms damage 4.5 million acres of forests and cost landowners \$860 million dollars (Michaels and Cherpack 1998, Herbert et al. 1996, Marsinko et al. 1997, USDA 1997, Dale et al. 2001). As the frequency and intensity of disturbance events increase, the number of acres impacted and financial costs will dramatically increase.

Increased threats of non-native, invasive, and pest species: Non-native plants, pests, and pathogens are a significant threat to the ecology and financial stability of forests. It is estimated that introduced pests and pathogens result in the loss of \$2.1 billion dollars of forest products each year in the U.S. (Pimentel et al. 2005). Climate change is predicted to introduce new and/or intensify negative effects of these species (Porter et al. 1991, Coakley et al. 1999, Garrett et al. 2006). For example, increased temperatures can expand the geographic range of non-native species that were previously limited by climatic conditions (Skinner et al. 2003, Rahel and Olden 2008), non-native species can out-compete native seedlings and saplings and quickly colonize areas following timber harvests or natural disturbances (Dukes and Mooney 1999), and the increased frequency of extreme weather events can stress native plants and favor establishment and growth of invasive species (Burke and Grime 1996). These threats can result in direct mortality to trees and plants, reductions in growth and fitness, putting forests across Maine at risk for alterations in plant community composition, reduced quality and quantity of wildlife habitat, and loss of timber revenue.

Altered economic value of forests: The most immediate financial impact of climate change may be a reduction of the time period with conditions favorable for harvesting and transporting wood (Spittlehouse and Stewart 2003). A reduction in the number of days with frozen soil or an increased length of mud season has the potential to dramatically increase logging costs. In addition, increased precipitation and storm events will impact the condition of road networks and stream crossing structures (Gunn et al. 2009). An increased frequency of large disturbance events (Baker 1995, Union of Concerned Scientists 2006) may increase the risks of damage to financially mature stands. These changes may require altering long-standing harvest schedules (e.g., spring shutdowns, winter harvests), upgrades to logging infrastructure (e.g., haul roads, skid trails, landings, stream crossings), alterations in mechanical harvesting equipment and transportation techniques (e.g., skidders vs. cut-to-length systems, skid trail design techniques, updated road construction and stream crossing BMPs), and updating silviculture methods (e.g., growth and yield curves, target species, rotation lengths).

Changed public uses and values of forests: Climate change will alter the way the public uses and values forest land both directly (e.g., feasibility of recreation activities, quality of outdoor experiences, comfort and safety during outdoor activities) and indirectly (e.g., amount and timing of snow cover, water and air temperature, wildlife distribution) (Scott and Jones 2005). Trail-based winter recreation, including snowmobiling, cross-country skiing, and snowshoeing, are most vulnerable to climate change, due to their dependence on natural snow (Scott and Jones 2005). In Maine, predicted changes in snow pack will leave less snow for fewer days, with severe implications for snowmobiling, which contributes over 170 million dollars a year to the state's economy (Reiling 1999).

Climate change will also have negative consequences for human health and safety. For example, vector-borne diseases, including Lyme disease and Eastern equine encephalitis (EEE), are projected to increase in central Maine as the climate warms and precipitation patterns change (Robbins 2009, Sorg 2009, Harvard Medical School 2010). The growth rate, distribution, and potency of poison ivy are expected to increase under increased carbon dioxide (CO₂) concentrations (Mohan et al. 2006). These health risks are closely associated with outdoor activities, particularly forest-based recreation. The increased risk to human health may reduce the popularity of outdoor recreation and alter the perceived value of forest land to society.

Forests provide a myriad of ecosystem functions, or services, that are essential to people and wildlife, including regulating hydrology (Brauman et al. 2007, Day and Dickinson 2008), moderating air and water temperature, removing pollution, sequestering carbon, and improving air and water quality (Nowak 1995,

Nowak and Crane 2000). In Maine, the value of forests in sequestering carbon and removing pollution exceeds \$80 million (Nowak and Greenfield 2008). As the climate changes, these ecosystem services will play an increasingly important role in maintaining habitats, human health and safety, watershed health, and infrastructure.

