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Natural Resource Stewardship and Science

Forest Vulnerability to Climate Change and Tree Pests at Marsh-Billings-Rockefeller National Historical Park

Natural Resource Report NPS/MABI/NRR—2014/828

ON THE COVER
Hardwood forest and large sugar maple tree, Marsh-Billings-Rockefeller National Historical Park.
NPS photo.

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Nicholas Fisichelli[1], Maria Janowiak[2], Kyle Jones[3], Matthew Peters[4]

[1]US National Park Service
Natural Resource Science and Stewardship
Climate Change Response Program
Fort Collins, CO 80525
nicholas_fisichelli@nps.gov

[2]US Forest Service
Northern Institute of Applied Climate Science
Houghton, MI 49931

3US National Park Service
Marsh-Billings-Rockefeller National Historical Park
Woodstock, VT 05091

[4]US Forest Service
Northern Research Station
Delaware, OH 43015

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Abstract

Climate change is affecting species and resources across National Parks. Shifting climatic conditions are likely to result in novel species assemblages; this means that some species currently present within parks may decline or disappear while more southerly or warm-adapted species may gain substantial habitat. Stewarding forests for continuous change is a challenge for park managers; however, understanding projected rates and directions of forest change should facilitate monitoring and management efforts on park lands and across the broader landscape. To support climate change adaptation within the forest management plan for Marsh-Billings-Rockefeller National Historical Park, we analyzed projected changes in tree habitat suitability for 80 trees species for three future periods (2040, 2070, and 2100) and also assessed recent and projected tree pest impacts to park forests. For tree habitat, we present model output from two climate scenarios, the 'least change' and 'major change' scenarios that represent a rough bound of plausible future conditions. General trends in the data indicate strongly decreasing potential habitat suitability for 10 species (12% of species), minor change for 24 species (29% of species), and large increases or new habitat for 48 species (59% of species). Some northern tree species, including fir, aspen, and paper birch, have moderate to strong decreases in suitable habitat under both future scenarios whereas most temperate species currently present retain suitable habitat. Under the warmest scenario, several oak, hickory, and pine species uncommon or absent in the park gain suitable habitat in central Vermont in the coming decades. Forest pest impacts have been relatively moderate over the past 15 years, though expansion rates of species such as hemlock woolly adelgid and emerald ash borer threaten the park in the next two decades. The combination of rapid climate change and tree pests may accelerate decline of some tree species and inhibit other species from occupying climatically suitable habitat. Results presented here will be used by managers at Marsh-Billings-Rockefeller NHP as they adapt their forest management plan to achieve desired conditions in a continuously changing world.

Introduction

This report is a vulnerability assessment of tree species within Marsh-Billings-Rockefeller National Historical Park (i.e., the Mount Tom Forest) to climate and tree pests and weeds. It is designed to inform climate change adaptation strategies within the park's forest management plan (NPS 2006), which outlines the values of forests within the park and the objectives of management:

"The Mount Tom Forest is a key component of the cultural landscape of the 555-acre Marsh-Billings-Rockefeller National Historical Park and plays an important role in the Park's interpretation and demonstration of stewardship. The Forest Management Plan provides a strategy for managing the Mount Tom Forest that will:

- perpetuate the tradition of sustainable forest management on the property
- incorporate a long-term perspective on the changing composition and character of the Forest
- value the Forest as both a natural and cultural resource
- emphasize the relationship of the Park's forest management to broader community well-being and sustainability
- strengthen civic engagement and stewardship

The Plan is guided by seven specific management goals related to:

- historic character
- ecological health
- sustainable management practices
- education and interpretation
- visitor use and recreation
- watershed and community connections
- adaptive management"

The Mount Tom Forest includes plantations of North American and European species as well as native forest types common to the region. Active forest management within the park includes periodic thinning, harvesting, and planting and these activities can be informed by potential climate change effects to perpetuate desired forest conditions within the park. This process begins with understanding potential impacts and species likely to gain or lose potential habitat in the region.

Forest managers are dealing with both rapid directional change and multiple uncertainties (Heller and Zavaleta 2009) and understanding potential directions of change as well as sources of uncertainty is vital for effective land management (Harris et al. 2012, Fisichelli et al. 2014a). Global change agents, including rising temperatures, pollution, fragmentation, and nonnative insect pests, diseases, and invasive plants, are altering ecosystem processes, structure, and composition (Vitousek 1994, Grimm et al. 2013). Interpretations of climate-vegetation models that project shifts in habitat suitability due to climate change can inform natural resource planning and management actions. Many tree species are keystone or foundation species and shifts in forest composition and structure will affect other trophic levels within the ecosystem (Ellison et al. 2005). Biotic stressors, such as nonnative tree pests and nonnative invasive plant species, can exacerbate climate stress and alter compositional trajectory of forests (Dukes et al. 2009, Sturrock et al. 2011). Furthermore, climate and forest changes may have cascading effects on cultural resource protection, forest operations, and recreation.

Climate is changing rapidly and many parks across the NPS (81% of natural resource parks) are already experiencing climatic conditions at the warm extremes of their historical range of variability (Monahan and Fisichelli 2014), and climate change has caused measurable responses by birds, mammals, and vegetation within national parks (Moritz et al. 2008, Tingley et al. 2009, Dolanc et al. 2013). Mean annual temperatures across the U.S. are roughly 1.5 °F (0.8 °C) higher than those at the end of the 19th century. Warming is evident in most regions of the contiguous U.S., with an especially high rate of increase in the upper Midwest and Northeast (NCADAC 2013). Current projections indicate numerous likely aspects and effects of a changing climate change over coming decades, including:

- a rise in mean annual temperatures in the eastern U.S. of 3-5 °F (1.7-2.8 °C) by mid-century and 4-8 °F (2.2-4.4 °C) by 2100, compared with the 1961-1990 average (Kunkel et al. 2013),
- highly variable precipitation with most areas in the eastern U.S. likely to see increases in winter precipitation and decreases in summer totals, though there is greater uncertainty in precipitation than temperature (Kunkel et al. 2013),
- expanded growing seasons, lower snow depths, earlier spring snowmelt and runoff, and fewer but heavier rain events (NCADAC 2013).
- altered type, frequency, and intensity of episodic disturbances such as wildfires, wind and ice storms, and insect and pathogen outbreaks (Dale et al. 2001),
- and pulses of change as ecosystems self-sort and reorganize after these disturbance events.

It must also be stressed that climate change is not a spatially uniform and linearly changing phenomenon, but rather shows great heterogeneity over time and across space.

Climate change affects all tree life stages, from seed development, germination, and emergence (Walck et al. 2011) to seedling growth and recruitment (Fisichelli et al. 2012, 2013a, 2014) to survival of overstory trees (Allen et al 2010). The paleorecord from the past 12,000+ years shows tree species shifting their ranges 100s to 1000s of miles across eastern North America in response to past changes in climate (Davis 1983, Webb 1987). Observational studies also indicate range shifts over the past century, likely due to recent warming (Beckage et al. 2008; Lenoir et al. 2009). Forests on Isle Royale National Park, for example, have experienced expansions of temperate tree species and declines of boreal trees over the past 50 years, commensurate with a warming trend (Kraft et al. 2010). Although species tracked climate change in the past, many may fail to keep pace with rapid 21st century climate change, potentially resulting in depauperate forests or shifts to other ecosystem types (Iverson et al. 2004, Scheller & Mladenoff 2008).

The temperate-boreal transition zone of eastern North America (Goldblum & Rigg

2010), in which Marsh-Billings-Rockefeller NHP occurs, contains overlapping range limits of cold-adapted boreal trees and warm-adapted temperate species. These forests may be especially sensitive to climate change (Fisichelli et al. 2013a). Tools such as the Climate Change Tree Atlas (Prasad et al. 2007) and tree pest information used in this report enable managers to explore potential ecosystem changes in the coming decades and century. Understanding the direction and rate of change in tree species habitat suitability, including both expansions and contractions over the next 30-90 years, will help managers focus monitoring and management efforts to achieve desired conditions within the Mount Tom Forest.

Norway spruce (Picea abies), Marsh-Billings-Rockefeller National Historical Park. NPS photo.

Methods

Climate change, tree habitat suitability changes, similarity of future forest composition to current composition across the landscape, European tree responses to climate, and tree pest and weed methods are covered below. Projections of tree habitat suitability changes in response to climate are based on climate projections and the relationships between environmental factors – including climatic variables – and individual species' abundance and distribution (Prasad et al. 2007, Iverson et al. 2008). Thus, habitat suitability changes integrate two parts of climate change vulnerability for each tree species (potential impact = climate change exposure + sensitivity; Glick et al. 2011). The third component of vulnerability assessments, adaptive capacity, is covered through the Modification Factors (ModFacs) analyses and assessment of tree pests present in the region.

Climate data

Climate change cannot be precisely predicted in part because of irreducible uncertainties regarding the future greenhouse gas emissions pathway and discrepancies among climate models. We selected a potential range of future climatic conditions using two general circulation models (Parallel Climate Model [PCM] and HadleyCM3 [Had]) and two greenhouse gas emissions scenarios (B1 and A1FI) that bracket the probable range of future greenhouse gas emissions (Figure 1, IPCC 2007). Neither climate projection is assigned a probability here; rather the two models and emissions scenarios provide the 'least change' and 'major change' bounds on the plausible range of future conditions. The PCM combined with the B1 scenario presents a 'least change' climate scenario based on dramatic cuts in greenhouse gas emissions and modest climatic changes (Figure 2, 3), and the Had-A1FI combination represents a 'major change' scenario under high greenhouse gas emissions. These two models project an increase in mean annual temperature of 3-6 °C (5.4-10.8 °F) over the 21st century in the eastern U.S. and a decrease (-27%) or increase (+75%) in precipitation, depending on geographic location and climate model (values are compared with the 1961-1990 baseline).

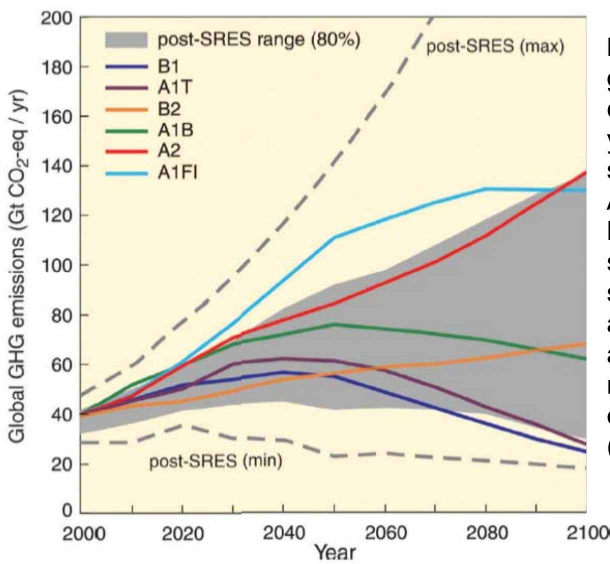

Figure 1. Global greenhouse gas emissions (in gigatons of carbon dioxide equivalent per year) under six potential scenarios (B1, A1T, B2, A1B, A2, and A1FI). The dashed lines show the full range of scenarios. The B1 and A1FI scenarios were used in the analyses in this report as lower and upper bounds, respectively, of plausible future emissions. Figure from IPCC (2007).

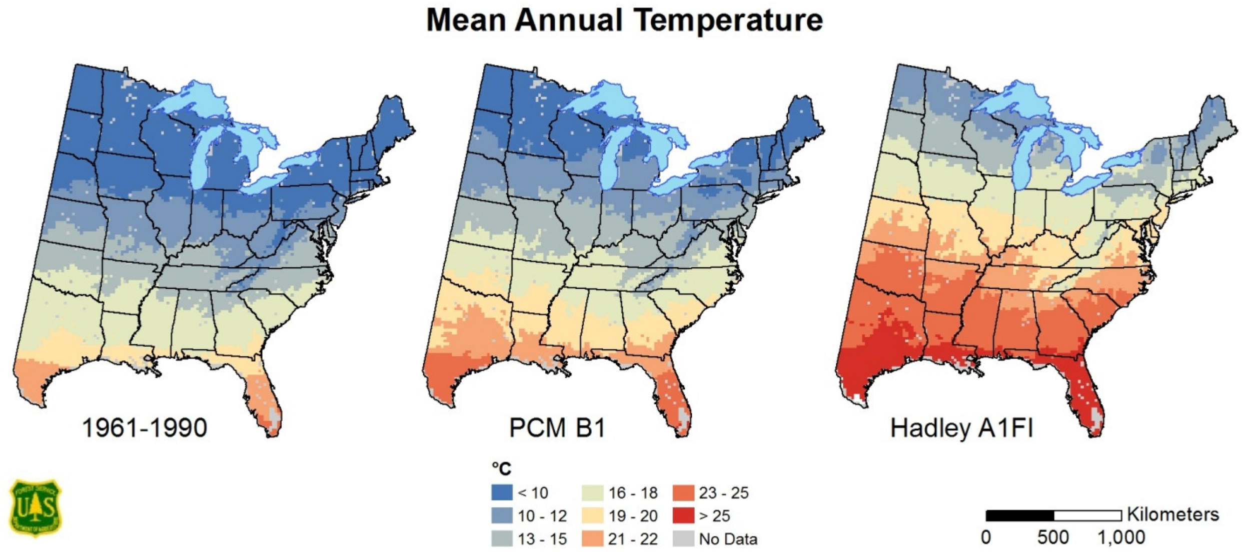

Figure 2. Baseline (1961-1990) and projected mean annual temperature for the end of the 21st century. The PCM-B1 model represents the lowest levels of warming under a very low greenhouse gas emissions scenario. The HadleyCM3-A1FI model shows the warmest projections under the high greenhouse gas emissions scenario. Emissions scenarios are from IPCC (2007).

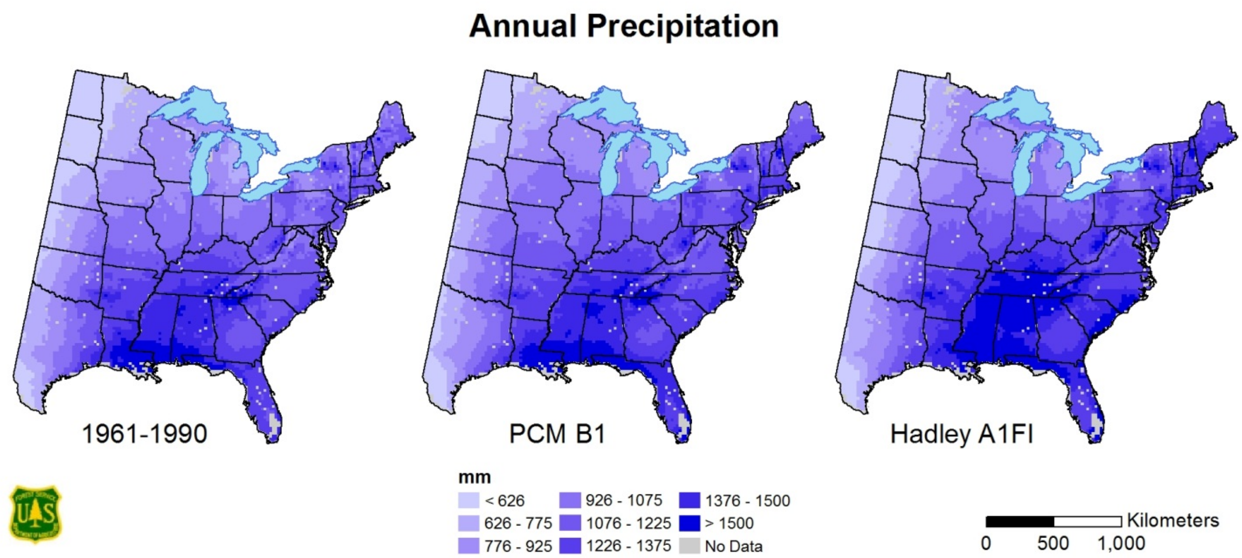

Figure 3. Baseline (1961-1990) and projected mean annual precipitation for the end of the 21st century. PCM-B1 and Hadley-A1FI represent the coolest and warmest temperature projections and indicate slight to moderate increases in annual precipitation for the eastern US. Emissions scenarios are from IPCC (2007).

Suitable habitat modeling

The projections of suitable habitat for tree species come from the USDA Forest Service Climate Change Tree Atlas (see Prasad et al. 2007 and Iverson et al. 2008 for more in depth details of these methods). The statistical model used in these analyses, the DISTRIB model, uses an ensemble of regression tree techniques to statistically correlate tree abundance to 38 environmental predictor variables, including climate (Table 1), across the eastern United States (Iverson et al. 2008). Climate projections are modeled among 3-D grids, which typically range from 0.5 – 2.5 degrees latitude and longitude at the Equator. Encompassing such a large area, these models provide little information at local scales. Therefore, statistical techniques have been developed to downscale projections to resolutions between one-tenth and one-eighth of a degree (11 – 13 km). Future climate projections (PCM-B1 and Had-A1FI), downscaled by Hayhoe et al. (2007), relate modeled climate values to local observations through probability functions. See Iverson et al. (2008) for more in depth information on the methods.