Allen-Whitney Forest Climate Change Adaptation Plan

The projected impacts of climate change at AWF (summarized in Appendix A) are numerous. The goal of climate change adaptation is not to stop changes in climate or preserve the current composition of plant and animal species, timber markets, or recreational uses as they exist today, but to safeguard the ecological functions and diverse benefits of forestland. This plan focuses on adaptation strategies that address features that are the most vulnerable to climate change impacts and that have the greatest likelihood of helping to achieve NEFF's management goals for the property. For each adaptation strategy, we identified BMPs necessary for achieving climate change adaptation. Many potential BMPs are not feasible, due to financial costs, jurisdictional issues, or required scale of implementation. We only included adaptation strategies and BMPs that were practical and useful, inexpensive to implement, had limited ecological and social side effects, and were in-line with NEFF's mission and management goals.



Adaptation Strategy #1: Maintain species, structural, and age class diversity

Background: Forests dominated by a single species of tree, or composed of uniform age classes may be highly vulnerable to climate change impacts (Bodin and Wiman 2007). Sustainable management strategies that maintain species, structural, or age class diversity are important in the face of climate change because they: can create mosaics of habitats for existing wildlife species and new species that may move into the area, diversify stands with species and age classes that are less vulnerable to environmental stresses and disturbance events, reduce risk of damage and financial loss, and create economic opportunities by managing for species that are suited to the changing climatic conditions. Harvest strategies that retain some mature, canopy trees while creating cohorts of younger trees provide a sustainable supply of trees for habitat and timber markets.

- 1. **Create multi-aged stands:** Use uneven-aged management practices such as multi-stage shelterwood harvests, and structural and patch retention to maintain or create multiple age classes within stands. This creates stands of more diverse age classes, and allows retention of important structural attributes of mature trees (Franklin et al. 2007). It also creates favorable conditions for growth of young and vigorous trees that may be more resilient and better adapted to the changing climatic conditions.
- 2. Plan to diversify species mix of red pine plantations: The 66 acres of red pine plantations are uniform in both species and age class and are highly vulnerable to catastrophic disturbances. Unfavorable markets for red pine limit options for using timber management to diversify these stands. If markets for red pine improve enough to make harvesting even marginally profitable, the species and age classes of these plantations should be diversified. Multi-stage shelterwood harvests allow the establishment of white pine and red oak seedlings and then allow older seedlings to develop into canopy trees.
- 3. **Retain areas with no or limited harvesting:** Stands dominated by large, old trees are an increasingly rare forest type (Freedman et al. 1996) and can substantially contribute to wildlife habitat (Hagan and Whitman 2004) and to carbon sequestration (Luyssaert et al. 2008, Nunery and Keeton 2010). At AWF state regulations restrict and limit timber harvest activities within 250 feet of Shed Pond and within 75 feet of stream channels and wetlands to protect water quality and aquatic and terrestrial habitat. These harvest limitations also allow trees to grow larger and older than traditionally harvested stands, and accrue many of the unique characteristics of old forests (Hagan and Whitman 2004). Limited harvest operations may be appropriate in other areas with unique ecological features, difficult access, or high recreational value.
- 4. Use short-rotation forestry when appropriate: In stands with good equipment access (e.g., near established roads, skid trails and landing), operating conditions (e.g., dry, well-drained soils, favorable topography), and suitable species composition, consider shortening rotation length. Shorter rotation length can establish new cohorts of young, vigorous trees well suited for variable conditions under climate change and create early-successional forest habitat, which is declining in New England (NRCS 2007). In addition, more frequent access to the most easily accessible stands may reduce the financial pressure to harvest other areas during marginal or unfavorable weather conditions, and may justify improvements in infrastructure (e.g., skid trails, stream crossings, landings) which can lower the impact of harvesting activities.

Adaptation Strategy #2: Conduct low-impact and sustainable timber harvests

Background: The temperature increases and alterations in precipitation patterns associated with climatic change (e.g., shortened winter logging periods, extended mud season, and increased frequencies of severe storm events) are likely to reduce the number of days with conditions favorable for low-impact logging (Gunn et al. 2009). This may increase logging costs as machinery sits idle during marginal and unfavorable conditions, and increase pressure on managers to operate during such conditions, risking damage to soils and water quality. BMPs and sustainable harvesting strategies can protect soil and water quality during increasingly marginal and challenging weather conditions. In addition, the degradation of conditions may require upgrading logging infrastructure (haul roads, skid trails, stream crossings, and landings) to improve access to timber and reduce impacts to soil and water quality.