The abundance of tree species within an area, identified as the Importance Value (IV), is the average of relative stem density and relative basal area. Forest Inventory and Analysis (FIA) data from the period 1980-1993 were used to calculate mean IVs within 12 x 12 mi (20 x 20 km) grids for 134 tree species. Model runs used mean monthly climate normals for 1961-1990 (Table 1) and three future 30 year time periods ending in the years 2040, 2070, and 2100. Model output indicates potential suitable habitat for a tree species, and not where the species may occur at a particular point in time.

Due to variations among model runs and climatic predictors, it is important to consider a larger areal extent for species-specific assessments, rather than a single cell. Also, the DISTRIB models are parameterized with FIA data, and individual plots might not be representative of the local species composition that results from competition, site quality, and disturbance events. Therefore, we buffered the area surrounding the park to include ≥40 DISTRIB cells using a process that iteratively selects grid cells until a minimum of 40 are identified (Figure 4). We selected cells that intersected the boundary of the park followed by those that occurred within a 10 km buffer, increased by 2 km during each additional iteration.

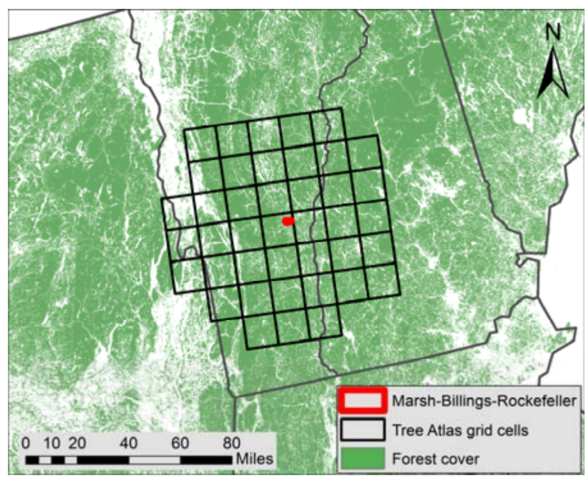

Figure 4. The area of analysis for Marsh-Billings-Rockefeller National Historical Park included 41 pixels (each 12 x 12 mi, 20 x 20 km) for a total area of 5904 mi^2 (16,400 km^2).

Reading the Complete Output Tables

We compiled summaries of IVs for 134 eastern US tree species for the Marsh-Billings-Rockefeller National Historical Park region based on 41 grid cells (see Appendix 1 for the complete tables, species with no suitable habitat [baseline or future] are omitted). As explained below, these tables include the actual FIA IV, current modeled IV, model reliability, future IVs at 2040, 2070, and 2100 under the 'least change' and 'major change' climate model and emissions scenario pairs (described above in "Climate data"), a change class designation, positive and negative modifying traits, and an adapt score.

Baseline and future models and change classes

Actual (FIA) IV is the sum of a species' IVs in all cells in which it occurs (cells with multiple plots were first aggregated to the mean IV among all plots for each species). The baseline (modeled) IV is the predicted IV under baseline (1961-1990) climate conditions for the region. Model reliability, indicated as low, medium, or high, was calculated from the pseudo R^2 of the randomForest model, consistency among 30 bagging tree models, and a fuzzy kappa score. For the region including the park, we summed projected IVs for each species at the three time periods and divided this value by the baseline IV to produce ratios of future to baseline IVs. This ratio provides a means to examine how suitable habitat within the region could change over this century (e.g., ratios > 1 indicate an increase in suitable habitat relative to the 1961-1990 baseline while ratios <1 indicate decreases in suitable habitat). Each species was also assigned a change class based on the ratio of future to current modeled IV (see Appendix 2 for change class designations). For example, a doubling of future habitat compared with baseline habitat (ratio = 2) is a 'large increase' and a 50% reduction in habitat (ratio = 0.5) is a 'large decline'.

Table 1. Variables used in the DISTRIB model to predict current and future tree species habitat (see Iverson et al. 2008 for further information).

Climate
Mean annual temperature (°C)
Mean January temperature (°C)
Mean July temperature (°C)
Mean May–September temperature (°C)
Annual precipitation (mm)
Mean May–September precipitation (mm)
Mean difference between July and January temperature (°C)
Elevation
Elevation coefficient of variation
Maximum elevation (m)
Average elevation (m)
Minimum elevation (m)
Range of elevation (m)
Soil class
Alfisol (%)
Aridisol (%)
Entisol (%)
Histosol (%)
Inceptisol (%)
Mollisol (%)
Spodosol (%)
Ultisol (%)
Vertisol (%)
Soil property
Soil bulk density (g/cm3)
Percent clay (<0.002 mm size)
Soil erodibility factor, rock fragment free
Percent soil passing sieve no. 10 (coarse)
Percent soil passing sieve no. 200 (fine)
Organic matter content (% by weight)
Potential soil productivity (m3 timber/ha)
Soil permeability rate (cm/h)
Soil pH
Depth to bedrock (cm)
Soil slope (%) of a soil component
Total available water capacity (cm, to 152 cm)
Land use and fragmentation
Fragmentation index
Cropland (%)
Forest land (%)
Nonforest land (%)
Water (%)

Modification Factors (ModFacs) and Adaptability Score

Each species received an adaptability score (adapt score) based on 12 disturbance and 9 biological traits (ModFacs) evaluated from the literature (Matthews et al. 2011). ModFacs are assigned positive or negative values, depending on whether they facilitate or inhibit climate change adaptation. For example, long-distance seed dispersal is scored as a positive trait facilitating climate change adaptation and specific habitat requirements and susceptibility to insect pests as negative traits. ModFacs were assessed relative to the species' entire range, and at local scales these traits can have the opposite effect due to management practices, patterns and intensities of natural disturbance events, or outbreaks of insect pests. Therefore, we encourage managers to consider each trait in the context of their region. Individual species were assigned an adaptability score based on the ranked ModFacs scores for all 134 tree species. Species with higher adaptability scores are likely to better cope with impacts from climate change projections.

Forest similarity

Climate change tree atlas data were used to assess the locations on landscape with baseline (1961-1990) forest habitat similar to future potential habitat for the study area around the park. This analysis was carried out using ecoregion section data; ecoregion sections are areas with similar interacting biotic and abiotic features (Bailey 2005, Prasad et al. 2007). Multivariate forest similarity was quantified via the asymmetrical Bray-Curtis distance measure, which performs well with plant community data (Legendre and Legendre 1998). Similarity was calculated as 1 – Bray-Curtis and thus resulted in values from 0 (totally dissimilar) to 1 (identical composition). Rare species (found in fewer than 5% of ecoregion sections) were removed from the similarity analyses to reduce the influence of very rare species. Similarity of Marsh-Billings-Rockefeller NHP forests were compared with ecoregion sections for all time periods (1990, 2040, 2070, and 2100) and climate scenarios ('least change' and 'major change').

Interpreting the output tables

"*All models are wrong, but some are useful"* – statistician George Box

Habitat suitability models are a useful tool for managers to examine potential patterns and direction of change in resources, but managers should keep several caveats and limitations in mind as they interpret these results. The model output presented here does not forecast future abundances of individual species or the overall future forest composition. Rather, it is meant to inform managers on potential changes in the suitability of habitat for tree species given both the current environmental conditions in which they are found and where those conditions may exist on the landscape in the future as the climate changes. The direction and magnitude of change in habitat suitability for suites of species should help inform managers of potential future forest conditions. Managers should use local knowledge of forest composition, tree species traits, and environmental conditions when assessing whether tree species may remain in current locations or occupy future suitable habitat. For example, the area of analysis here includes a large area outside of the park boundary, some of which includes fragmented habitat. Thus, a manager should consider how any differences in forests inside and outside the park may affect future response to climate change, such as whether conditions across the larger landscape will enable species to migrate into and out of the park. The park may be well beyond the current range limits of some species, and thus a dispersal distance barrier may preclude a southern species from growing in the park in the near future, even if the habitat becomes suitable. Furthermore, the analyses presented here are based on 144 mi^2 (400 km^2) blocks of land. Local topographic complexity may create refugia with cool microclimates that enable northern species to persist on the landscape longer into the future. Local examples of refugia within and south of a park can inform managers as to where species may persist for longer periods under climate change. Habitat suitability models should be used in conjunction with other tools and data, such as observational studies, field and greenhouse experiments, vulnerability assessments, and scenario planning exercises, to envision the range of plausible futures for national park forests.

European (plantation) trees and climate

The Climate Change Tree Atlas only includes trees species native to the eastern U.S. and thus we carried out a literature review of Norway spruce (*Picea abies*), European larch (*Larix decidua*), and Scots pine (*Pinus sylvestris*) responses to climate change. Findings are presented in the Results sections.

Tree pests and weeds

We assessed insect pests, diseases and invasive plant species for the park and surrounding area from multiple sources of data. Presence of nonnative forest insects and diseases (i.e., tree pests) was derived from the US Forest Service Alien Forest Pest Explorer (AFPE) Database (foresthealth.fs.usda.gov/portal/Flex/APE). Occurrence data are available at county or state level spatial scales, depending on pest species. We considered the park within the infested area for a pest if the park boundary intersected an infested zone. Thus, pests may not be present within a park at the time of mapping, but at minimum, parks are at high risk of becoming infested in the near future. We used the National Insect and Disease Survey (USDA Forest Service, Forest Health Technology Enterprise Team) to assess recent damage (acreage and vector, 1997-2012) to park forests. Near-future (2013-2027) insect and disease risk to tree species within the park come from the National Insect and Disease Risk Maps (USDA Forest Service, Forest Health Technology Enterprise Team, Krist et al. 2014). Nonnative and invasive plants (weeds) occurrence data for the park come from the NPS Inventory and Monitoring Program's NPSpecies database (irma.nps.gov/NPSpecies/) and a 2012 inventory.

Results

Potential tree habitat suitability

Analyses for the Marsh-Billings-Rockefeller NHP region resulted in 80 tree species with baseline (1961-1990) and/or future habitat suitability (see Appendix 1 for the complete model results for each species). General trends in the data indicate decreasing habitat suitability for 12 species, no change in habitat for three species, increases for 21 species, new habitat for 28 species, and mixed results between 'least change' and 'major change' scenarios for 16 species (Table 2).

Species currently present within the park or common in the region show a range of potential future habitat suitabilities (Figures 5, 6, 7). For 12 common broadleaf tree species abundant on the landscape during the baseline period (1961-1990), changes in potential habitat suitability range from large decreases to small increases (Figure 5). The northern (boreal) broadleaf species paper birch (*Betula papyrifera*) and quaking aspen (*Populus tremuloides*) have large decreases in potential habitat by 2100, with decreases much stronger under the 'major change' scenario. The common species sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*) show small decreases in potential habitat by 2100 and red oak (*Quercus rubra*) shows a small increase in habitat suitability. Red maple (*Acer rubrum*), white ash (*Fraxinus americana*), eastern hophornbeam (*Ostrya virginiana*), black cherry (*Prunus serotina*), and American basswood (*Tilia americana*) have minor changes in potential habitat under both the 'least change' and 'major change' scenarios. Other broadleaf species with lower baseline abundances include species which show larger potential increases in habitat suitability such as shagbark hickory (*Carya ovata*), white oak (*Quercus alba*), and black locust (*Robinia pseudoacacia*) (Figure 6). Conifers present in the region include both northern (boreal) and temperate species (Figure 7). The northern (cold-adapted) conifers *Abies balsamea* (balsam fir), *Picea mariana* (black spruce), *Picea rubens* (red spruce), and *Thuja occidentalis* (northern white-cedar) all show decreases in potential future habitat. *Picea glauca* (white spruce), also a cold-adapted conifer, has a wide range of potential future habitat that even includes potential minor increases. Red and white pines (*Pinus resinosa* and *Pinus strobus*) and eastern hemlock (*Tsuga canadensis*), all have more temperate distributions, and generally retain baseline habitat into the future. Finally, currently uncommon eastern redcedar (*Juniperus virginiana*) shows large potential increases in habitat under the 'major change' scenario.

Tree species with large increases or new potential habitat include species with current range limits within or south of the study region (Table 2). Due to warming conditions, several oak, hickory, and pine species common in the southeast and south central U.S. are likely to have suitable habitat in the region by the end of the 21st century. Under the 'major change' scenario, 19 southern species gain new suitable habitat in the study region.

Table 2. Potential changes in habitat suitability by 2100 for 80 tree species in the region including Marsh-Billings-Rockefeller National Historical Park. See Appendix 1 for scientific names and Appendix 2 for change class definitions.

Declines under Both Scenarios:

Common Name	Least Change	Major Change
American mountain-ash	Large decrease	Large decrease
Balsam fir	Large decrease	Large decrease
Balsam poplar	Extirpated	Extirpated
Black ash	Small decrease	Extirpated
Black spruce	Extirpated	Extirpated
Mountain maple	Extirpated	Extirpated
Northern white-cedar	Small decrease	Small decrease
Paper birch	Small decrease	Large decrease
Pin cherry	Small decrease	Extirpated
Quaking aspen	Small decrease	Large decrease
Red spruce	Small decrease	Small decrease
Sugar maple	Small decrease	Large decrease

No Change under Both Scenarios:

Common Name	Least Change	Major Change
Eastern hophornbeam	No Change	No change
Serviceberry	No Change	No change
White ash	No Change	No change

Increases under Both Scenarios

Common Name	Least Change	Major Change
American elm	Small increase	Large increase
American hornbeam	Small increase	Large increase
Bitternut hickory	Small increase	Small increase
Black locust	Large increase	Large increase
Black oak	Large increase	Large increase
Black walnut	Small increase	Large increase
Black willow	Large increase	Large increase
Bur oak	Small increase	Large increase
Chestnut oak	Large increase	Large increase
Eastern cottonwood	Large increase	Large increase
Eastern redcedar	Large increase	Large increase
Green ash	Small increase	Large increase
Mockernut hickory	Small increase	Large increase
Northern red oak	Small increase	Small increase

Mixed Results

Common Name	Least Change	Major Change
American basswood	No Change	Small increase
American beech	No Change	Large decrease
Bigtooth aspen	No Change	Large decrease
Black cherry	No Change	Small decrease
Boxelder	No Change	Large increase
Butternut	Small increase	No change
Chokecherry	No Change	Extirpated
Eastern hemlock	No Change	Large decrease
Eastern white pine	No Change	Large decrease
Gray birch	No Change	Small decrease
Red maple	No Change	Small decrease
Red pine	No Change	Large decrease
Striped maple	No Change	Large decrease
Tamarack (native)	Small decrease	No change
White spruce	Small increase	Large decrease
Yellow birch	No Change	Large decrease

New Suitable Habitat

Common Name	Least Change	Major Change
Black hickory	--	New entry
Blackgum	New entry	New entry
Blackjack oak	--	New entry
Cedar elm	--	New entry
Chinkapin oak	--	New entry
Common persimmon	--	New entry
Eastern redbud	New entry	New entry
Flowering dogwood	New entry	New entry
Hackberry	New entry	New entry
Honeylocust	New entry	New entry
Loblolly pine	--	New entry
Osage-orange	New entry	New entry
Pawpaw	--	New entry
Pecan	--	New entry
Pin oak	New entry	New entry
Post oak	--	New entry
Red mulberry	New entry	New entry
Sassafras	New entry	New entry

Table 2 continued.

Increases under Both Scenarios

Common Name	Least Change	Major Change
Pignut hickory	Large increase	Large increase
Scarlet oak	Large increase	Large increase
Shagbark hickory	Small increase	Large increase
Silver maple	Small increase	Large increase
Slippery elm	Large increase	Large increase
Sweet birch	Small increase	Small increase
White oak	Large increase	Large increase

New Suitable Habitat

Common Name	Least Change	Major Change
Shellbark hickory	--	New entry
Shingle oak	--	New entry
Shortleaf pine	--	New entry
Southern red oak	--	New entry
Sugarberry	--	New entry
Sweetgum	--	New entry
Sycamore	New entry	New entry
Virginia pine	--	New entry
Winged elm	--	New entry
Yellow-poplar	New entry	New entry

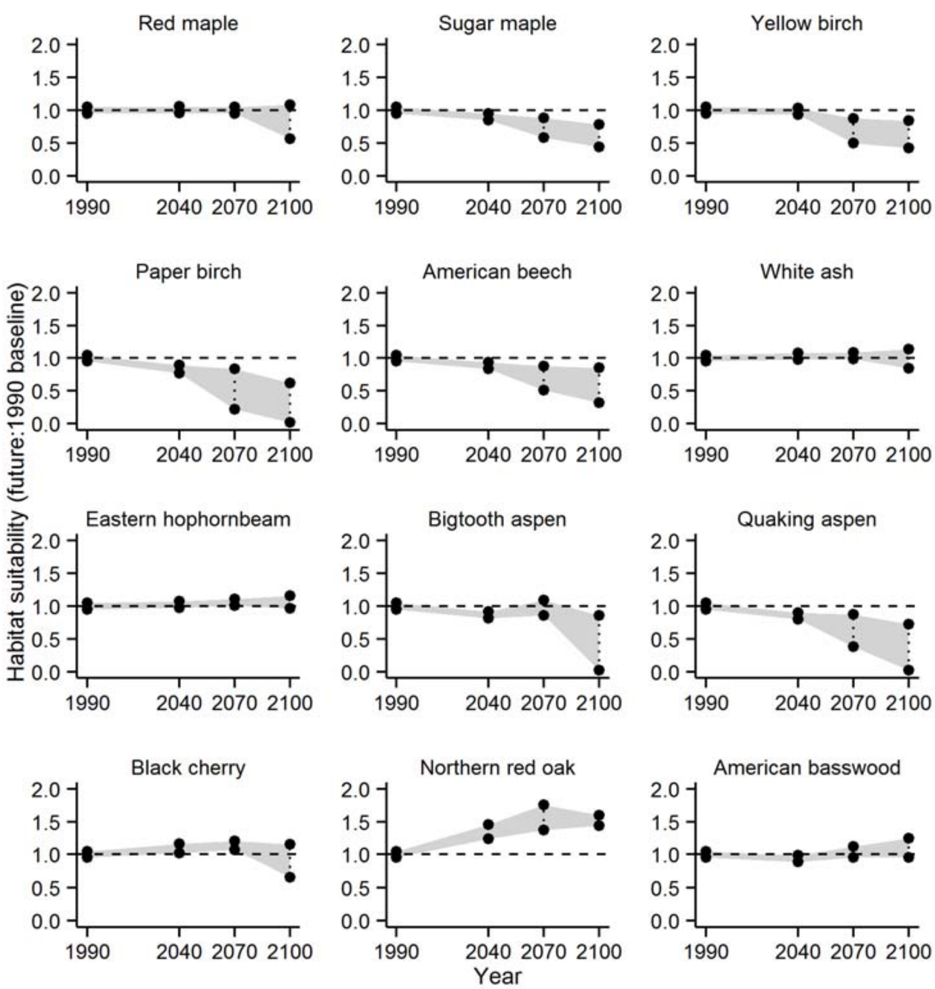

Figure 5. Projected changes in habitat suitability for 12 common broadleaf tree species in the Marsh-Billings-Rockefeller NHP area. 'Least change' and 'major change' projections (black dots) are for three future periods, compared with late 20th century habitat. Y-axis is the ratio of future to late 20th century habitat suitability (e.g., 2.0 = doubling of suitable habitat; 0.5 = 50% reduction in habitat).

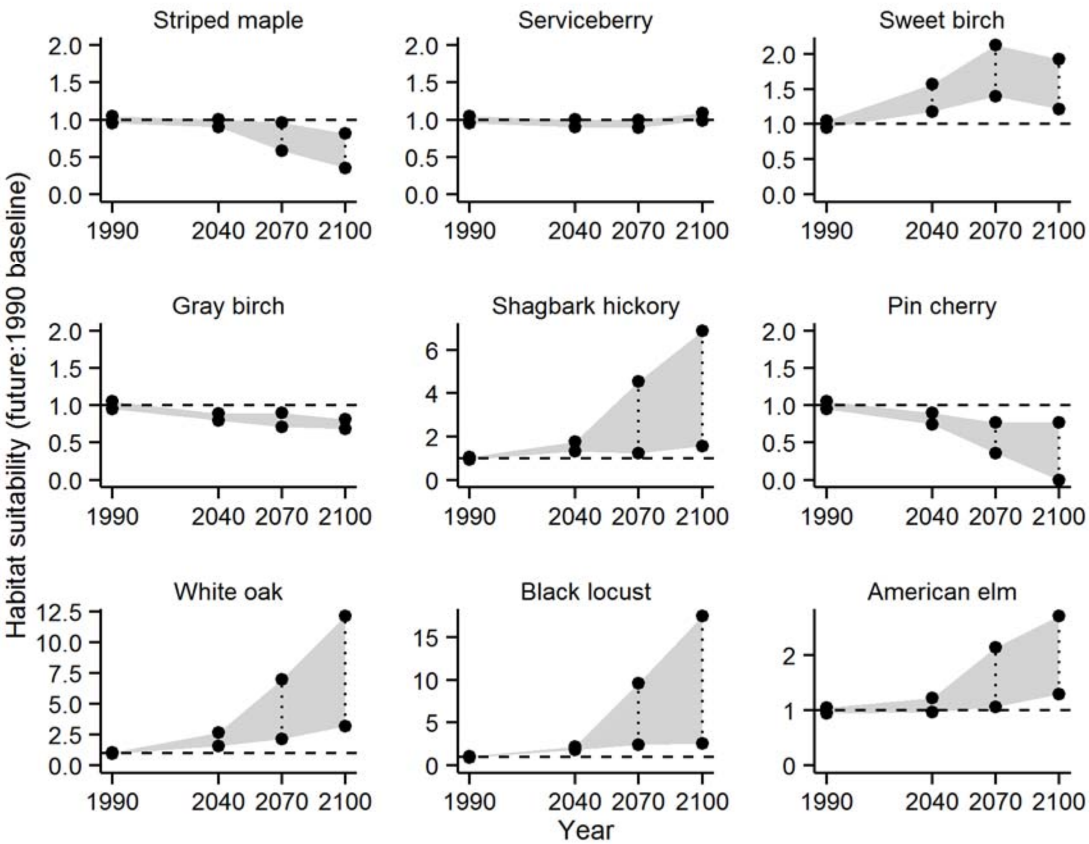

Figure 6. Projected changes in habitat suitability for 9 additional broadleaf tree species in the Marsh-Billings-Rockefeller NHP area. ‘Least change’ and ‘major change’ projections (black dots) are for three future periods, compared with late 20th century habitat. Y-axis is the ratio of future to late 20th century habitat suitability (e.g., 2.0 = doubling of suitable habitat; 0.5 = 50% reduction in habitat).

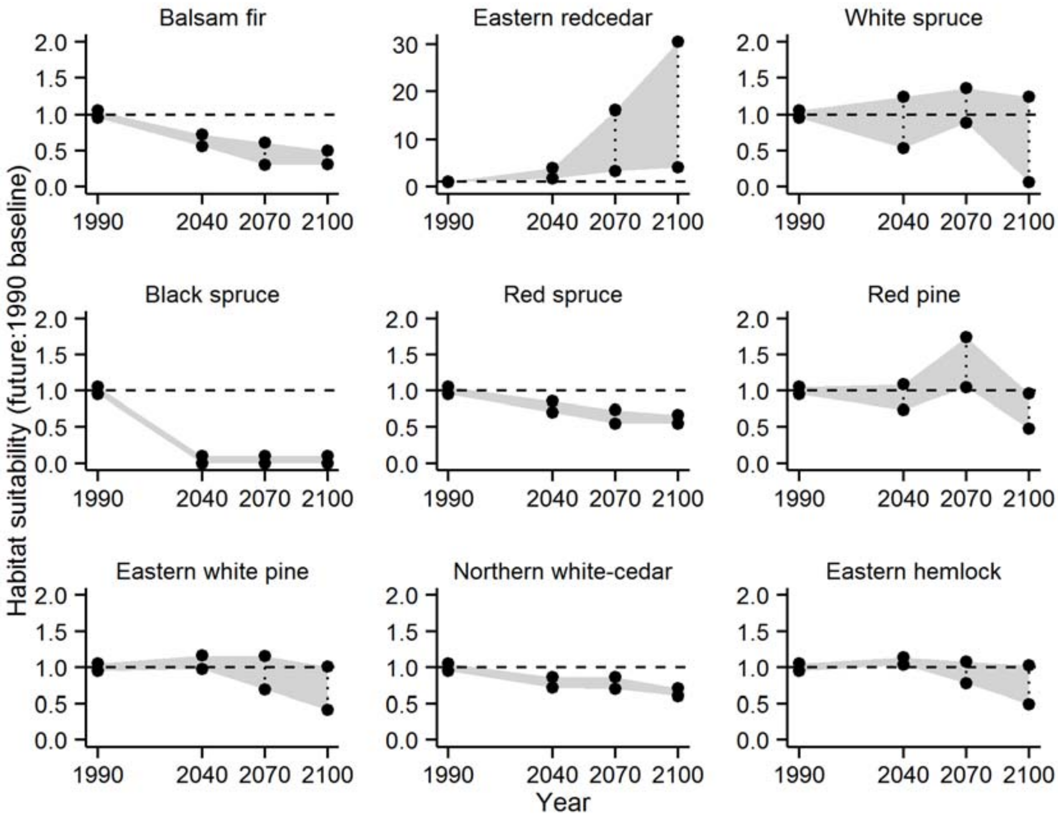

Figure 7. Projected changes in habitat suitability for 9 conifer tree species in the Marsh-Billings-Rockefeller NHP area. 'Least change' and 'major change' projections (black dots) are for three future periods, compared with late 20th century habitat. Y-axis is the ratio of future to late 20th century habitat suitability (e.g., 2.0 = doubling of suitable habitat; 0.5 = 50% reduction in habitat).

Forest similarity

Over time, future forest composition of the Marsh-Billings-Rockefeller NHP region becomes more similar to baseline composition (1990) in ecoregion sections located to the south and west of the park, though this varies with time and climate scenario (Figure 8, Table 3). Changes in similarity are much greater for the 'major change' than the 'least change' scenario across all future periods and maximum potential similarity decreases over future periods. Not surprisingly, forest composition during the baseline period (1990) was most similar to baseline composition in the two ecoregion sections overlapping the area of analysis (Green, Taconic, Berkshire Mountains and New England Piedmont). Under the 'least change' scenario, these two sections retain highest similarity to future potential forests of the park area (shifting from a high of 0.93 in 2040 to a low of 0.82 in 2100). Under the 'major change' scenario, the two local ecoregion sections also retain highest similarity for 2040, and by 2070 this shifts to the south (Lower New England) and west (Hudson Valley). For 2100, areas with baseline forest composition most similar to potential park area forest under 'major change' include sections centered in Tennessee and maximum similarity of these sections drops to 0.66 (compared with 0.36 for the local Vermont sections).

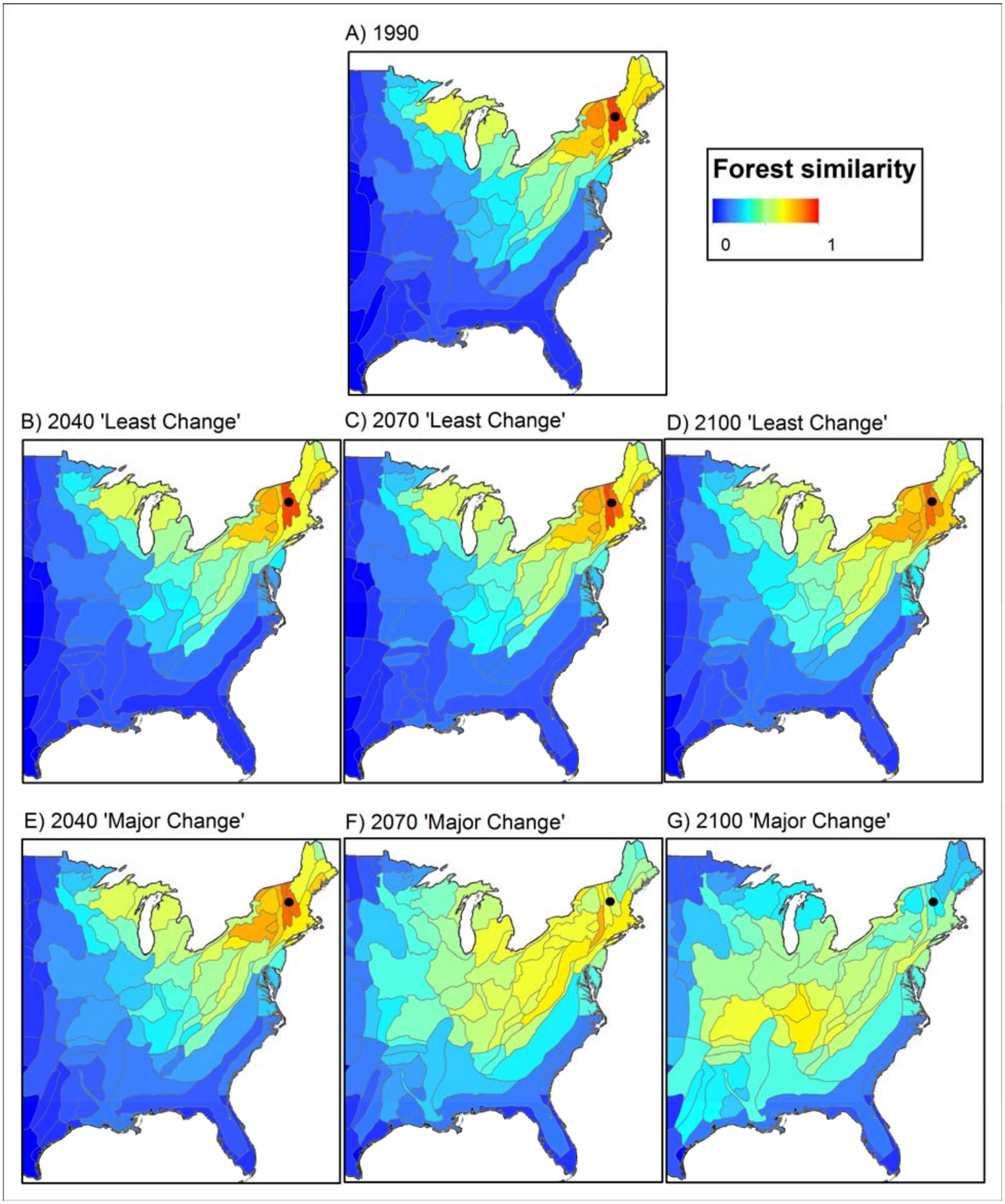

Figure 8. Forest similarity maps of baseline (1990) and potential future forests (2040, 2070, 2100) of the Marsh-Billings-Rockefeller NHP region compared with baseline (1990) forest composition calculated at the Ecoregion Section level. Similarity ranges from 0 (dissimilar) to 1 (identical composition) and is calculated as 1 – Bray-Curtis dissimilarity measure (see Methods for details).

Table 3. Forest similarity of baseline (1990) and potential future forests (2040, 2070, 2100) of the Marsh-Billings-Rockefeller NHP region compared with baseline (1990) forests of select Ecoregion Sections (selection based on being in the top two most similar for at least one of the climate scenarios and time periods). Similarity ranges from 0 (dissimilar) to 1 (identical composition) and is calculated as 1 – Bray-Curtis dissimilarity measure (see Methods for details).

Ecoregion			Baseline	Climate scenario					
				Least Change			Major Change		
Province	Section	States	1990	2040	2070	2100	2040	2070	2100
Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow	Green, Taconic, Berkshire Mountains	CT, MA, NY, VT	0.92	0.93	0.90	0.87	0.89	0.62	0.36
	New England Piedmont	MA, NH, VT	0.93	0.92	0.89	0.82	0.85	0.58	0.33
Eastern Broadleaf Forest (Oceanic)	Lower New England	CT, MA, ME, NJ, NH, NY, PA, RI	0.60	0.64	0.67	0.71	0.67	0.70	0.48
	Hudson Valley	NJ, NY, PA	0.66	0.68	0.72	0.78	0.75	0.79	0.54
Eastern Broadleaf Forest (Continental)	Interior Low Plateau, Shawnee Hills	IL, KY, TN	0.29	0.30	0.33	0.38	0.36	0.57	0.66
	Interior Low Plateau, Highland Rim	AL, IN, KY, TN	0.27	0.28	0.31	0.35	0.33	0.55	0.65

European (plantation) trees and climate

Norway spruce (*Picea abies*), European larch (*Larix decidua*), and Scots pine (*Pinus sylvestris*) are conifer tree species native to Europe, widely planted in the U.S., and found at Marsh-Billings-Rockefeller NHP (Figure 9). Scots pine and European larch are early-successional, shade-intolerant species capable of fast growth rates, and Norway spruce is more shade tolerant and able to establish in the understory (Matras and Pâques 2008, Charru et al. 2014). European larch is considered sensitive to interspecific competition and Norway spruce is a superior competitor (Charru et al. 2014). These species have broadly overlapping climatic tolerances. Where the spruce and larch overlap, Norway spruce is dominant at lower elevations and European larch better tolerates extreme conditions near treeline in European forests (Schumacher and Bugmann 2006). Scots pine has the greatest range distribution of the three species and can be found in warmer, colder, and drier locations. In North America, recommended hardiness zones for Norway spruce, European larch, and Scots pine are 3 to 7, 3 to 6, and 3 to 8a, respectively (Burns and Honkala 1990, Arbor Day Foundation; Figure 9G,H,I). It is important to note that hardiness zones provide general guidance and may not capture climatic conditions under which a closed canopy forest could persist (e.g., moisture and light levels). Thus, although these species may survive as individual planted trees (ornamentals planted around the estate), a plantation forest may be difficult to maintain in a warmer climate.

These tree species are likely sensitive to climate change, though predicting performance outside of their native ranges is difficult. For example, the highest forest similarity of Marsh-Billings-Rockefeller NHP in 2100 under the 'major change' climate scenario (Figure 8G) roughly corresponds to locations at or near the southern (warm) extent of suitable hardiness zones for the European tree species (Figure 9G,H,I). Numerous studies within their native ranges, especially for Norway spruce and Scots pine, provide general indications of their sensitivities to climate change.