Best Management Practices:

- Continue to apply BMPs and sustainable forestry practices: BMPs are a highly effective and costeffective way of minimizing impacts to soil and water quality during harvest operations (MFS 2004). Climate change is predicted to increase stressors on trees and forest species and increase periods of wet and muddy soil making the use of BMPs during timber harvest operations even more important. Utilizing experienced foresters and logging contractors who are well versed in applying BMPs, and utilizing low impact logging techniques, can protect forest health, productivity, wildlife habitats, and water quality.
- 2. Create infrastructure that can withstand a variety of weather conditions: Decreasing dependability of frozen soils, increasing probabilities of large storm events, and general uncertainties about weather and soil conditions may require upgrades to logging infrastructure. Redesigning haul roads, skid trails, landings, and stream crossings to provide access in a wide range of conditions will ensure low-impact access for harvesting equipment and allow rapid mobilization and exploitation of narrow windows of

weather and favorable operating conditions. Costs of improvements may be offset by improved access to timber and reduced number of "shut down" days.

3. Track and respond to changing soil-weather conditions that can affect logging operations: Be flexible in timing harvests and be prepared to mobilize rapidly when the conditions are In 2009 and 2010 NEFF took favorable. advantage of unusually dry conditions in April and May and completed harvests during what was traditionally considered "mud-season." This is contrary to long-standing practices when operations were shut down during spring when conditions were unfavorable for cutting and transporting wood. This type of flexibility will likely become standard operating procedure under climate change.



Reduced predictability in the timing and duration of frozen ground makes harvest planning challenging.

Adaptation Strategy #3: Maintain and increase red oak and white pine on site

Background: Red oak and white pine are well suited for the warmer temperatures and altered precipitation patterns expected under climate change in Maine (Iverson et al. 2008). Both species are present at AWF in sufficient numbers to ensure successful natural regeneration on site. Red oak is highly valuable for wildlife (DeGraff and Yamasaki 2001) and both red oak and white pine are highly valued for forest products (McWilliams et al. 2005).

Best Management Practices:

1. Use shelterwood harvest systems to increase red oak and white pine: In stands with an oak or white pine component in the understory, conduct multi-stage shelterwood harvests to reduce dominance of tree species that are vulnerable or not well adapted for changing climatic conditions (e.g., hemlock, balsam fir, spruce) and create growing space for white pines and red oaks. Canopy openings should be >50% to provide favorable light conditions to grow these seedlings and saplings into larger trees (Martin and Lorimer 1997, Balch 2010). In hardwood and mixed wood stands that have an oak overstory but lack oak seedlings and saplings, conduct 3-stage shelterwood harvests to encourage seed production and crown development, reduce competition for seedlings, and open up the overstory to provide light for seedlings by (OMNR 1995).



White pine regeneration in a shelterwood harvest.



Red oak seedling at AWF.

Adaptation Strategy #4: Be aware and plan for threats facing hemlock stands

Background: Hemlock is a common species in AWF and, although it is not commercially valuable, it provides important habitat for wildlife. Hemlock is a cold-adapted species, and the predicted increases in temperature may stress hemlocks and reduce health of hemlocks (Iverson et al. 2008). Temperature stress combined with the expansion of Hemlock Wooly Adelgid (HWA) and Elongate Hemlock Scale (EHS) populations in Maine has profoundly negative implications for the long-term survival of hemlock in AWF. Both HWA and EHS are pest species that, once established in a stand, causes declines and eventual mortality of hemlock trees. Warmer winter temperatures increase survival and productivity of these pests (Parker et al. 1998). Infestations of HWA and EHS have been detected in southern and mid-coast Maine and the range of this pest is rapidly expanding northward.