Norway spruce has responded positively to recent warming (increased growth rates) in areas with sufficient soil moisture availability and negatively to warming (increased mortality) in areas with increasing water stress (Brunette et al. 2014, Charru et al. 2014). In France, declining Norway spruce on dry sites is being replaced by Douglas-fir (*Pseudotsuga menziesii*) (Brunette et al. 2014). One study of Norway spruce across sites in Germany found a climate sensitivity threshold of 46.4 °F (8 °C, mean annual temperature) and of 31.5 inches (800 mm, mean annual precipitation), with temperatures above and precipitation below these values causing a decrease in performance (Kölling et al. 2009). For comparison, the 1971-2000 annual temperature and precipitation averages near Marsh-Billings-Rockefeller NHP were 45.2 °F (7.3 °C) and 38.3 inches (973 mm; see Appendix 4). Future climate projections indicate that mean annual temperature (30 year mean) will very likely surpass 46.4 °F (8 °C) by mid-century, whereas annual precipitation projections (30 year means) remain well above 31.5 inches (800 mm) across the 21st century (mean projection = 39.2 inches [996 mm]; Appendix 4).

Literature on tree responses to a changing climate is much more extensive for Norway spruce than European larch. Based on native ranges, natural histories, and competitive dynamics, European larch is likely at least as sensitive to climate change as Norway spruce. Thinning of competing vegetation has been shown to decrease the long-term impacts of drought on both species (Kohler et al. 2010). Another important factor that may allow both of these species to persist in North America in locations outside of the climate space of their native ranges is the absence of many tree pest and disease species native in Europe, such as the European spruce bark beetle (*Ips typographus*) (Økland et al. 2011).

Finally, Scots pine will likely also be impacted by climate change with increases in growth for northern populations and modest decreases in growth and strong reductions in survival for southern populations within its native range (Reich and Oleksyn 2008). Intraspecific genetic variability and phenotypic plasticity may enable species, such as Scots pine, to retain habitat as the climate changes (Benito Garzón et al. 2011).

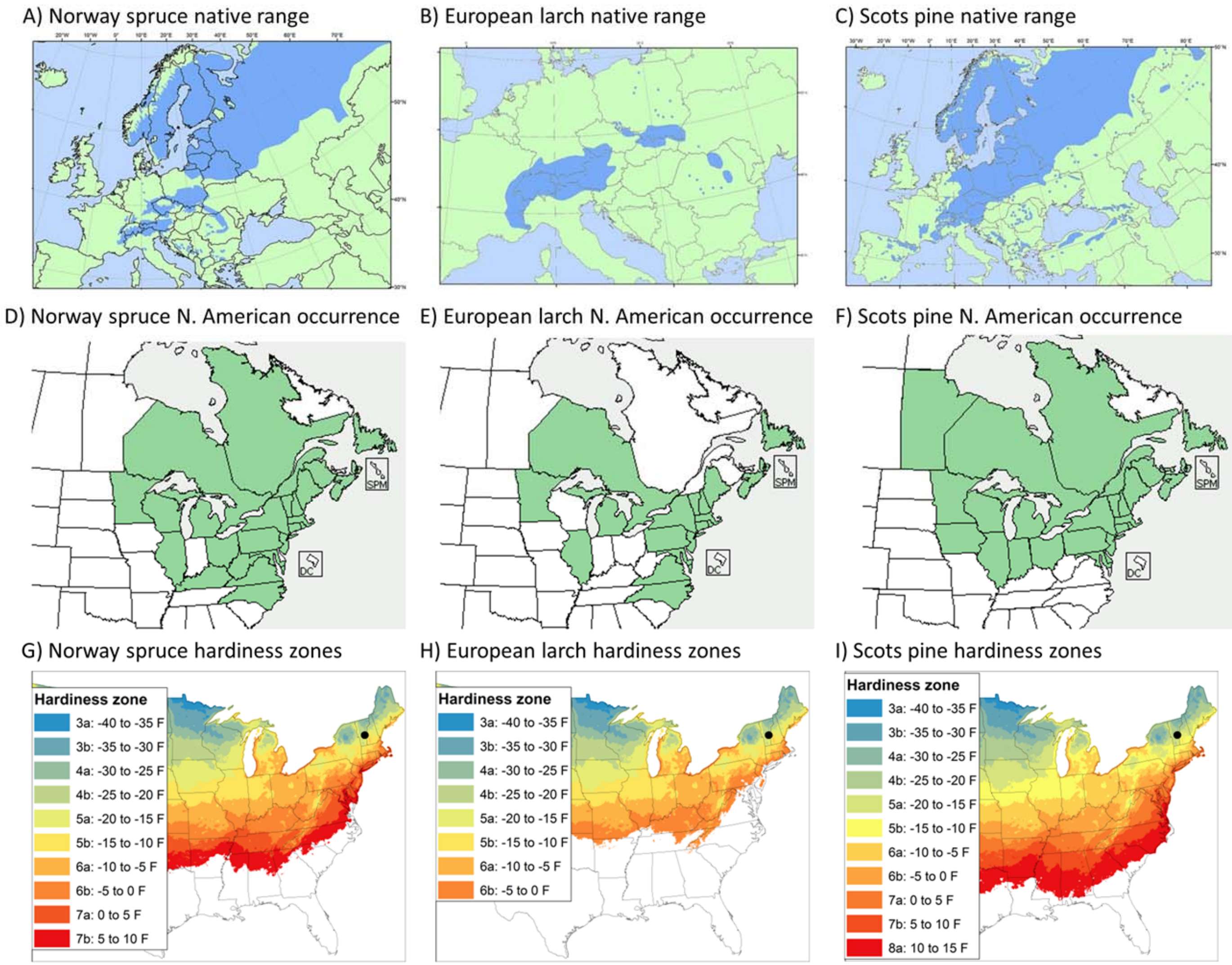

Figure 9. Native ranges, U.S. states and Canadian provinces with occurrence records, and recommended USDA hardiness zones for Norway spruce, European larch, and Scots pine. Native range maps from the European Forest Genetic Resource Programme (euforgen.org). North American occurrence maps from the USDA Plants Database (plants.usda.gov). Hardiness zones from the USDA Agricultural Research Service (planthardiness.ars.usda.gov) and recommended hardiness zones from Burns and Honkala (1990) and the Arbor Day Foundation (arborday.org).

Tree pests and weeds

Marsh-Billings-Rockefeller NHP is located within the infestation zones of 47 nonnative tree pests, including beech bark disease, Dutch elm disease, and gypsy moth (Table 4, see Appendix 3 for complete list). Notable forest pests not present in the park but found within New England include Asian longhorned beetle, emerald ash borer, and hemlock woolly adelgid (Table 4).

Table 4. Notable nonnative tree pests present and absent from the area including Marsh-Billings-Rockefeller National Historical Park.

Species present
Balsam woolly adelgid
Beech bark disease
Butternut canker
Chestnut blight
Dutch elm disease
Eastern spruce gall adelgid
Gypsy moth
Larch casebearer
Larch sawfly
White pine blister rust
Species absent
Asian longhorned beetle
Dogwood anthracnose
Emerald ash borer
European larch canker
Hemlock woolly adelgid
Sudden oak death
Winter moth

The National Insect and Disease Survey detected damage to forests of Marsh-Billings-Rockefeller NHP by native and nonnative factors during 9 of 16 survey years (1997-2012, Table 5). Major causes of damage included beech bark disease and forest tent caterpillar.

Several forest insects and diseases pose a risk to trees species at Marsh-Billings-Rockefeller NHP over the next 15 years and could cause a loss of 9% of the total tree basal area in the park (2013-2027; Tables 6,7). Maple decline, root diseases, hemlock woolly adelgid, and emerald ash borer may cause mortality to sugar maple (*Acer saccharum*), eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), and ash species (*Fraxinus* spp.), respectively. It is important to note here that modeled rates of spread result in species such as emerald ash borer and hemlock woolly adelgid reaching the park within the next 15 years, and that these may be conservative estimates based only on previously known populations. For example, emerald ash borer was recently documented in New Hampshire, though this population was included in rates of spread.

Nonnative plant species comprise a large portion of the flora at Marsh-Billings-Rockefeller NHP (128 of 397 species, 24%) and common invasive plants recently documented at the park (2012) include Norway maple, Japanese barberry, and common buckthorn (Table 8). Although the National Park Service already conducts an annual invasive plant treatment program at the park, invasive species are present and with ongoing forest management activity could become a greater problem if left unmanaged. Already present and future tree pests and weed invaders have the potential to alter forest trajectories in response to climate at Marsh-Billings-Rockefeller NHP.

Table 5. Acreage and vector of damage to Marsh-Billings-Rockefeller NHP forests between 1997 and 2012. Damage detected during 9 of 16 years by the National Insect and Disease Survey (USDA Forest Service, Forest Health Technology Enterprise Team).

Damage agent	1998	1999	2001	2002	2003	2004	2005	2006	2008	Total
beech bark disease			146.18	29.88	110.82	26.74				313.62
drought		28.08		22.71						50.79
early birch leaf edgeminer				22.6						22.6
forest tent caterpillar						59.57	44.27	237.62		341.46
hardwood anthracnose	92.15									92.15
lightning									1.95	1.95
Total	92.15	28.08	146.18	75.19	110.82	86.31	44.27	237.62	1.95	**822.57**

Table 6. Insect and disease agents modeled to cause tree mortality at Marsh-Billings-Rockefeller NHP in the next 15 years (2013-2027). Data from the National Insect and Disease Risk Maps (Krist et al. 2014).

Agent	BA host (% of total BA)	Host BA loss (% of host BA)	Total BA loss (% of total BA)
Dutch elm disease	0%	36%	0%
Emerald ash borer	6%	26%	1%
Maple decline	16%	18%	3%
Root diseases	31%	9%	3%
Hemlock woolly adelgid	26%	8%	2%
Beech bark disease	5%	3%	0%
ALL AGENTS			**9%**

Table 7. Potential tree mortality and resulting loss in density and basal area for tree species at Marsh-Billings-Rockefeller NHP in the next 15 years (2013-2027) due to insects and disease. Data from the National Insect and Disease Risk Maps (Krist et al. 2014).

Host tree species	Basal area (ft2)	Acres w/ host	Host prevalence (% of total BA)	Host density (ft2/acre	Absolute BA loss (ft2)	Relative host loss (% of host BA)	Relative BA loss (% of total BA)	Density loss (ft2/acre)
Sugar maple	9,038	441	16%	20	1,634	18%	3%	4
Eastern white pine	12,611	356	22%	35	1,568	12%	3%	4
Easter hemlock	15,073	498	26%	30	1,151	8%	2%	2
Ash spp.	3,245	356	6%	9	852	26%	1%	2
American beech	3,174	342	5%	9	123	4%	0%	0
ALL TREE SPECIES	**58,228**	**569**		**102**	**5,480**		**9%**	**10**

Table 8. Invasive plant species found at Marsh-Billings-Rockefeller National Historical Park during the 2012 inventory.

Scientific name	Common name
Acer plantanoides	Norway maple
Aegopodium podagraria	Goutweed
Alliaria petiolata	Garlic mustard
Anthriscus sylvestris	Wild chervil
Berberis thunbergii	Japanese barberry
Berberis vulgaris	European barberry
Celastrus orbiculatus	Oriental bittersweet
Chelidonium majus	Celandine
Dennstaedtia punctulobula	Hay scented fern
Elaeagnus umbellata	Autumn olive
Houstonia caerulea	Bluets
Hesperis matronalis	Dame's rocket
Lonicera morrowii	Morrow's honeysuckle
Lysimachia nummularia	Moneywort
Rhamnus cathartica	Common buckthorn
Robinia pseudoacacia	Black locust
Solanum dulcamara	Deadly nightshade
Thelypteris noveboracensis	New York fern
Tussilago farfara	Colt's foot

Discussion

Suitable habitat for tree species in eastern North America is projected to shift north. The results presented here for the Mount Tom Forest, specifically decreases in suitable habitat for many cold-adapted northern tree species and persistence or habitat expansion for warm-adapted species as the climate continues to warm, agree with other modeling efforts and field studies of eastern tree species (Scheller and Mladenoff 2005; Beckage et al. 2008; Potter et al. 2010). Even under the 'least change' climate scenario there are major shifts in habitat suitability for some species, including major declines for northern tree species in the park (e.g., balsam fir and paper birch). Importantly, even under the 'major change' climate scenario, many common species will maintain baseline habitat levels into the future (e.g., red maple [*Acer rubrum*], American basswood [*Tilia americana*], and eastern white pine [*Pinus strobus*]). Other species may see large gains in potential habitat, such as oaks and hickories (e.g., white oak [*Quercus alba*] and shagbark hickory [*Carya ovata*]). The magnitude and rate of change will depend on many local scale factors, such as management actions and the presence of tree pests, which may either accelerate or slow changes in forest composition (Fisichelli et al. 2014a).

It is difficult to forecast how current European trees (Norway spruce, European larch, Scots pine) growing at Marsh-Billings-Rockefeller NHP will fare in the future. Unknown seed sources and uncertainties in performance and plasticity of seedlings, saplings, and overstory trees at North American sites obfuscate simple projections of future habitat. For example, genetic and phenotypic diversity of Scots pine is very large, with at least 20 distinct geographic varieties within its native range (Burns and Honkala 1990). Diversity within these European species may enable managers to maintain these conifers within the park in the future (see Forest Adaptation Strategies section below).

Mature paper birch (*Betula papyrifera*) in Marsh-Billings-Rockefeller National Historical Park. Future suitable habitat for paper birch at the park is likely to decrease, with greater potential habitat loses associated with greater warming. NPS photo.

Adaptive capacity

Rapid spatial shifts in suitable habitat may not translate into rapid changes in forest composition. Management practices and species-specific traits and responses to interactions among multiple stressors will ultimately determine the rate and direction of forest change (Matthews et al. 2011).

Trees are long-lived and overstory canopy individuals may persist for relatively long periods, even after climatic conditions have shifted beyond optimal ranges. In the absence of human intervention, this dynamic has the strong potential to slow the rate of forest change in response to climate change. Furthermore, many southern species may not reach Marsh-Billings-Rockefeller NHP via natural migration for many decades after the habitat becomes suitable due to habitat fragmentation and dispersal limitations (Ibanez et al. 2008, Scheller and Mladenoff 2008). Lastly, it is important to note that complex local topography may create local refugia - areas with cool microclimates where northern species may persist.

In addition to shifting mean temperatures and precipitation totals, other global change stressors and enhanced climate variability will also shape forest change patterns. Nonnative invasive species, including plants, pests, and diseases, will also respond to climate change and may alter the ability of tree species occupy potential suitable habitat (Hellman et al. 2008; Dukes et al. 2009; Matthews et al. 2011). For example, the potential expansion of introduced insects such as hemlock woolly adelgid and emerald ash borer into the park within the next 15 years (Table 7) could strongly limit the ability of hemlock and ash, respectively, to retain climatically suitable habitat. Syndromes such as oak decline and maple decline, due to multiple factors including drought and pests, may inhibit species otherwise adapted to grow in warmer temperatures.

For instance, white ash is expected to have very minor changes in potential suitable habitat due to climate change (Table 2), but is expected to succumb from the arrival of the emerald ash borer. Black ash, showing large decreases in potential suitable habitat, is also expected to be largely lost to the emerald ash borer. If any potential remedy is found to the emerald ash borer, black ash will still be negatively affected by climate change.

Although it is difficult to project the responses of individual tree pests to climate change, in general warming temperatures are likely to exacerbate pest outbreaks by reducing overwinter mortality and reducing generation times and thus increasing reproduction rates (Dukes et al. 2009).

Hemlock trees killed by hemlock woolly adelgid in Shenandoah National Park. Nonnative insect pests are exacerbating climate change impacts and causing accelerated changes in forest composition. Photo by Nicholas Fisichelli, NPS.

Other global change stressors include nonnative earthworms and overabundant white-tailed deer (*Odocoileus virginianus*), which alter understory conditions and the competitive dynamics among regenerating seedlings (Rooney & Waller 2003; Fisichelli et al. 2013b). For example, selective browsing by deer on temperate broadleaf species can confer a competitive advantage to unpalatable boreal conifer species, even as temperatures rise (Fisichelli et al. 2012). Finally, pollution, including ozone and nitrogen and sulfur deposition, will interact with climate change to alter ecosystems and may favor invasive species (Porter et al. 2012).

Increases in the frequency or intensity of storms common in the northeast, such as hurricanes, ice storms, and nor'easters, may accelerate changes in forest composition by felling overstory trees and releasing understory saplings to form the new canopy layer. Conversely, late spring frosts associated with increased climate variability may slow forest change by selecting for cold-adapted species (Augspurger 2009; Fisichelli et al. 2014b). Warmer temperatures and a more variable precipitation regime may lead to more frequent and longer lasting droughts, which may predispose forests to greater impacts from wildfires, disease, and insect outbreaks (Westerling et al. 2006; Dukes et al. 2009).

Forest adaptation strategies

As active forest stewards, Marsh-Billings-Rockefeller NHP has the opportunity to apply various adaptation actions that achieve cultural and natural resource goals. Many characteristics of the Mount Tom Forest and ongoing management will facilitate adaptation. This includes the great diversity of native tree species, numerous common species with climatically suitable future habitat, broad suite of potential silvicultural methods, and the very long history of forward-looking forest management at the park (see Appendix 5 for the summary of the forest adaptation workshop held at the park in May 2014). Swanston and Janowiak (2012) provide an extensive overview of adaptation strategies and approaches (Table 9).

Many potential approaches exist that forest managers can focus on today, both within and across jurisdictional boundaries. These include reducing existing non-climate stressors (e.g., nonnative species and pollution), enhancing landscape connectivity, and restoring ecological processes such as fire and hydrologic regimes (NFWPCAP 2012). Continued management of nonnative invasive plant species can increase the capacity of desired native species to respond to changing climatic conditions.

Alterations to thinning and harvesting schedules and planting of tree species with suitable current and future habitat and relatively low risk of mortality from tree pests (Swanston and Janowiak 2012) are also available options for forest management consideration at the park. Promoting heterogeneity in forest types and age structure and greater biodiversity within and across stands is one possible approach to foster landscape-scale adaptive capacity.

Forest blowdown near Bass Harbor in Acadia National Park. Increased storm frequency or intensity associated with climate change may accelerate forest compositional shifts in the Northeast by felling the current overstory and allowing new species to capture growing space. Photo by Kathryn Miller, NPS.

Table 9. Potential adaptation strategies and approaches.

Strategy 1: Sustain fundamental ecological functions
1.1 — Maintain or restore soil quality and nutrient cycling
1.2 — Maintain or restore hydrology
1.3 — Maintain or restore riparian areas
Strategy 2: Reduce the impact of existing biological stressors
2.1 — Maintain or improve the ability of forests to resist pests and pathogens
2.2 — Prevent the introduction and establishment of invasive plant species and remove existing invasives
2.3 — Manage herbivory to protect or promote regeneration
Strategy 3: Protect forests from severe fire and wind disturbance
3.1 — Alter forest structure or composition to reduce risk or severity of fire
3.2 — Establish fuelbreaks to slow the spread of catastrophic fire
3.3 — Alter forest structure to reduce severity or extent of wind and ice damage
Strategy 4: Maintain or create refugia
4.1 — Prioritize and protect existing populations on unique sites
4.2 — Prioritize and protect sensitive or at-risk species or communities
4.3 — Establish artificial reserves for at-risk and displaced species
Strategy 5: Maintain and enhance species and structural diversity
5.1 — Promote diverse age classes
5.2 — Maintain and restore diversity of native tree species
5.3 — Retain biological legacies
5.4 — Restore fire to fire-adapted ecosystems
5.5 — Establish reserves to protect ecosystem diversity
Strategy 6: Increase ecosystem redundancy across the landscape
6.1 — Manage habitats over a range of sites and conditions
6.2 — Expand the boundaries of reserves to increase diversity
Strategy 7: Promote landscape connectivity
7.1 — Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity
7.2 — Establish and expand reserves and reserve networks to link habitats and protect key communities
7.3 — Maintain and create habitat corridors through reforestation or restoration
Strategy 8: Enhance genetic diversity
8.1 — Use seeds, germplasm, and other genetic material from across a greater geographic range
8.2 — Favor existing genotypes that are better adapted to future conditions
8.3 — Increase diversity of nursery stock to provide those species or genotypes likely to succeed
Strategy 9: Facilitate community adjustments through species transitions
9.1— Anticipate and respond to species decline
9.2— Favor or restore native species that are expected to be better adapted to future conditions
9.3 — Manage for species and genotypes with wide moisture and temperature tolerances
9.4 — Emphasize drought- and heat-tolerant species and populations
9.5 — Guide species composition at early stages of stand development
9.6 — Protect future-adapted regeneration from herbivory
9.7 — Establish or encourage new mixes of native species
9.8 — Identify and move species to sites that are likely to provide future habitat
Strategy 10: Plan for and respond to disturbance
10.1 — Prepare for more frequent and more severe disturbances
10.2 — Prepare to realign management of significantly altered ecosystems to meet expected future environmental conditions
10.3 — Promptly revegetate sites after disturbance
10.4 — Allow for areas of natural regeneration after disturbance
10.5 — Maintain seed or nursery stock of desired species for use following severe disturbance
10.6 — Remove or prevent establishment of invasives and other competitors following disturbance

Source: Butler, P.R., C.W. Swanston, M.K. Janowiak, L.R. Parker, M.J. St. Pierre, and L.A .Brandt. 2012. Adaptation Strategies and Approaches. In: C.W. Swanston and M.K. Janowiak, editors. *Forest Adaptation Resources: Climate change tools and approaches for land managers.* Gen. Tech. Rep. NRS-87. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station, p 15-34. www.nrs.fs.fed.us/pubs/42179

Potential adaptation strategies for European tree species include selection of southern and drought tolerant provenances. This could enable these culturally-significant species to persist longer into the future at the park. Additional options for existing stands include increasing the frequency of thinning to reduce competition and increase water and light availability, thereby strengthening the ability to withstand other stressors such as drought and disease (Kohler et al. 2010). Growing outside of their native ranges, these European tree species are also dealing with a different suite of pests and diseases; lower levels of this type of stress could facilitate longer tree persistence under a warmer climate.

Management actions applied during influential periods in stand development may have lasting desired effects. Selective pressures are generally very high at the seedling stage, as indicated by high mortality rates and turnover. Conversely, residence time in the canopy can last decades to centuries. Thus, the dynamics that occur during the narrow temporal window after disturbances as seedlings establish and saplings capture growing space will have long-term implications on forest composition (Oliver 1981). For example, selection harvesting could be utilized to favor advance regeneration of target species adapted to future conditions.

Specific trees, species, or sites within a park may have strong cultural significance and the projections of habitat suitability can help managers craft resistance strategies to assist persistence on the landscape into the future. For example, cold-adapted conifers, such as balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) may persist on lower slope positions and along wetland edges where they receive adequate light and moisture and lower air temperatures due to cool air drainage patterns. Thinning of competing vegetation around high-value trees may also enhance near-term resistance to climate change. Although persistence of the current suite of local species may seem desirable and feasible in the near future, it is important to bear in mind that some of these species are likely to become more susceptible to other pests and pathogens as the climate shifts beyond the historical range of variability.

Forest understory in Marsh-Billings-Rockefeller National Historical Park. Species composition and performance of seedlings and saplings in the forest understory can be used as a bellwether of future change. NPS photo.

Changes in the performance of tree species within the park may provide evidence of responses to ongoing climate change. Trees growing near their physiological limits are likely to show decreased resistance to the combination of climate and non-climate stressors and thus changes in mortality rates of overstory trees are a likely sign of forest change. For example, overstory trees growing on marginal sites, such as those with low nutrient or water availability, may show increased mortality rates in the near-term as temperatures continue to warm. Conversely, rich sites with adequate soil moisture may be locations where some species are able to persist longer into the future. Seedling establishment trends, such as beyond the local range limit of adult trees can occur relatively rapidly and indicate a positive response to recent warming (Fisichelli et al. 2014c).

Cascading effects

Changes in climate and forest composition will have cascading effects on other resources, park operations, and visitor experiences. Species such as red squirrel may respond negatively to the combined climate and forest changes whereas other species such as the opossum may expand their ranges. Shifts in the fire regime due to changes in climate and forest composition may require parallel shifts in fire management to both protect cultural resources (fire suppression) and foster ecological processes (prescribed fire). Visitor use patterns, especially during shoulder seasons, may change with climate, necessitating shifts in staffing and facility operations. Many other impacts are also possible, for example increasing mortality rates of the current overstory due to climate and pest stressors and increasing storms may exacerbate trail maintenance backlogs in the future.

Conclusions

Northern forests are changing and direct and indirect climate effects are playing an increasing role in this dynamic. Stewarding NPS forests for continuous change is a challenge for park managers; however, understanding projected rates and direction of forest change should facilitate forward-looking management efforts at Marsh-Billings-Rockefeller NHP. As climate change continues and forest responses accelerate, management goals and actions will need to be updated to achieve desired conditions in a continuously changing world.

Norway spruce plantation, Marsh-Billings-Rockefeller National Historical Park. Climatic conditions outside the historical range of variability will result in forest changes beyond the magnitude observed in the past. NPS photo.

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Appendix 1. Climate change tree atlas potential habitat suitability output for 82 tree species with baseline (1961-1990) and/or future (2040 [2010-2039], 2070 [2040-2069], 2100 [2070-2099]) habitat in the region including Marsh-Billings-Rockefeller National Historical Park.

Potential habitat suitability is quantified as tree importance, the average of relative stem density and relative basal area summed across all cells used in analyses. Two climate projections, the PCM B1 and Had A1FI, represent the 'least change' and 'major change' climate scenarios, respectively (see Methods for more details) and are meant to capture a broad range of plausible future conditions. Species are sorted by scientific name. Change class designations here are based on year 2100 output averaged across the two climate scenarios. Modifying factor codes are: BRO-browse, CPR-CO_2/productivity, CWU-CO_2/water use efficiency, COL-competition/light, DISE-disease, DISP-dispersal, DRO-drought, ESP-edaphic specificity, EHS-environmental habitat specificity, FRG-fire regeneration, FTK-fire topkill, FLO-flood, HAR-harvest, ICE-ice, INS-insect pests, POL-pollution, SES-seedling establishment, TGR-temperature gradients, VRE-vegetative reproduction, WIN-wind. Change class rules are shown in Appendix 2.

		Baseline		2040		2070		2100				Modifying Factors		
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Model Reliability	Positive Traits	Negative Traits	Adapt Score
Abies balsamea	Balsam fir	208	273	198	152	166	82	136	84	Lg. Dec.	High	COL	INS FTK DRO	2.7
Acer negundo	Boxelder	1	11	7	12	9	16	9	98	Lg. Inc.	Medium	SES DISP DRO COL SES	FTK	7.4
Acer pensylvanicum	Striped maple	100	100	99	92	96	58	82	35	Sm. Dec.	High	COL SES	DRO	5.1
Acer rubrum	Red maple	458	517	516	524	522	510	559	290	No Change	High	SES ESP ESP COL DISP		8.5
Acer saccharinum	Silver maple	3	10	9	19	14	48	17	85	Lg. Inc.	Medium	DISP SES COL	DRO FTK	5.6
Acer	Sugar maple	619	557	528	477	493	326	438	246	Sm. Dec.	High	COL		5.8

Scientific Name	Common Name	Baseline: Actual (FIA)	Baseline: Current (modeled)	2040: PCM B1	2040: Had A1FI	2070: PCM B1	2070: Had A1FI	2100: PCM B1	2100: Had A1FI	Change Class	Model Reliability	Modifying Factors: Positive Traits	Modifying Factors: Negative Traits	Modifying Factors: Adapt Score
saccharum												ESP		
Acer spicatum	Mountain maple	6	14	3	0	0	0	0	0	Extirpated	High	COL VRE ESP	DRO FTK	5.9
Amelanchier spp.	Serviceberry	19	54	50	53	50	52	58	54	No Change	Medium	COL SES	DRO	4.8
Asimina triloba	Pawpaw	0	0	0	0	0	6	0	16	New-High	Low	COL	DRO	3.7
Betula alleghaniensis	Yellow birch	202	184	189	172	161	92	155	78	Sm. Dec.	High	DISP	FTK INS DISE	3.4
Betula lenta	Sweet birch	53	56	66	88	78	119	108	68	Sm. Inc.	High	DISP	FTK COL INS DISE	3.2
Betula papyrifera	Paper birch	175	149	134	115	125	32	92	2	Lg. Dec.	High	FRG DISP ESP	FTK COL INS DRO	3.4
Betula populifolia	Gray birch	24	38	32	32	34	27	31	26	Sm. Dec.	Medium	DISP ESP	FTK COL INS DISE	3.6
Carpinus caroliniana	American hornbeam	9	15	12	31	15	46	28	44	Lg. Inc.	Medium	COL SES	FTK DRO	5.1
Carya cordiformis	Bitternut hickory	9	0*	5	12	5	38	10	48	Lg. Inc.	Low	DRO	COL	5.6
Carya glabra	Pignut hickory	3	5	11	16	12	65	27	78	Lg. Inc.	High	ESP	INS DRO	4.7
Carya illinoinensis	Pecan	0	0	0	0	0	0	0	36	New-High	Low		FTK INS COL	2.2
Carya laciniosa	Shellbark hickory	0	0	0	0	0	1	0	8	New-High	Low	COL	FTK ESP	3.7
Carya ovata	Shagbark hickory	13	9	12	16	11	41	14	62	Lg. Inc.	Medium		INS FTK	4.4
Carya texana	Black hickory	0	0	0	0	0	18	0	162	New-High	High		ESP COL	4.1
Carya tomentosa	Mockernut hickory	3	5	5	6	6	33	8	60	Lg. Inc.	High		FTK	5.4
Celtis laevigata	Sugarberry	0	0	0	0	0	1	0	42	New-High	Medium	COL SES	FTK	4.6

Scientific Name	Common Name	Baseline: Actual (FIA)	Baseline: Current (modeled)	2040 PCM B1	2040 Had A1FI	2070 PCM B1	2070 Had A1FI	2100 PCM B1	2100 Had A1FI	Change Class	Model Reliability	Modifying Factors: Positive Traits	Modifying Factors: Negative Traits	Modifying Factors: Adapt Score
Celtis occidentalis	Hackberry	0	0	0	8	3	73	10	125	New-Both	Medium	DRO	FTK	5.7
Cercis canadensis	Eastern redbud	0	0	0	0	0	33	5	65	New-High	Medium			4.9
Cornus florida	Flowering dogwood	0	0	7	22	15	128	32	163	New-Both	High	COL		5.0
Diospyros virginiana	Common persimmon	0	0	0	0	0	23	0	117	New-High	Medium	COL ESP		5.8
Fagus grandifolia	American beech	361	369	337	318	324	188	316	116	Sm. Dec.	High	COL	INS FTK	3.6
Fraxinus americana	White ash	182	202	204	211	203	217	230	171	No Change	High		INS FTK COL	2.7
Fraxinus nigra	Black ash	12	18	14	15	11	8	9	0	Lg. Dec.	High		INS COL DISP DRO SES FTK ESP	1.7
Fraxinus pennsylvanica	Green ash	10	6	7	11	8	14	8	49	Lg. Inc.	Medium		INS FTK COL	4.0
Gleditsia triacanthos	Honeylocust	0	0	5	10	8	52	12	101	New-Both	Low		COL	5.5
Juglans cinerea	Butternut	21	1	9	9	9	7	8	0	Sm. Inc.	Low		FTK COL DRO DISE	2.3
Juglans nigra	Black walnut	1	5	7	12	8	72	14	99	Lg. Inc.	Medium	SES	COL DRO	4.0
Juniperus virginiana	Eastern redcedar	9	8	14	31	26	129	32	244	Lg. Inc.	Medium	DRO	FTK COL INS	3.9
Larix laricina	Tamarack (native)	4	0*	3	1	1	0	1	5	No Change	High		FTK COL INS	3.1
Liquidambar styraciflua	Sweetgum	0	0	0	0	0	16	0	87	New-High	High	VRE ESP	FTK COL DRO	4.1
Liriodendron tulipifera	Yellow-poplar	0	0	0	6	5	68	13	84	New-Both	High	SES DISP ESP	INP	5.3

Scientific Name	Common Name	Baseline: Actual (FIA)	Baseline: Current (modeled)	2040: PCM B1	2040: Had A1FI	2070: PCM B1	2070: Had A1FI	2100: PCM B1	2100: Had A1FI	Change Class	Model Reliability	Modifying Factors: Positive Traits	Modifying Factors: Negative Traits	Modifying Factors: Adapt Score
Maclura pomifera	Osage-orange	0	0	0	3	0	7	6	42	New-Both	Medium	ESP ESP		6.3
Morus rubra	Red mulberry	0	0	1	13	6	99	12	158	New-Both	Low	COL DISP	FTK	4.7
Nyssa sylvatica	Blackgum	0	0	0	3	0	35	9	58	New-Both	High	COL FTK		5.9
Ostrya virginiana	Eastern hophornbeam	144	100	105	100	109	102	97	116	No Change	Medium	COL ESP SES		6.4
Picea glauca	White spruce	8	17	9	21	15	23	21	1	No Change	Medium		INS	3.9
Picea mariana	Black spruce	2	8	0	0	0	0	0	0	Extirpated	High	COL ESP DISP	FTK INS DRO	4.3
Picea rubens	Red spruce	210	164	140	115	121	90	110	90	Sm. Dec.	High	ESP COL	FTK SES	2.9
Pinus echinata	Shortleaf pine	0	0	0	0	0	6	0	115	New-High	High	ESP	COL INS DRO	3.6
Pinus resinosa	Red pine	17	23	17	25	24	40	22	11	Sm. Dec.	Medium		INS COL DISP	3.9
Pinus rigida	Pitch pine	1	0*	0	0	0	0	0	0	Lg. Dec.	High		COL INS	3.8
Pinus strobus	Eastern white pine	409	290	337	282	335	199	293	121	Sm. Dec.	High	DISP	DRO FTK INS	3.3
Pinus taeda	Loblolly pine	0	0	0	0	0	0	0	44	New-High	High	ESP	INS INP DRO COL	3.4
Pinus virginiana	Virginia pine	0	0	0	0	0	5	0	44	New-High	High		COL POL	3.8
Platanus occidentalis	Sycamore	0	0	0	3	0	32	8	45	New-Both	Medium			4.8
Populus balsamifera	Balsam poplar	10	6	2	0	0	0	0	0	Extirpated	High	FRG VRE	COL DRO	4.0
Populus deltoides	Eastern cottonwood	3	5	6	15	12	71	17	108	Lg. Inc.	Low	SES	INS COL DISE FTK	3.9