- 1. **Track HWA and EHS in Maine and on-site:** Track new reports of HWA and EHS infestations to determine the risk to hemlock trees. If infestations are detected in close proximity to AWF, screen hemlock stands for presence of HWA and EHS. Monitoring is not prohibitively labor intensive (level of effort: 10-25 trees per stand and 2-4 branches per tree; Ward et al. 2004) and can be done during several months of the year (November-July; Ward et al. 2004). Focus monitoring efforts along edges, trail corridors, and waterways (Gucinkski et al. 2001, Beinger-Truaz et al. 1992, Brzeskiewicz 2008). Utilize harvests to assess upper canopy branches (A. Kanote personal communication 5/11/11). Monitoring can be completed by the property steward or other volunteers.
- 2. **Reduce risk of introduction and spread of pest species:** If HWA and/or EHS are detected in close proximity or within AWF, conduct harvests when these species are least mobile (from mid-August to February). This can significantly reduce the risk of transportation on logging equipment between woodlots and within AWF (Orwig and Kittredge 2005). If you cannot harvest during this time period and these pests are detected in areas where logging contractors operate, power-washing logging equipment can reduce the risk of introduction from off site.
- Be prepared to implement hemlock management options if HWA/EHS arrives: If infestations 3. are reported nearby, the arrival of HWA/EHS at AWF are likely imminent. Once a site is infested, mortality of trees is rapid (4-10 years: Moser and Obrycki 2009, possibly 10+ years in Maine [A. Kanote personal communication 9/8/10]) and legacy trees left on site have a very low survival rate (20%: Orwig and Kizlinski 2002). The effectiveness of biological controls is currently being tested and this may be a viable management option in the future. Currently managers have 2 options: (1) let hemlocks decline and allow stands to slowly transition to deciduous hardwoods (Orwig and Foster 1998, Orwig 2002) and white pines (Kizlinksi et al. 2002) or (2) harvest hemlocks before significant declines (before 50-75% of foliage is lost [Orwig and Kittredge 2005]) to capture financial value, speed up stand conversion (Orwig and Kittredge 2005), and help create conditions that will favor the regeneration of red oak and white pine, two species that are predicted to thrive in the future. A combination of these approaches at the site can help balance short- and long-term economic and environmental objectives. When evaluating management options, consider existing management goals for the stand (rotation length, harvest intensity, desired species composition, or ecological or economic objectives), ease of access for harvesting equipment, and proximity to recreation trails, as standing dead trees can be safety hazards.

Adaptation Strategy #5: Promote regeneration of native tree species

Background: Invasive plant species are expected to thrive under a changing climate because they can handle a wide range of climatic conditions and tolerate environmental stressors better than native plants (Burke and Grime 1996). This may allow non-native species to out-compete native seedlings and saplings and quickly colonize areas following timber harvests or natural disturbances (Dukes and Mooney 1999). Loss of native forest species causes alterations in plant communities, reduces the quality and quantity of wildlife habitat, and reduces timber revenue. Prevention and early detection of invasive species can avoid negative ecological impacts, as well as prevent costly management actions and loss of timber value.

- 1. **Track existing and emerging threats of invasive species**: Track changes in the distributions of invasive species in Maine and identify new and emerging threats by using USFS's Alien Forest Pest Explorer. This allows you to track the range and determine forest susceptibility of over 70 forest pest species. In addition to this website, the Maine Forest Service produces educational materials for forest landowners, and offers workshops on identification and management of invasive species. This provides managers with a low-cost way for identifying and prioritizing monitoring efforts.
- 2. Develop a modest but effective monitoring program for invasive species: Widespread and intensive monitoring for invasive species is expensive and beyond the capacity of most landowners. A targeted monitoring program that focuses only on species at high risk for infestation in AWF in "hot spots" where infestation is most likely can provide managers with useful data with minimal investments of time and resources. In AWF high-risk species include those already established on site (buckthorn, barberry, multiflora rose, and shrub honeysuckle), and species with a high probability of future establishment and potential to result in large ecological and financial damage (e.g., HWA, EHS, Emerald Ash Borer, Asian Longhorn Beetle). Hot spots for invasive species include areas near current and historic roads (Gucinski et al. 2001, Sumners 2005), trails (Beninger-Truax et al. 1992), within recent harvests and other highly disturbed areas (Dukes and Mooney 1999), near waterways (Brzeskiewicz 2008), and near existing populations of invasives (Arim et al. 2006). NEFF can build capacity for invasive species monitoring by using NEFF education and outreach events to educate people about invasive species and recruit volunteers and seek grants and cost-share programs to pay for removal and management.
- 3. **Control invasive species at the early stages of infestation:** If monitoring detects that regeneration of native species is being threatened by competition from non-native species take immediate steps to remove and/or control non-native species. Early detection can prevent large infestations and can protect wildlife habitat and timber values.