Scientific Name	Common Name	Baseline		2040		2070		2100		Change Class	Model Reliability	Modifying Factors		
		Actual (FIA)	Current (modeled)	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI			Positive Traits	Negative Traits	Adapt Score
Populus grandidentata	Bigtooth aspen	31	42	35	38	36	46	36	1	Sm. Dec.	High	FRG DISP	COL DRO FTK	5.1
Populus tremuloides	Quaking aspen	97	116	94	103	101	44	84	2	Lg. Dec.	High	SES FRG ESP	COL DRO FTK	4.7
Prunus pensylvanica	Pin cherry	31	39	35	29	30	14	30	0	Lg. Dec.	Medium	SES FRG FTK	COL	4.2
Prunus serotina	Black cherry	81	139	142	162	149	167	161	92	No Change	High	DRO ESP	INS FTK COL	3.0
Prunus virginiana	Chokecherry	4	7	7	7	4	0	6	0	Sm. Dec.	Low		COL	3.8
Quercus alba	White oak	10	23	36	61	50	161	74	279	Lg. Inc.	High	ESP ESP SES FTK	INS DISE	6.1
Quercus coccinea	Scarlet oak	1	0*	3	8	5	51	15	68	Lg. Inc.	High	VRE ESP ESP	INS DISE FTK	4.6
Quercus ellipsoidalis	Northern pin oak	1	0*	0	0	0	0	0	2	No Change	Medium	DRO FTK	COL	6.0
Quercus falcata var.falcata	Southern red oak	0	0	0	0	0	0	0	37	New-High	High	SES		5.3
Quercus imbricaria	Shingle oak	0	0	0	0	0	8	0	13	New-High	Medium	ESP	COL	4.9
Quercus macrocarpa	Bur oak	2	0*	2	12	4	28	6	80	Lg. Inc.	Medium	DRO FTK		6.4
Quercus marilandica	Blackjack oak	0	0	0	0	0	10	0	115	New-High	Medium	DRO SES FRG VRE	COL FTK	5.6
Quercus muehlenbergii	Chinkapin oak	0	0	0	0	0	22	0	66	New-High	Medium	SES		4.8

Scientific Name	Common Name	Baseline: Actual (FIA)	Baseline: Current (modeled)	2040: PCM B1	2040: Had A1FI	2070: PCM B1	2070: Had A1FI	2100: PCM B1	2100: Had A1FI	Change Class	Model Reliability	Modifying Factors: Positive Traits	Modifying Factors: Negative Traits	Adapt Score
Quercus palustris	Pin oak	0	0	0	5	5	18	5	15	New-High	Medium		FTK COL INS DISE	2.8
Quercus prinus	Chestnut oak	5	12	14	27	18	119	47	127	Lg. Inc.	High	SES VRE ESP FTK	INS DISE	6.1
Quercus rubra	Northern red oak	119	129	160	188	177	227	206	186	Sm. Inc.	High		INS	5.4
Quercus stellata	Post oak	0	0	0	0	0	38	0	368	New-High	High	DRO SES FTK	COL INS DISE	5.7
Quercus velutina	Black oak	2	13	21	45	40	126	54	236	Lg. Inc.	High	DRO ESP	INS DISE	4.9
Robinia pseudoacacia	Black locust	3	5	9	11	12	48	13	87	Lg. Inc.	Low		COL INS	3.8
Salix nigra	Black willow	9	6	10	19	13	43	23	64	Lg. Inc.	Low		COL FTK DRO	2.8
Sassafras albidum	Sassafras	0	0	0	7	7	52	13	97	New-Both	High		COL FTK	4.2
Sorbus americana	American mountain-ash	7	0*	0	0	0	0	0	0	Lg. Dec.	Medium		FTK COL ESP	3.1
Thuja occidentalis	Northern white-cedar	28	57	41	49	49	40	35	40	Sm. Dec.	High	COL	FTK	4.2
Tilia americana	American basswood	36	41	38	39	39	46	39	51	No Change	Medium	COL	FTK	4.6
Tsuga canadensis	Eastern hemlock	384	323	354	346	349	250	332	160	Sm. Dec.	High	COL	INS DRO	2.7
Ulmus alata	Winged elm	0	0	0	0	0	4	0	110	New-High	High		INS DISE	3.6
Ulmus americana	American elm	27	62	60	76	66	133	80	168	Lg. Inc.	Medium	ESP	DISE INS	4.0
Ulmus crassifolia	Cedar elm	0	0	0	0	0	0	0	12	New-High	Low		DISE	3.3
Ulmus rubra	Slippery elm	0	6	6	17	9	53	14	62	Lg. Inc.	Medium	COL	FTK DISE	4.8

Appendix 2. Change class rules for common (IV > 5) and rare (IV ≤ 5) species.

Future:Current modeled IV	Change Class
	Common species
0	extirpated
>0 to <0.5	large decrease
0.5 to 0.8	small decrease
>0.8 to <1.2	no change
1.2 to 2.0	small increase
>2	large increase
	Rare species
<0.2	large decrease
0.2 to <0.6	small decrease
0.6 to <4	no change
4 to 8	small increase
>8	large increase

Appendix 3. Nonnative tree pests (47 species) with infestation zones that include Marsh-Billings-Rockefeller National Historical Park.

Data derived from the US Forest Service Alien Forest Pest Explorer (AFPE) Database (http://foresthealth.fs.usda.gov/portal/Flex/APE).

CommonName	
Ambermarked Birch Leafminer	Larch Casebearer
Asiatic Oak Weevil	Larch Sawfly
Balsam Woolly Adelgid	Linden Aphid
Beech Bark Disease	Maple Petiole Borer
Birch Casebearer	Mountain-Ash Sawfly
Birch Leafminer	Norway Maple Aphid
Black Vine Weevil	Oystershell Scale
Butternut Canker	Peach Twig Borer
Calico Scale	Pear Sawfly
Chestnut Blight	Pear Thrips
Dutch Elm Disease	Pine False Webworm
Eastern Spruce Gall Adelgid	Pine Shoot Beetle
Elm Leafbeetle	Poplar sawfly
Elm Leafminer	Poplar-And-Willow Borer
European Bark Beetle	San Jose Scale
European Pine Sawfly	Satin Moth
European Pine Shoot Moth	Scleroderris Canker
European Spruce Needleminer	Smaller European Elm Bark Beetle
European Spruce Sawfly	Spruce Bud Scale
European Web-spinning Larch Sawfly	Strawberry Root Weevil
Gypsy Moth	White Pine Blister Rust
Imported Willow Leaf Beetle	Willow Scab
Introduced Pine Sawfly	Woolly Beech Aphid
Japanese Beetle	

Appendix 4. Historical and Projected Climate Trends, Marsh-Billings-Rockefeller National Historical Park, Vermont

Prepared by Nicholas Fisichelli, NPS Climate Change Response Program April 22, 2014

Climate Change and National Parks

Climate change, in conjunction with other stressors, impacts all aspects of park management from natural and cultural resources to park operations and visitor experience. Effective planning and management must be grounded in our comprehension of past dynamics as well as the realization that future conditions may shift beyond the historical range of variability. Climate change will manifest itself not only as shifts in mean conditions (e.g., increasing mean annual temperature and sea level) but also as changes in climate variability (e.g., more intense storms and flooding). These changes may alter vegetation composition and structure of the landscape and accelerate weathering, deterioration, and loss of cultural resources. Park managers are dealing with both rapid directional change and multiple uncertainties (Heller and Zavaleta 2009). Understanding climate change projections and associated levels of uncertainty will facilitate planning actions that are robust regardless of the precise magnitude of change experienced in the coming decades.

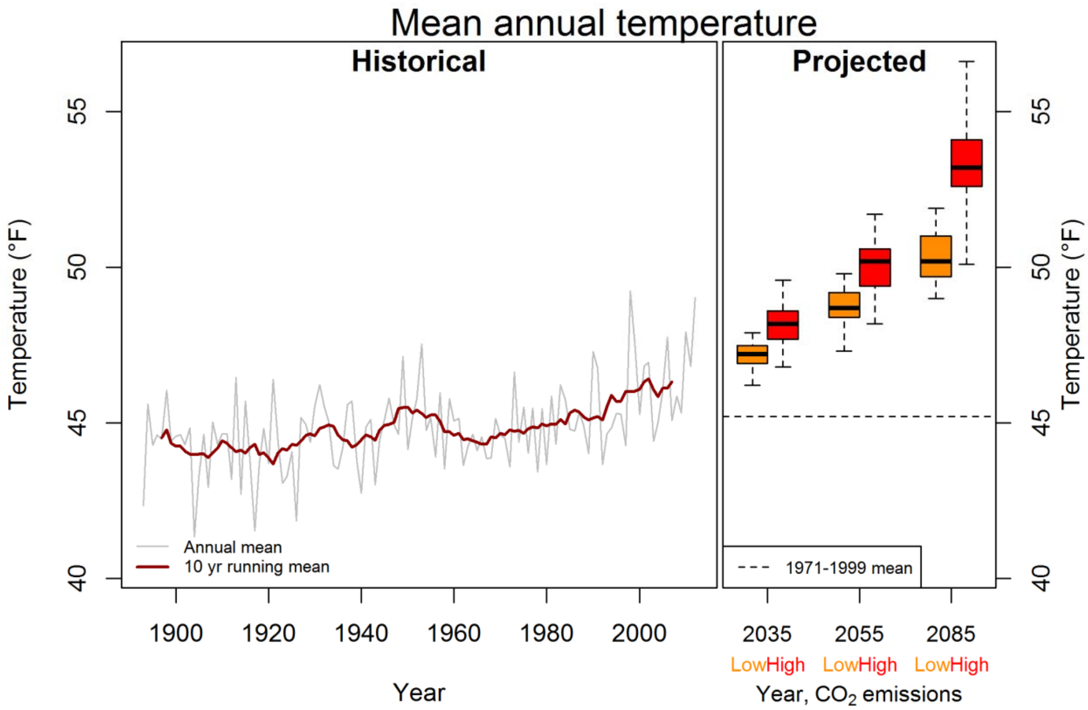
Historical climate trends

Historical climate trends (1893-2012) for Marsh-Billings-Rockefeller NHP are based on data from a nearby long-term weather station (Hanover, NH station 273850, approximately 13 miles east northeast of the park) acquired from the United States Historical Climatology Network (www.ncdc.noaa.gov). Over the 120 year instrumental record, mean annual temperature showed an increasing linear trend (+0.17 °F [0.09 °C] per decade, $p<0.0001$; Figure 1). The rate of warming has been more rapid since 1960 (+0.49 °F [0.27 °C] per decade, $p<0.0001$). Warming since 1893 was also statistically significant across all four seasons, with the most rapid rate in winter (+0.26 °F [0.14 °C] per decade, $p<0.0001$; Figure 2). Annual precipitation also showed an increasing trend, due in part to numerous high annual totals over the past two decades (6 of the 10 wettest years have occurred since 1996; Figure 1). Seasonally, only fall precipitation showed a significant increasing trend ($p<0.05$; Figure 3). Additional climate trends in the Northeast include a > 10 day expansion of the frost free season (1991-2011 relative to 1901-1960) and a strong increase (+74%) in the amount of precipitation falling in the heaviest rain events (NCADAC 2013).

Future climate projections

Future climate projections for the area including Marsh-Billings-Rockefeller NHP are from multi-model averaged data (Kunkel et al. 2013). Mean annual temperature, compared with the 1971-1999 average, is projected to increase 3-5 °F (1.7-2.8 °C) by mid-century and 5-8 °F (2.8-4.4 °C) by the end of the century, depending on the greenhouse gas emissions scenario (Figure 1). Past greenhouse gas emissions, the residence time of these gases in the atmosphere, and our current emissions trajectory suggest that climate change will be substantial (Wigley 2005, Peters et al. 2013). Warming by mid-century is projected for all seasons (Figure 4), and there is wide agreement among individual climate models in the direction and general magnitude of warming over the coming decades. Total annual precipitation may increase slightly and summer precipitation decrease slightly by mid-century compared with late 20th century values (Figure 1, 5); however, precipitation variability is likely to remain large over the coming decades, and there is greater uncertainty in precipitation than temperature projections (Kunkel et al. 2013).

In addition to warmer mean temperatures and changes in annual and seasonal precipitation, climate change will exhibit itself in many other ways within the region including Marsh-Billings-Rockefeller NHP. These include more frequent heat waves, droughts, floods, and an extended frost-free season. The number of days with maximum temperatures > 95 °F is projected to increase 3-6 days/year by mid-century around the park while the number of days with minimum temperatures below 10 °F and 32 °F are both projected to decrease by approximately 3 weeks (high [A2] emissions scenario 2041-2070 compared with 1980-2000; Kunkel et al. 2013). Small changes in total precipitation may mask large shifts in the precipitation regime and associated impacts to ecosystems. The annual number of days with heavy rainfall (> 1 inch) is projected to increase 20 % (high [A2] emissions scenario, 2041-2070 compared with 1980-2000; Kunkel et al. 2013). Significantly warmer temperatures and a more variable precipitation regime may lead to both more frequent droughts and more severe flooding and erosion. See the draft National Climate Assessment for more in-depth information on climate change projections and impacts (NCADAC 2013; http://ncadac.globalchange.gov/).



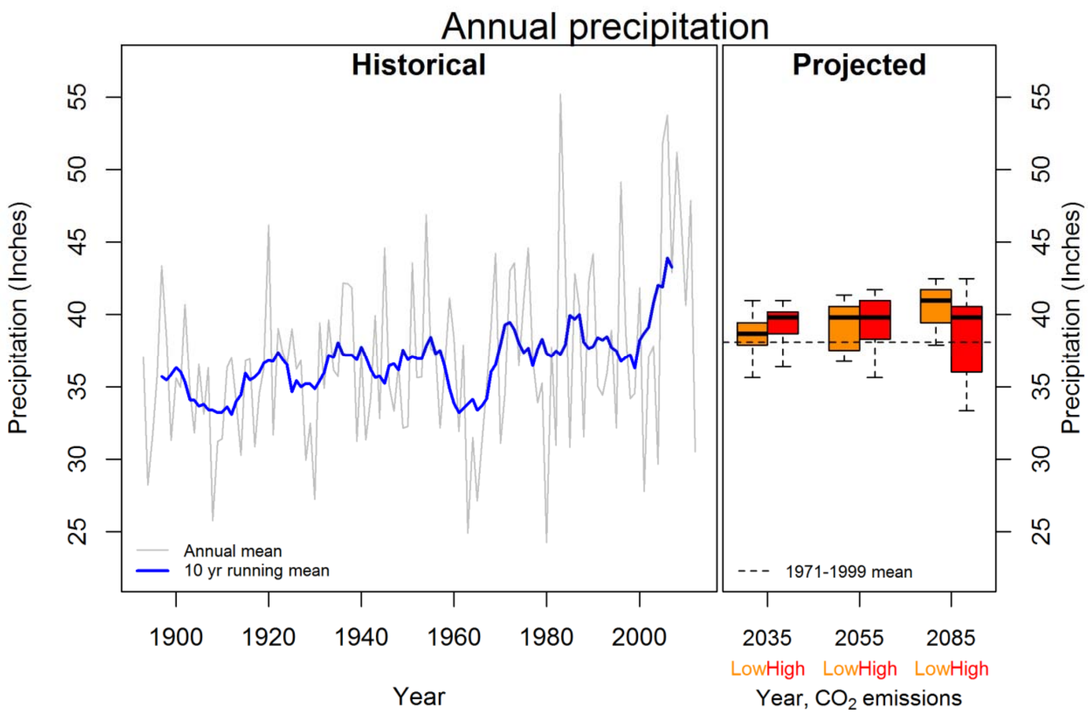


Figure 1. Historical and projected mean annual temperature and annual precipitation for Marsh-Billings-Rockefeller National Historical Park. Historical data (1893-2012) are from the Hanover, NH weather station (ncdc.noaa.gov).Projected climate change (30 year means) for the region including the park (data from Kunkel et al. 2013, see Tables 4, 6 and Figures 16, 27) are for three future periods centered on 2035 (2021-2050), 2055 (2041-2070), and 2085 (2070-2099). Two greenhouse gas emissions scenarios are presented, the **low** (**B1**) and **high** (**A2**) scenarios (IPCC 2007). Projected climate boxplots indicate the variability in future projections among 14-15 CMIP3 climate models. Values for the area including Marsh-Billings-Rockefeller NHP are based on the mean model output for that location (bold horizontal black line)

and the range of climate model projections for the northeast region (the upper and lower bounds of the boxes indicate the 25th and 75th percentile model output values and the whiskers show the minimum and maximum change).

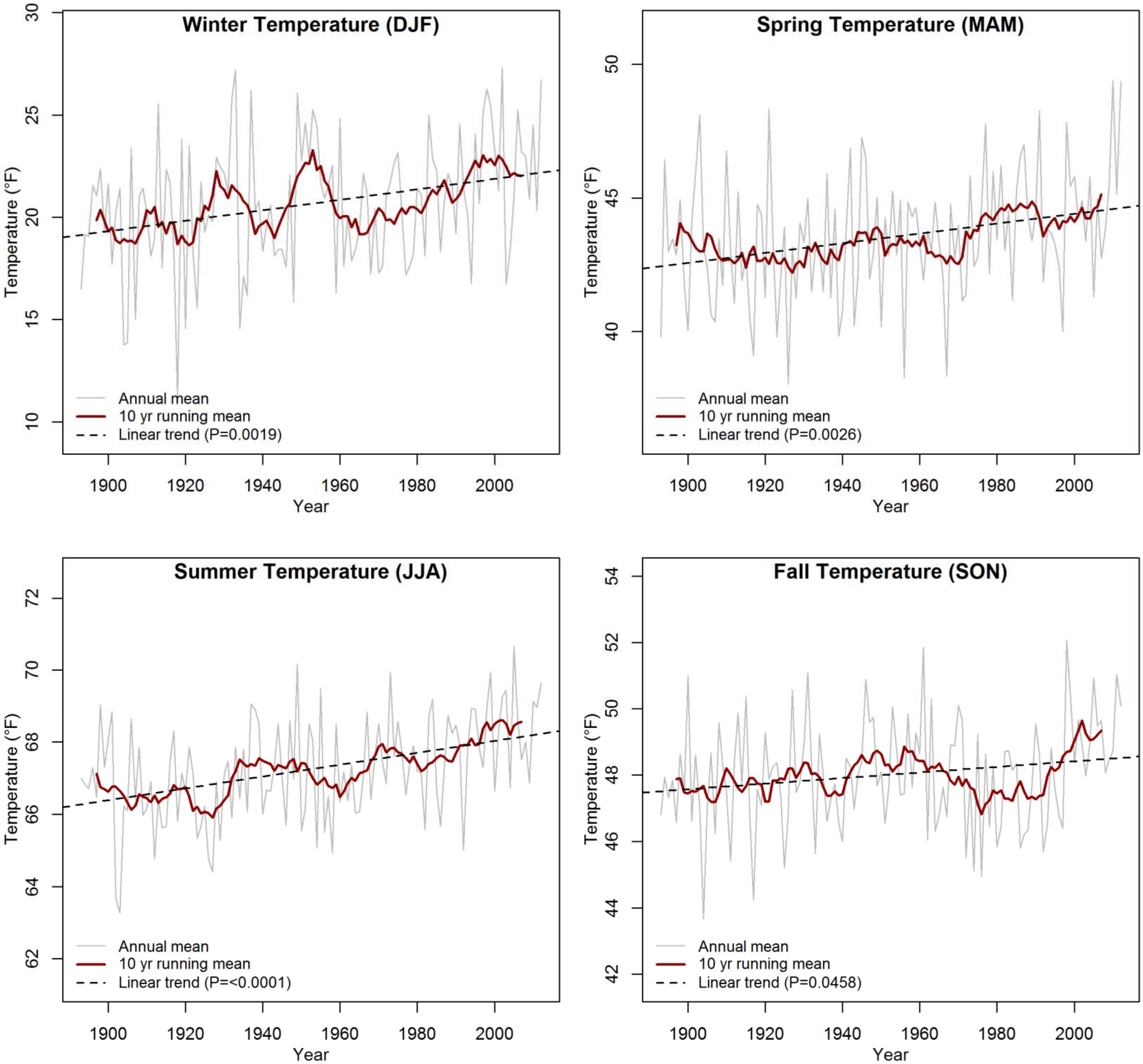


Figure 2. Seasonal temperature trends (1893-2012) from the Hanover, NH long-term weather station (ncdc.noaa.gov).

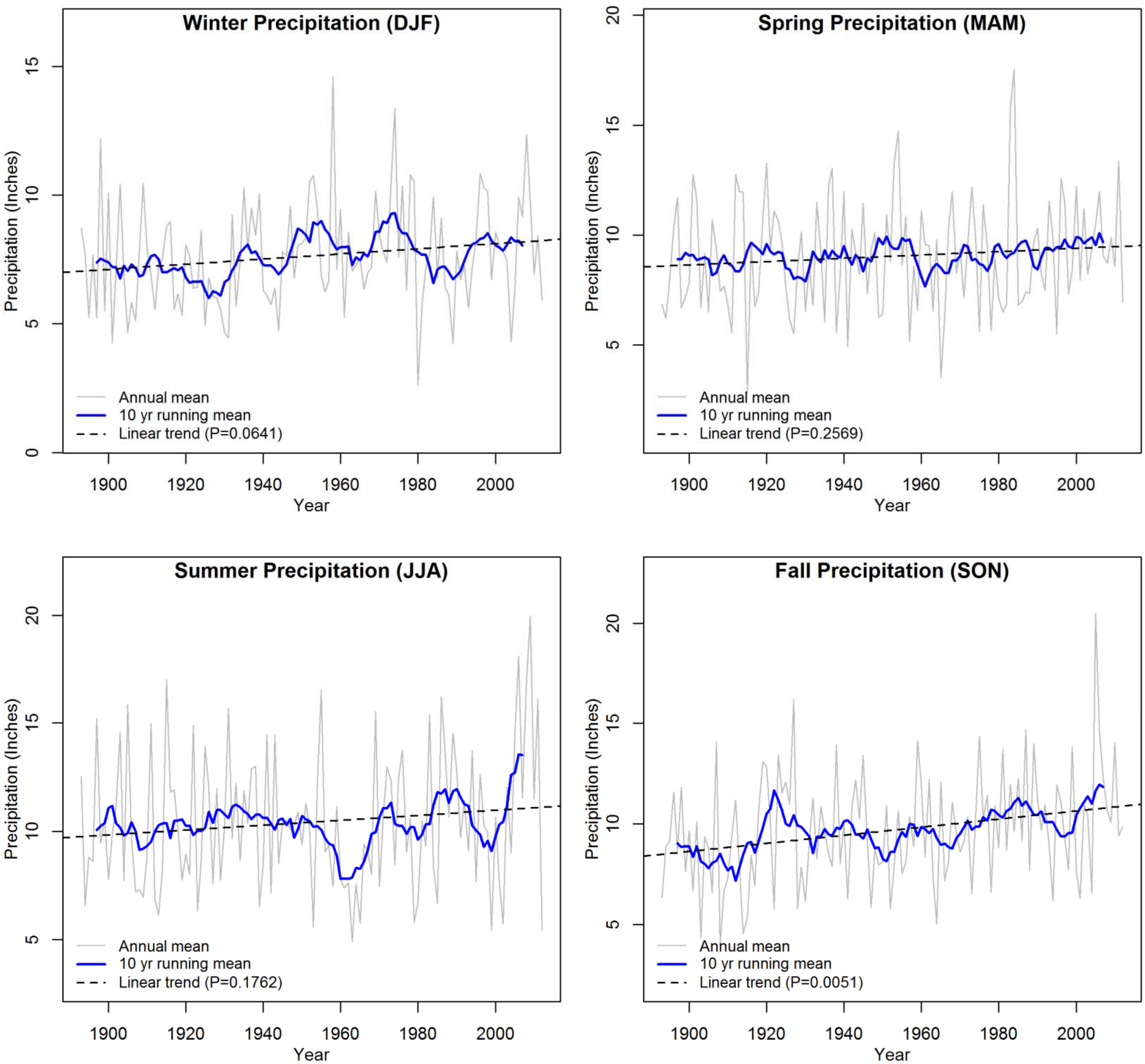


Figure 3. Seasonal precipitation trends (1893-2012) from the Hanover, NH long-term weather station (ncdc.noaa.gov).

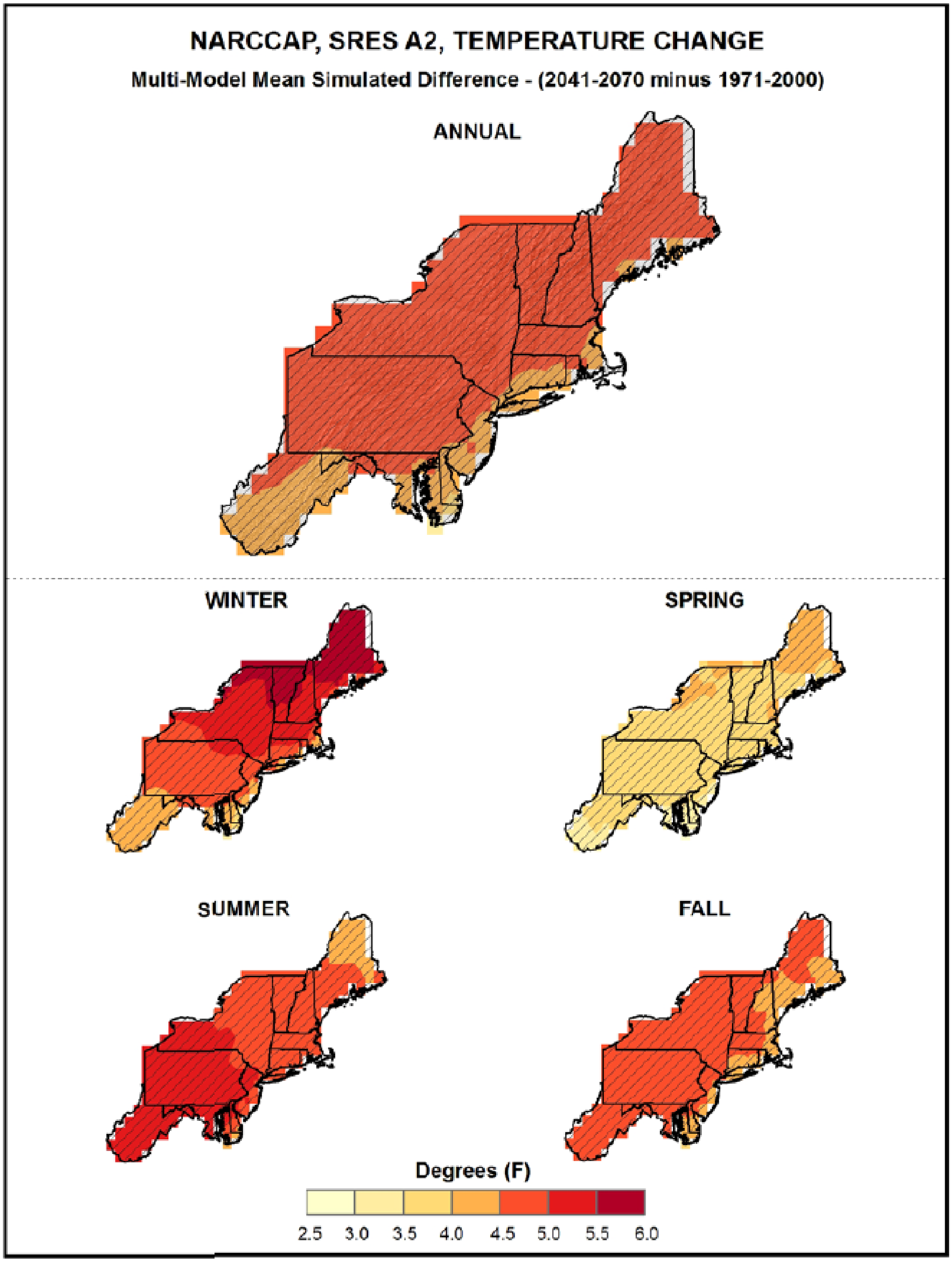


Figure 4. Projected annual and seasonal temperature change. Maps show projected change in average surface air temperature in mid-century (2041-2070) relative to the later part of the last century (1971-2000). Projected changes are averages from 11 NARCCAP regional climate simulations for the high (A2) CO_2 emissions scenario. Color with hatching indicates that more that 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change. Figure and legend from Kunkel et al. (2013).

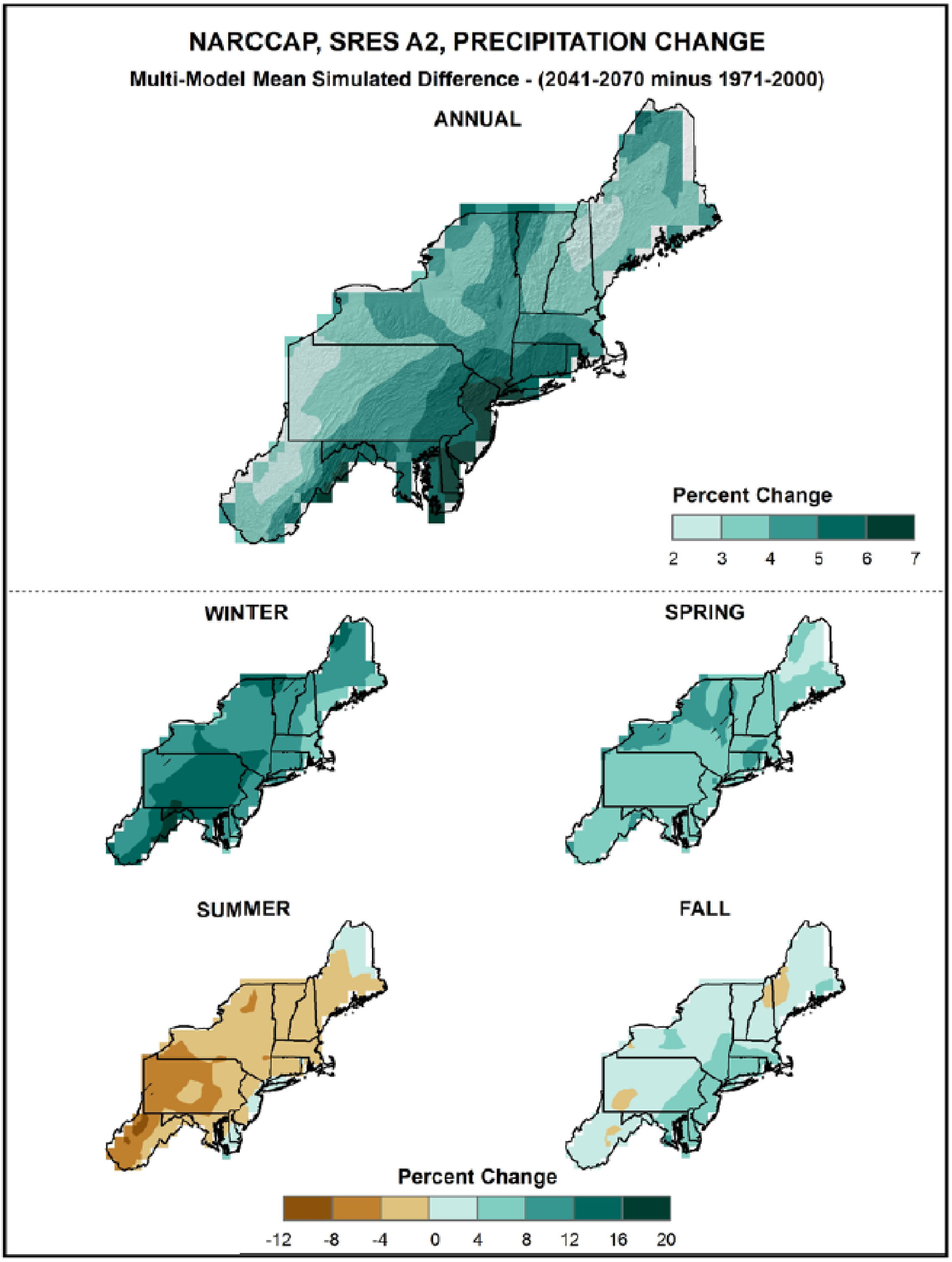


Figure 5. Projected annual and seasonal precipitation change. Maps show projected change in precipitation for mid-century (2041-2070) relative to the later part of the last century (1971-2000). Projected changes are averages from 11 NARCCAP regional climate simulations for the high (A2) CO_2 emissions scenario. Color only indicates that less than 50% of the models show a statistically significant change in precipitation. Color with hatching indicates that more that 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change. Figure and legend from Kunkel et al. (2013).

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Appendix 5. Forest adaptation workshop summary, Marsh-Billings-Rockefeller National Historical Park, May 2014.

Project Area

Marsh-Billings-Rockefeller National Historical Park is a 550-acre park located east of Vermont's Green Mountains. The Park contains the Mount Tom Forest, which is the earliest surviving example of planned and managed reforestation in the country. It is a living exhibit that illustrates the evolution of forest stewardship in America, from the earliest scientific silvicultural practices borrowed from nineteenth-century Europe to contemporary practices of sustainable forest management. Nine of the plantations set out by Frederick Billings in the late 1800s still stand. Older trees, such as open-grown sugar maples that date to the Marsh period and hemlocks over 400 years old, can still be found throughout the property.

Natural resource professionals are working to understand and assess how climate change may affect the natural and planted forests present in the Park. This information will be incorporated into the natural resource management and conservation activities taking place at the Park. A workshop was held in May 2014 to consider how scientific information from the vulnerability assessment could be integrated into Park activities in order to develop actionable steps to adapt forests at the Park to changing conditions and monitor outcomes. Participants represented the Park, the National Park Service (NPS) Climate Change Response Program, the NPS Northeast Temperate Network I&M program, the NPS Northeast Region Office, Redstart Consulting, the Northern Institute of Applied Climate Science, the US Forest Service, and the Vermont Agency of Natural Resources.

Climate Change and the Park

Climate Change Impacts

Climate change is going to have profound impacts on the forests in the Northeast region in coming decades. In order to better understand the anticipated effects of climate change on the forest ecosystems present in the Park, staff from the NPS Climate Change Response Program led the development of a vulnerability assessment for Marsh-Billings-Rockefeller National Historical Park, focusing on information that would support the Park's forest management plan and support activities to help forests adapt to changing conditions. These findings are summarized in the body of this document. Climate change impacts that were discussed as being particularly important to the forests at the Park included:

- Some northern tree species, including fir, aspen, and paper birch, are projected to have moderate to strong decreases in suitable habitat under both future climate scenarios, while many temperate species currently present are expected to retain suitable habitat.