Japanese barberry along a trail.



Buckthorn is established within a stand.

Adaptation Strategy #6: Minimize negative impacts of disturbance events

Background: The frequency and intensity of widespread disturbances such as storms, droughts, periods of extreme heat, fires, insect or disease outbreak are predicted to increase due to climate change (Dale et al. 2001). Disturbance events can damage canopy trees, resulting in injury or death and loss of economic value. As the frequency and intensity of disturbance events increase, the number of acres impacted, and the financial costs of these impacts, will increase. Most importantly, landowners can reduce the risk of disturbance events by having stands with diverse age classes (see Adaptation Strategy #1), but can increase protection against financial loss by anticipating and preparing for disturbance events.

- 1. Identify stands most vulnerable to disturbance events: Consider the vulnerability of specific species (e.g., softwoods and other shallow-rooted species) and stand features (e.g., ridgelines, buffers, forest edges) to disturbance events when creating harvest plans and management strategies. For example, softwoods are often shallow rooted and are prone to wind damage and these species may not be well suited for buffer strips or retention patches, especially on exposed ridges or near edges of harvest blocks or clearings. For areas most vulnerable to disturbance events, evaluate the viability of existing infrastructure (e.g., landings, skid trails, haul roads) for salvage logging and when feasible develop multi-season access points that can be used in a variety of weather conditions.
- 2. Monitor regeneration and invasive species after stand-replacing events: If stands are impacted by a catastrophic natural disturbance event, periodically (<5-year time interval) monitor these stands to ensure regeneration is composed of native species. If non-native species are found to be present, additional management actions may be needed. See Strategy 5 for details on invasive species monitoring.</p>



High winds can damage large numbers of trees.

Adaptation Strategy #7: Create a low-impact recreational trail system

Background: Outdoor recreation is a vital part of the social and economic fabric of many Maine communities. Trail-based recreation adds over \$500 million dollars annually to the state's economy (Reiling 1999, Morris et al. 2005, Morris et al. 2006). Winter recreation is highly vulnerable to climate change due to its dependence on natural snow (Scott and Jones 2005). The primary winter use of AWF is by snowmobilers. As the depth and duration of snow cover decreases, using trails during marginal snow conditions could lead to trail damage. Extreme precipitation events associated with climate change can degrade trail quality and become a significant source of sediment to water bodies (Wilkerson and Whitman 2010). Trails that are well designed and in good condition (i.e., drain water, no ruts) will allow snowmobiles to safely operate on less snow and reduce trail damage and increase user enjoyment for all recreational users.

- 1. Maintain low-impact and high-quality trails: Work with local snowmobile clubs and trail users to evaluate the condition of trails and stream crossings and identify areas needing improvement. Increased precipitation can cause wet and muddy conditions that can quickly degrade trails, increase environmental damage, and decrease user enjoyment. Trail closures during wet weather and marginal snow conditions can prevent damage to trail infrastructure, but in routinely wet or degraded areas consider improving or re-routing trails to avoid future problems. Snowmobile clubs are eligible for grants and cost-share funding for trail improvements, and lands with public access are eligible for recreation trail program grants for trail improvements.
- 2. **Clearly communicate permitted recreational uses:** As the number of days with snow cover and the reliability of having adequate snowfall for winter sports decreases it is likely that recreationists will want to diversify their winter activities. The rapid increase in ATV sales (ME ATV Task Force 2003, Cordell et al. 2005, Jensen and Guthrie 2006) suggests that ATVs will supersede snowmobiling as a recreation activity (Scott et al. 2008). NEFF does not allow ATVs on their properties and this position is unlikely to change despite the growing popularity of ATVs. Posting clear signage on allowable recreation activities as well as frequent communication with local motorized clubs can make allowable uses of the property publically known and reduce unauthorized ATV access to the property.



Wet conditions can cause damage to trails.



Snowmobiling is a popular activity that is highly vulnerable to climate change.

Adaptation Strategy #8: Encourage deer management

Background: Winter stress caused by cold temperatures, snow depth, and lack of food is the primary stressor of deer herds in Maine (Pekins and Tarr 2009). The severity of winter conditions affects deer survival, herd size and density (Verme 1968). As winters warm and the depth and duration of snow cover decrease, herd size and deer density will increase. Large populations of deer have negative impacts on forests and human health. Large deer herds can over-browse vegetation and interfere with forest regeneration by altering species composition and reducing vegetation (Marquis et al. 1990). Deer are carriers of Lyme disease and when deer densities exceed 15 deer per square mile the abundance of deer ticks and instances of Lyme disease increase dramatically (Rand et al. 2003). The scale and regulatory implications of deer management requires involvement of Maine Inland Fisheries and Wildlife and cooperation and support from forest landowners.

Best Management Practices:

1. **Provide hunting opportunities:** Continue to allow recreational access to hunters at AWF and support programs to educate the public about responsible use of private property to ensure continued access to forest land for recreation and hunting.



Hunting can keep deer populations from becoming too large.



Healthy forest regeneration can be threatened large populations of deer.



Large numbers of deer are linked to increased instances of Lyme disease.

Adaptation Strategy #9: Be aware of the need for cross-sector and interagency adaptation planning at landscape, state, and regional scales

Background: Many impacts of climate change cannot be addressed by landowners at the stand or ownership scale due to financial costs, jurisdictional issues, or alignment with landowner goals and objectives. To safeguard forestland against climate change impacts, regional and state-wide approaches that address forestry operations, wildlife management (e.g. hunting seasons, target species), land use planning, and landowner assistance programs will be necessary. Climate change impacts are cross-sectoral, and coordination among government agencies, non-profits, and stakeholders in multiple sectors (e.g., natural resources, public health and safety, emergency management, recreation, and economic development) is required to effectively prepare for them.

- 1. Be aware of landscape-scale adaptation planning efforts: Landscape-level planning efforts are essential to conserve the ecological (e.g., large forest blocks, travel corridors, watershed function), economic (e.g., timber markets, harvesting operations and infrastructure, nature-based tourism), and recreational (e.g., trails, hunting access, fishing opportunities) benefits of forests under a changing climate. The Kennebec Woodland Partnership is a local effort trying to develop landscape-level conservation and land use planning strategies in Kennebec County. This effort can inform and facilitate landscape-level planning efforts at AWF.
- 2. Be aware of interdisciplinary adaptation efforts: Climate change also has serious implications for human health and safety. Although many of these issues are beyond the scope of forest landowners, there are opportunities for involvement when health issues intersect with forest use. For example, vector-borne diseases, including Lyme disease, Eastern equine encephalitis (EEE), and West Nile virus, are projected to increase in central Maine as the climate warms and precipitation patterns change (Robbins 2009, Sorg 2009, Harvard Medical School 2010). These health risks are closely associated with outdoor activities, particularly forest-based recreation, and have the potential to reduce the popularity of outdoor recreation. Public health officials have identified steps forest users can take to reduce risks of contracting Lyme, EEE, and West Nile virus while still enjoying outdoor activities. Landowners, along with land trusts and state agencies, can help educate forest users about reducing their risks while recreating outdoors.

Appendix A. Primary Climate Change Stressors Relevant to Allen-Whitney Forest (AWF)				
Category	Projected Change	Impact (+/-)	References	
Species Distr	ribution and Alteration of	Temperature and Precipitation Patterns		
Increases in average seasonal temperatures		• Increase in length of growing season and growth rate (+)	• McMahon et al. 2010, Ollinger et al. 2008, Shaler et al. 2009	
		• Heat stress can result in reduced fitness and/or mortality (-)	• Ollinger et al. 2008	
		• Increased water temperature in streams, Shed Pond, and forested wetlands (-)	• Hart et al. 2009	
		• Changes in over-winter survival (+/- depending on species)	• Pekins and Tarr 2008, Patterson 1995	
	Alterations in precipitation patterns	• Increased winter precipitation may be likely. However, increased evapotranspiration (EVT) rates and summer drought frequency and intensity stress plants and animals (-)	• Niinemets and Valladares 2006	
		• Alters hydrology of Shed Pond, streams, and forested wetlands (-)	• NRC 2008, Frumoff et al. 2007	
	Shorter periods of frozen ground and/or	• Root damage due to cold exposure and freeze/thaw action (-)	• Jacobson et al. 2009, Cox and Malcolm 1997, Ollinger et al. 2008	
	snow cover	• Changes in over-winter survival (+/- depending on species)	• Pekins and Tarr 2008, Patterson 1995	
		• Reduces snowmobile and ski season, and increases potential damage to	• Scott and Jones 2005 and Wilkerson and Whitman 2010	
		trails (-)	• Campbell et al. 2005	
		May impact forest plant communities (-)		
	Increases in red oak	• Commercially important species (+)	• McWilliams et al. 2005	
		• A native species well suited for climate change (+)	• Iverson et al. 2008	
		Mast species important for wildlife	• DeGraff and Yamasaki 2001	
	Declines in hemlock	• Alters natural forest composition (-)	• Iverson et al. 2008	
		• Infestations of HMA kills mature trees (-)	 Orwig and Kizlinkski 2002 	
	Increases in deer populations	• Browse damage to vegetation and reduction in natural forest regeneration (-)	• Tilghman 1989, Rooney 2001	
		• Increased density of deer linked to occurrence of Lyme disease and other tick-borne diseases (-)	• Wilson et al. 1988 and Rand et al. 2003	
		• Increased herd sizes and opportunities for hunting (+)	• Williamson et al. 2006	
	Biodiversity	• Loss of species at the southern end of range (-)	• Burns et al. 2003	
		• Receiving area for species at northern end of range (+)	• Parmesan et al. 1999	
Disturbance Regimes				
Increases in magnitude and frequency of		• Exposure to single or multiple stressors can reduce growth, fitness, and/or death (-)	• Niinemets and Valladares 2006	
	"extreme" weather events (e.g., heat	• Increased frequency of stand-replacing events that alter forest structure and composition (-)	• Boose et al. 2001, Union of Concerned Scientists 2006	
	waves, droughts, floods, ice storms, high wind events)	• Increased water temperature and alteration of hydrology in streams, Shed Pond, and forested wetlands	• Hart et al. 2009, NRC 2008	

	Increases in magnitude	• Increases successional processes which enhance forests ability to adapt to	• Overneck et al. 1990. Gunn et al. 2009	
	and frequency of	climate change (+)	overpeen et al. 1990, Ourni et al. 2009	
	"extreme" weather	• White pine and red oak have some resistance to ice damage (+)	• Hauer et al. 1994	
	events (cont.)	Hemlock is highly resistant to ice damage	• Hauer et al. 1994	
		Oaks are resistant to wind damage	• Barnes et al. 1998	
		 Plantations have significant risk for damage and death () 	Bodin and Wiman 2007	
		Diverse species and age classes are more regilient to disturbances (+)	Bodin and Wiman 2007	
	Increased risk of	• Diverse species and age classes are more resident to disturbances (+)	• Ver Werner 1070	
	wildfire	• Can cause stand-replacing events that aid in establishing vigorous new tree	• Van Wagner 1970	
	whentie	Bight for loss of property, timber, and human health and safety ()	• Eleppicen et al. 2000	
Non Native	Invasive and Pest Speci	• Kisk for loss of property, under, and numan health and safety (-)	• Flattingati et al. 2000	
inon-inauve	Increased risk of new		• Bahaland Older 2009, Dala et al 2001, Sleinnen et al	
	pests and pathogens	• Allows establishment of species currently limited by existing environmental factors (e.g. winter/summer temperatures, precipitation levels, growing	• Ranel and Olden 2008, Dale et al. 2001, Skinner et al.	
	and/or reoccurrence	season)	2003	
	of existing pests and	Hemlocks vulnerable to mortality from HWA which are currently limited	• Paradis et al. 2008	
	pathogens	by cold winter temperatures (-)	aradis et al. 2000	
		Potential softwood pests (pine bark beetle, white pine blister rust, spruce	• MES 2008	
		budworm) (-)	- 111 0 2000	
		Potential hardwood pests (emerald ash borer, Asian Longhorned Beetle	• USES 2004 USES 2008	
		Sudden Oak Death) (-)		
	Expansion of range	• Increase invasive species already on site due to tolerance of wide range of	• Williamson 1999; Weltzin et al. 2003	
	and abundance of	conditions and ability to quickly colonize open niches (-)		
	existing non-native	• Allows establishment of species currently limited due to existing	• Rahel and Olden 2008, Dale et al. 2001, Skinner et al.	
	species and	environmental factors (e.g., winter/summer temperatures, precipitation	2003	
	introduction of new	levels, growing season) (-)		
	non-native species	• Exotic species can dominate understory and reduce regeneration of native	• Burke and Grime 1996	
		species (-)		
	Non-native species are	• Increased CO ₂ concentrations increase growth rates of invasive plants	• Belote et al. 2003, Ziska and George 2006	
	well adapted to	more than native plants (-)		
	disturbance and	• Increases likelihood of establishment of non-native, invasive species that	• Dukes and Mooney 1999	
	changes in climate	are able to grow quickly in disturbed environments (-)		
Financial	Implications			
	Alteration in species	• Increases in red oak, a commercially important species and well suited for	• McWilliams et al. 2005	
	1111X	cumate change (+)	. 1	
		• Declines in hemlock due to increases in temperature and spread of HMA	• Iverson et al. 2008	
		(+ not a commercially valuable species, - alteration of forest community		
		• Species heat evited for new elimetic and division have a service i	• Spittlehouse and Stowert 2004	
		• species best suited for new climatic conditions have a commercial	• Sphuenouse and Stewart 2004	
		• Equat management can enhance extention of economically	• Lacola at al. 2000	
		• Forest management can enhance retention of economically valuable species	• Jageis et al. 2009	
		or species survey for new chinatic conditions or emerging markets (+)		

Operational chang (i.e., longer "mud season" and short periods of frozen ground and/or sno cover)	 Limits schedule for forest management operations (-) Increases potential damage to road infrastructure and recreation trails (-) Limits ability to conduct lower-impact winter harvests (-) 	 Gunn et al. 2009, Shaler et al. 2009 Spittlehouse and Stewart 2003 Gunn et al. 2009, Shaler et al. 2009
Increases in magni and frequency of "extreme" weather events (e.g., heat waves, droughts, floods, ice storms, high wind events)	 Loss of timber revenue from damaged stands (-) Stands with diverse species and age classes reduce risk to landowners(+) Management activities (exotic species control, partial cutting, thinning, and fire protection) can reduce extent of disturbance events (+) 	 Ross and Lott 2003 Bodin and Wiman 2007 Dale et al. 2001, Volney and Hirsch 2005
Natural regenerati	 Exotic species can dominate understory and reduce regeneration of native species (-) Young trees (seedlings and saplings) are most susceptible to stress (-) Growing season and growth rate expected to increase (+) 	Burke and Grime 1996Spittlehouse and Steward 2004, Jagels et al. 2009Shaler et al. 2009
Public uses and values		
Decrease in snow cover (depth and duration) and incr in "mud season"	 Reduces recreation opportunities for winter sports (snowmobiling, cross-country skiing, snowshoeing) as the length of winter sport season decreases (-) Trails deteriorate due to wet/muddy conditions, lack of snow cover (-) 	 Scott and Jones 2005, Frumhoff et al. 2007, Scott et al. 2008 Wilkerson and Whitman 2010
Increases in deer population	 Increases in hunting opportunities (+) Increases in Lyme Disease and other tick borne illnesses (-) Browse damage to vegetation and reduction in natural forest regeneration (-) 	 Williamson et al. 2006 Wilson et al. 1988, Rand et al. 2003 Tilghman 1989, Rooney 2001
Human health and welfare	 Increase in survival and reproduction of deer ticks, mosquitoes and associated instances of Lyme disease, encephalitis, and other vector-borne diseases (-) Plants with highly allergenic pollens thrive and produce more pollen under conditions of higher levels of carbon dioxide (-) Increases in toxicity and growth rate of poison ivy (-) Non-native shrubs strongly associated with high tick counts (-) Increased water temperatures alters reproduction rates and survivability of insects (- mosquitoes and other pests) 	 Rand et al. 2003, Epstein 2008, Rosenzweig et al. 2001 Epstein 2005 Mohan et al. 2006 Elias et al. 2006 Paaijmans et al. 2010

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