- Under the warmest scenario, several oak, hickory, and pine species uncommon or absent in the park gain suitable habitat in central Vermont in the coming decades.

- There is great uncertainty regarding the potential effects of climate change on the planted European conifer species Norway spruce, Scots pine, and European larch. The available literature suggests that all three species are at some increased risk of decline in the future from climate change (especially drought effects), although the magnitude of this risk is unclear. Norway spruce currently appears to be declining in some places on the Park grounds.

- Efforts to prevent and remove invasive species in the Park have reduced the impact of these species, which can increase the adaptive capacity of desired forest species.
- Forest pest impacts have been relatively moderate over the past 15 years, though expansion rates of species such as hemlock woolly adelgid and emerald ash borer threaten the park in the next two decades. In the case of hemlock woolly adelgid, increases in winter temperatures are expected to increase the likelihood of the pest's survival in northern areas and thus spread into the Park.
- The combination of rapid climate change and tree pests may accelerate decline of some tree species and inhibit other species from occupying climatically suitable habitat.
- Many legacy and plantation trees are at increased risk of windthrow from extreme weather events because of their large size and old age, especially on exposed sites.
- The vulnerability of forests will vary based on numerous site conditions, including: soils, aspect, landform (i.e., convex versus concave shapes), tree species composition, forest productivity, and past and current forest management.
- The extensive network of carriage roads across the park is vulnerable to damage from increases in extreme rain events.

Challenges and Opportunities for Management

In this step, workshop participants explored the opportunities and challenges to meeting the property and stand-level management goals and objectives under changing conditions (Table 1). Many of the challenges were based upon the vulnerabilities identified in the previous step, such as the challenge of maintaining plantations along main carriage road corridors to reflect the historic character of the site when these species may be at increased risk of decline from a changing climate.

Table 1. Summarized notes of the discussion of management challenges and opportunities in meeting the Park's management objectives given climate change.

Community Type	Management Objective *(from pages 47-48 of Plan)*	Challenges to Meeting Management Objective with Climate Change	Opportunities for Meeting Management Objective with Climate Change
Plantations	• Maintain portions of some plantations along the main carriage road corridors • Recruit softwood regeneration in other plantations • Elsewhere, retain plantations through current rotation and then transition to native species	• Many plantations are old (from late-1800s/early-1900s) and trees beginning to decline • Large uncertainty around how current European tree stems will fare in the park under a changing climate • Beech creates severe challenges to regenerating stands to both plantation and native species Norway spruce seedlings are establishing beneath intact canopies in some stands; Scotch pine and European larch are too shade-intolerant to regenerate naturally in plantations	• Some plantations past 'normal' maturity and thus are an opportunity to apply adaptation strategies • Stands can be regenerated now before the climate changes too dramatically (young seedlings more susceptible to drought than established trees) • Long-term goal is to transition many plantations to natural forest; opportunity to change species mix • Plantations have enough time for one additional thinning—time to test new ideas and learn

Community Type	Management Objective *(from pages 47-48 of Plan)*	Challenges to Meeting Management Objective with Climate Change	Opportunities for Meeting Management Objective with Climate Change
Hardwood and mixed forest stands	• Promote greater age and structural diversity using predominately uneven-age management techniques. • Harvest at silvicultural maturity with some large diameter trees retained for wildlife.	• Forest is missing early successional species and smaller diameter size classes for many species • Beech thickets due to beech bark disease and harvesting of overstory trees may outcompete regeneration of other tree species • Selective herbivory from deer and moose may reduce regeneration performance of palatable climate-adapted or desirable species • Current size class distributions for shade-intolerant species skewed towards many overstory trees, few seedlings, and very few saplings • Increased risk of ash loss from EAB • Increased risk of hemlock loss from HWA	• High tree species diversity and richer and moister sites reduce risk of declines • Management opportunity: mature hardwood stands reaching a transition stage (even-aged stands) • Most species present are "persistors" under a changing climate • Some drier sites have an oak component • Summer/fall harvesting reduces risks associated with shorter winter season • Some species present in low amounts (and likely adapted to future climatic conditions): black birch, black cherry, American elm, red oak • Other species present farther south in Vermont (and likely adapted to future climatic conditions): hickories, white oak, sycamore, slippery elm
Legacy trees	• Retain existing legacy trees as long as possible. • Replace related to the designed elements of the landscape in kind. • Recruit new legacy trees from within plantations and hardwood and mixed forest stands to maintain existing distribution of legacy trees throughout the property. Intent is to convey a sense of the long-term nature of forest change and provide ecological value.	• Wolf trees (large open-grown maples, now in forest) cannot be replaced because of continuous forest cover • In some areas, the species of legacy trees matters, which could be problematic for species that are anticipated to do poorly under climate change, particularly the European conifers	• Oak legacy trees could provide a seed source to increase that species
Carriage road corridors and vistas	• Maintain existing vistas, but relocate if needed to achieve other management objectives. • Consider reestablishment of historic vistas. • Thin understory along some carriage road sections. Retain large-diameter downed wood along corridor, but reduce the height or remove slash.	• Carriage roads may become a big upkeep and maintenance issue with heavier storms in the future. Bank erosion below culverts may get worse, some areas already eroding • Culturally appropriate pipe size of culverts is limited • Issues with timing of spring rains increases risk of damage. For example, volunteers clear leaves from ditches to reduce risk of washouts, but may not be available until later in the spring after many big events • Roads can't be closed or decommissioned, except in rare instances related to maintenance or erosion	• Roads are very well-maintained and presently there is capacity to address issues quickly
Wildlife habitat	• Transition to higher quality habitat.	• Increase in beech could be good for some, but not all wildlife species	• Disturbance could increase heterogeneity and thus variety of wildlife habitat by creating gaps, etc. • Adaptation actions, such as increasing oak and cherry, could also benefit many wildlife species.
Catastrophic events	• Allow areas to naturally regenerate. • In the event of loss due to insect and disease, regeneration of nonsusceptible species would be encouraged. • If loss occurs along main carriage road corridors, then establishment of small-scale plantations would be considered.	• Increases in the number and severity of events could make it harder to respond • Impossible to predict and difficult to plan for these events	• Disturbance could increase structural or species diversity by creating gaps, etc.

Adapting to Climate Change

Within this context, workshop participants identified a number of potential adaptation actions to enable the Park forests to adapt to continuously changing conditions (Table 2). In the northern hardwood forest, actions to maintain and enhance tree species diversity were prescribed to reduce the risk from climate change-related declines in the dominant species. This included the use of group selection and shelterwood harvests to provide natural regeneration and enhance the abundance of mid-tolerant species. Several of these species, including northern red oak and black cherry, are currently present on the property in relatively low amounts and are projected to fare better under climate change relative to other species that are currently present. At the same time, the group also identified that there may be challenges to implementing these silvicultural techniques because of concerns about the aesthetics of creating larger gaps during timber harvest.

Several potential adaptation actions were also identified for the plantations, and these varied based on whether the management intention was to maintain plantation characteristics or to move stands toward native species. For areas being maintained as plantations, the need to identify tree species or seed sources for future plantings featured prominently. Because the regeneration phase may be more sensitive to climate change than established saplings or trees, there may be a window of opportunity to reestablish stands in the near term (less than 20 years) before the climate changes dramatically. For areas identified for a transition to native vegetation, there may be additional options available for increasing tree species diversity and enabling ecosystems to adapt to change.

The managers generally viewed the proposed adaptation actions as slight adjustments to the current management trajectory because of the ecosystem focus in the current plan, as opposed to a significant departure from current management. Additionally, several "contingency plans" were discussed for responding to disturbances or other unforeseen events. For example, introduction of the emerald ash borer or hemlock woolly adelgid or a combination of threats could accelerate mortality of current overstory trees. Replacement of hemlock with another native conifer, after arrival of hemlock woolly adelgid, was discussed. Potential species included red spruce, though in the long-term this species may decline in the region and especially at lower elevations such as within the Park.

Table 2. Some proposed adaptation actions identified for the Marsh-Billings-Rockefeller National Historical Park in central Vermont.

Adaptation Approach	Potential Adaptation Tactic	Benefits or Drawbacks/Barriers
PARK-WIDE		
Prevent the introduction and establishment of invasive plant species and remove existing invasives	Continue existing work to prevent and remove invasive species	+ Already in progress
	Work with neighboring landowners to control invasive species	
Maintain or improve the ability of forests to resist pests and pathogens	Develop forest pest response plan	
	Incorporate climate change adaptation into interpretive themes: improve signage and content of ranger programs (forestry walk)	

Adaptation Approach	Potential Adaptation Tactic	Benefits or Drawbacks/Barriers
HARDWOOD AND MIXED FOREST		
2.1 — Maintain or improve the ability of forests to resist pests and pathogens 9.1— Anticipate and respond to species decline (Hemlock woolly adelgid)	•Increase early-detection and monitoring efforts for hemlock wooly adelgid, such as: •Partner with USFS to extend surveys done on National Forest lands to Park lands •Train volunteers as first detectors	+ Leverages existing efforts. USFS is already doing surveys. The VT Agency of Natural Resources has developed a training for volunteer detectors that the Park could use.
	Informed waiting: Learn about the use of biological controls for HWA and evaluate for potential use on Park lands in the future	
	Thin hemlock stands to increase vigor and reduce susceptibility to HWA	
	Targeted use of insecticides or biological controls to slow spread of HWA in the park	
	Use local propagation of hemlock at the park to reduce chances of HWA introduction	+ Already being done
	Identify hemlock trees of particular value (hemlock hedges, individual trees) for use of insecticide to maintain some hemlock trees as legacy trees into the future	+ Maintains some hemlock trees as legacy trees for cultural purposes
	Replacement of hemlock along riparian corridors when HWA kills trees	+ Mitigating factors: slow spread of HWA in northern New England + Need to monitor biological control efforts and efficacy in the region
9.1— Anticipate and respond to species decline 9.7 — Establish or encourage new mixes of native species (Hemlock wooly adelgid)	if hemlock decline is in the near-term and rapid, could try planting red spruce along riparian corridors to maintain dense year-round shade	+
2.1 — Maintain or improve the ability of forests to resist pests and pathogens 9.1— Anticipate and respond to species decline (Emerald ash borer)	Continue monitoring for emerald ash borer (EAB) presence	+
	Continue to select against some ash species in harvested stands to reduce density of trees and amount of phloem	+
5.2 — Maintain and restore diversity of native tree species 5.3 — Retain biological legacies	Use single tree and small group selection harvests (favors a small number of shade-tolerant species: maple and beech	—Such harvests favor a small number of shade-tolerant species (maple and beech) and do not diversify stands —Selective herbivory from deer and moose may reduce regeneration performance of palatable climate adapted species

Adaptation Approach	Potential Adaptation Tactic	Benefits or Drawbacks/Barriers
HARDWOOD AND MIXED FOREST		
5.2 — Maintain and restore diversity of native tree species	Create larger gaps during harvest to promote natural regeneration of a wider variety of tree species, including oaks	+ Increase species and structural diversity + May increase "persistor" and "increaser" species, such as red oak, black cherry, sweet birch — Aesthetics are a concern with larger gap sizes. Some visitors may not like large openings ('messy conditions'). May require removing large trees before economic maturity — Selective herbivory from deer and moose may reduce regeneration performance of palatable climate adapted species
	Increase signage and interpretive messages to help visitors understand reasons for larger gap size. Develop stewardship communication locations.	+
	Consider climate change effects on sites and trees based on slope, aspect, and landscape. Use this information to inform the selection of desired species	+ Sites susceptible to drying can be transitioned to more heat and drought-tolerant species. + Less susceptible sites can be refugia for mesic species.
9.7 — Establish or encourage new mixes of native species	Plant future-adapted tree species (e.g., oaks, hickories, sweet birch)	+ Larger gaps are needed, which may be hard to create — Planting is an unusual practice in these stands. — Additional cost
	Work with adjacent landowners to test out new ideas or practices	+ Adjacent landowners may have more management flexibility to test adaptation options not appropriate on park lands
9.6 — Protect future-adapted regeneration from herbivory	When planting palatable climate-adapted species, plant numerous seedlings within a pile to harvested tree tops to prevent deer or moose from browsing the seedlings	
	Use short-term, light-weight deer fencing	
10.1 — Prepare for more frequent and more severe disturbances	Plan for and utilize canopy-opening disturbances (e.g., wind, ice storms) to create opportunities for increasing tree species and structural diversity.	— Hard to plan for – can't control when/where disturbance occurs

Adaptation Approach	Potential Adaptation Tactic	Benefits or Drawbacks/Barriers
PLANTATIONS – Areas maintained as plantation over long term		
9.1— Anticipate and respond to species decline	Thin stands to improve vigor and reduce risks from drought	+ Many stands can have one additional thinning before end of rotation. + Above also provides opportunity to try new ideas and further assess climate change impacts
	Establish desired plantation species in the near-term (next 2 decades)	+ Takes advantage of conditions before climate changes dramatically
8.2 — Favor existing genotypes that are better adapted to future conditions 8.3 — Increase diversity of nursery stock to provide those species or genotypes likely to succeed 9.1— Anticipate and respond to species decline 9.4 — Emphasize drought- and heat-tolerant species and populations 9.5 — Guide species composition at early stages of stand development	Where plantation species are replanted, use local stock (heritage)	+ Plantation species have large native ranges and diverse genotypes
	Where plantation species are replanted, use stock from heat- and drought-adapted populations (e.g., from southern Europe)	
9.4 — Emphasize drought- and heat-tolerant species and populations 9.5 — Guide species composition at early stages of stand development	Plant species structurally/aesthetically similar to Norway spruce or other European species for replacement? Red spruce, Douglas-fir, tamarack	—Native species like red spruce are expected to decline. —Non-native species may be less desirable because of conflicts with the move toward greater ecological consideration
1.1 — Maintain or restore soil quality and nutrient cycling	May need to harvest in Norway spruce stands during winter to avoid root damage	
5.3 — Retain biological legacies 9.1— Anticipate and respond to species decline 9.2— Favor or restore native species that are expected to be better adapted to future conditions	Stand 18 example: could employ a two-tiered approach: maintain large old white pine near the carriage road and open up the back areas of the stand to encourage forest transition	
2.3 — Manage herbivory to protect or promote regeneration	Continue to ensure planted trees are not lost due to herbivory	
PLANTATIONS – Areas transitioning to native vegetation over long term		
9.1— Anticipate and respond to species decline 9.2— Favor or restore native species that are expected to be better adapted to future conditions 9.5 — Guide species composition at early stages of stand development 5.1 — Promote diverse age classes	Thin stands to improve vigor and reduce risks from drought	+ Many stands can have one additional thinning before end of rotation. + Above also provides opportunity to try new ideas and further assess climate change impacts
	Establish desired native species in the near-term (next 2 decades)	+ Takes advantage of conditions before climate changes dramatically + Regeneration phase may be more sensitive to climate change than established large saplings/trees + Great opportunity to push a more diverse mix of native species
	Allow for natural regeneration of native plants in old plantations	—Where established, beech will compete with desired species
	Utilize larger gap sizes to encourage a greater diversity of native regeneration	—Aesthetics are a concern with larger gap sizes. Some visitors may not like large openings (‘messy conditions’).
9.2— Favor or restore native species that are expected to be better adapted to future conditions 9.5 — Guide species composition at early stages of stand development 9.7 — Establish or encourage new mixes of native species	Next generation stems could come both from natural regeneration within the park and from new seed sources from warmer and drier parts of the native ranges	
1.1 — Maintain or restore soil quality and nutrient cycling	May need to harvest in Norway spruce stands during winter to avoid root damage	

Adaptation Approach	Potential Adaptation Tactic	Benefits or Drawbacks/Barriers
CARRIAGE ROADS		
1.1 — Maintain or restore soil quality and nutrient cycling 1.2 — Maintain or restore hydrology	Continue maintenance of roads, culverts, and other infrastructure	+ Road crowning, ditch cleaning, regular maintenance and other practices reduce risks from extreme events — May cost more in future
	Close carriage roads to reduce risks from extreme events	— unlikely due to easements and cultural significance
	Increase mowing along roadways if ticks increase	— Greater cost
LEGACY TREES		
	For conifer species – see Plantations above.	
8.2 — Favor existing genotypes that are better adapted to future conditions 9.2— Favor or restore native species that are expected to be better adapted to future conditions	Retain oak legacy trees and use as a seed source for future regeneration efforts	
WILDLIFE		
5.2 — Maintain and restore diversity of native tree species	Create larger gaps during harvest to promote natural regeneration of a wider variety of tree species. Increase the number of snags and amount of coarse woody debris and throughout the forest.	+ Increase species and structural diversity + May increase “persistor” and “increaser” species, such as red oak, black cherry, sweet birch + Provides additional wildlife habitat. — Aesthetics are a concern with larger gap sizes. Some visitors may not like large openings (‘messy conditions’).

Monitoring

Managers identified forest inventory data as an integral component of monitoring the effectiveness of adaptation actions over time. Permanent forest inventory plots were established within each stand on the property. The inventory provides a useful baseline for prescribing management activities for adaptation. For example, data on tree species abundance can be used to calculate tree species richness and diversity evenness and provided an indication of the relative risk associated with the loss of different tree species. Additionally, the presence of advanced regeneration of tree species that may be better adapted to future conditions can be assessed in the inventory data. In the future, repeat inventories will be used to evaluate whether the selected management activities increase the abundance of desired species in the understory and eventually the overstory.

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov