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Natural Resource Stewardship and Science

Climate Change and Forests of the Acadia National Park Region

Projected Changes in Habitat Suitability for 83 Tree Species

Natural Resource Report NPS/ACAD/NRR—2013/733

ON THE COVER
View of Jordan Pond from Penobscot Mountain, Acadia National Park.
Photograph by: Andrew Vincello, NPS.

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Projected Changes in Habitat Suitability for 83 Tree Species

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Abstract

Climate change is affecting species and resources across National Parks. Novel climatic conditions are likely to result in novel species assemblages; this means that the 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. To support such efforts for Acadia National Park, we analyzed projected changes in tree habitat suitability for 83 trees species for three future periods (2040, 2070, and 2100). We present model output from two scenarios, the ‘least change’ and ‘most change’ scenarios that represent the rough bounds of plausible future conditions. General trends in the data indicate strongly decreasing habitat suitability for 13 species (16% of species), minor change for 18 species (22% of species), and large increases or new habitat for 52 species (62% of species). Boreal tree species, including fir, spruce, aspen, and paper birch, have 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 common in the southeast and south central U.S. are likely to have suitable habitat in the Acadia region by the end of the 21st century. As climate change continues and forest responses accelerate, management will need to shift from actions that are no longer effective to new strategies that achieve desired conditions in a continuously changing world.

Acknowledgments

Thanks to G. Schuurman, K. Townsend, and K. Miller for comments on previous drafts of this report.

Introduction

Climate change effects alter ecosystem composition, structure, and function, and detecting and understanding species' range shifts and ecological community compositional changes is a vital undertaking for effective land management. Interpretations of climate-vegetation models, projecting shifts in habitat suitability due to climate change, can inform natural resource planning and management actions. Many tree species are keystone/foundation species and therefore shifts in forest composition and structure will affect other trophic levels within the ecosystem (Ellison et al. 2005). Furthermore, climate and forest changes will have cascading effects on resource management, park operations, and visitor experience. This report interprets projections of tree habitat suitability changes in response to climate for the region including Acadia National Park.

The climate is changing and these changes will likely continue and intensify in the coming decades (NCADAC 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 effects of 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.

National Park Service lands include over 13.5 million acres of forests, and climate change-related stressors already affect many forest-dependent species within and beyond park boundaries (Parmesan 2006). 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,b) 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 (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 (Goldbum & Rigg 2010), in which Acadia National Park 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. 2013b). Tools such as the Climate Change Tree Atlas (Prasad et al. 2007) 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 at relatively fine spatial and temporal scales (<20,000 km2 and over the next 30-90 years), will help managers focus monitoring and management efforts to achieve desired conditions within national park forests. Such information will also enable national park managers to plan for personnel or infrastructure necessary to manage altered seasonal use patterns (e.g. higher use in fall color season), changes in trail maintenance, a modified fire regime, and other impacts to daily operations.

View of the ocean and extensive forest cover, Acadia National Park. NPS photo.

Methods

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.

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 modeled the 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 'most 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 'most 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). It is important to note that current greenhouse gas emissions are on a trajectory similar to the higher IPCC emissions scenarios, including the A1FI (Peters et al. 2012).

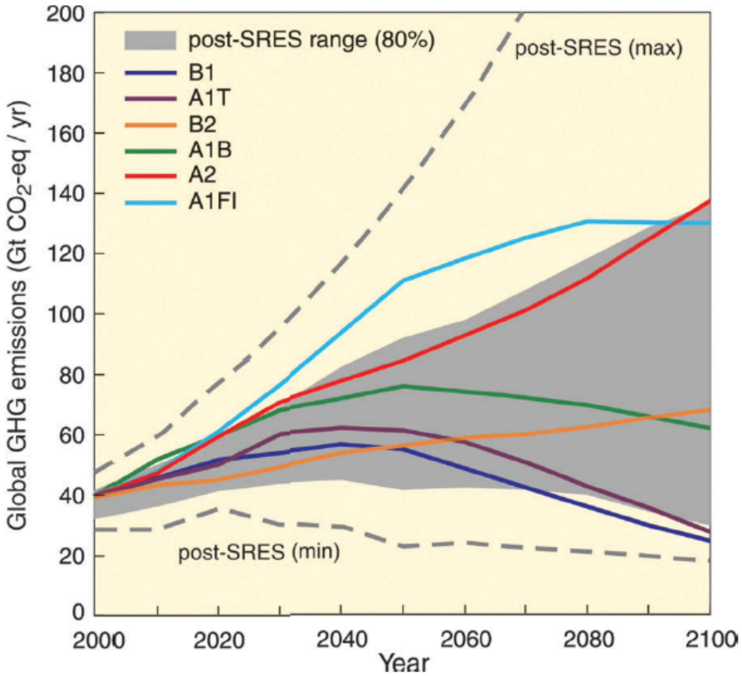

Figure 1. Global greenhouse gas emissions (in gigatons of carbon dioxide equivalent per year) under six potential scenarios (B1, A1T, B2, A1B, A2, and A1FI). The dashed lines show the full range of scenarios. The B1 and A1FI scenarios were used in the analyses in this report as lower and upper bounds,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

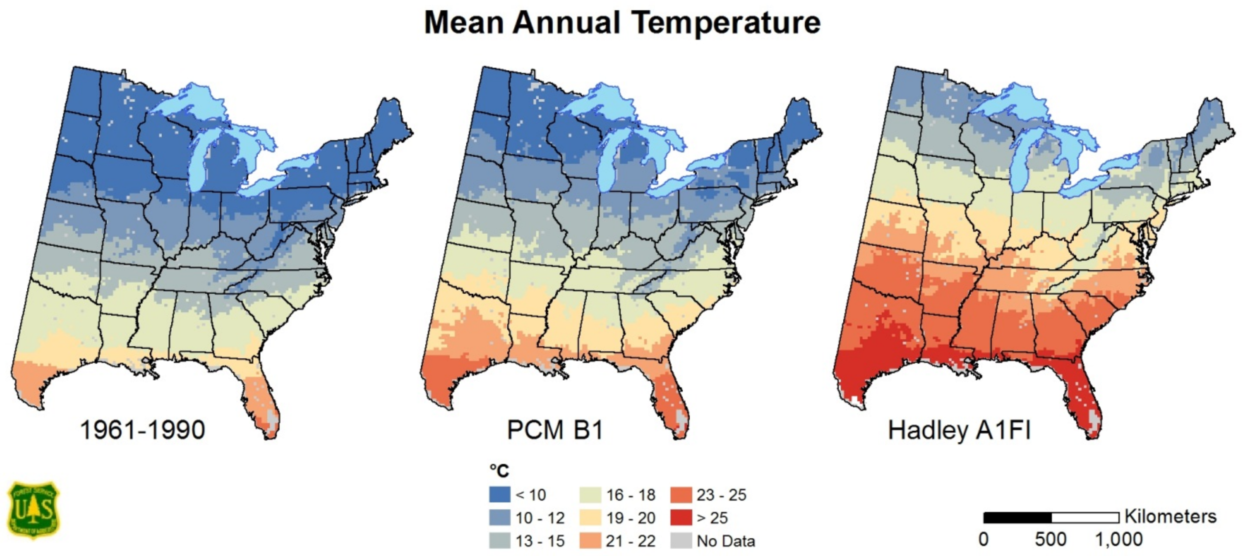

Figure 2. Baseline (1961-1990) and projected mean annual temperature for the end of the 21st century. The PCM-B1 model represents the lowest levels of warming under a very low greenhouse gas emissions scenario. The HadleyCM3-A1FI model shows the warmest projections under the high greenhouse gas emissions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

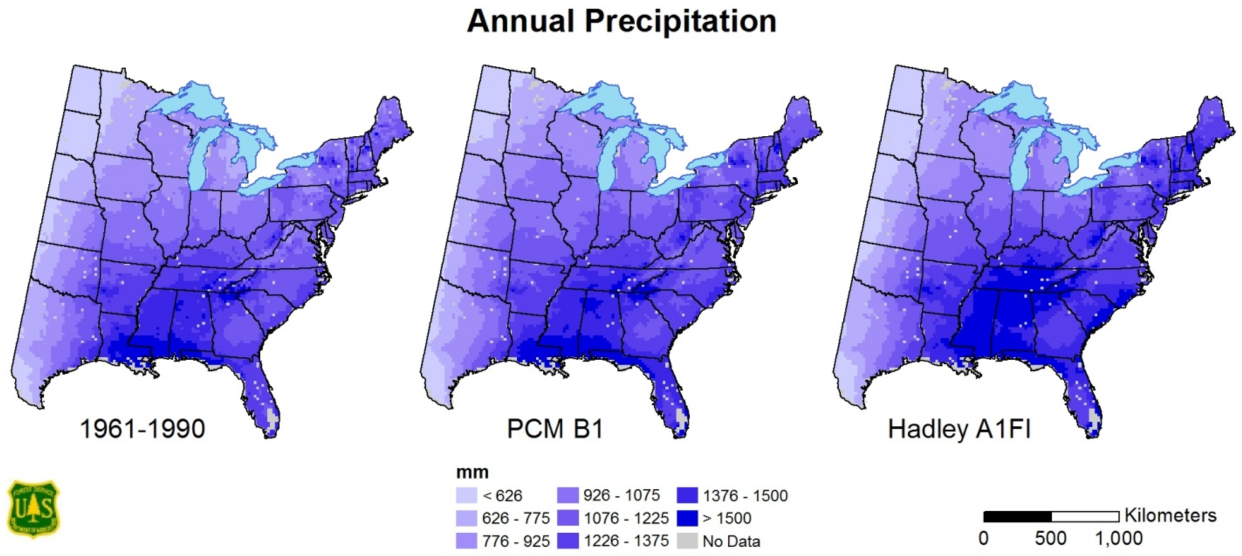

Figure 3. Baseline (1961-1990) and projected mean annual precipitation for the end of the 21st century. PCM-B1 and Hadley-A1FI represent the coolest and warmest temperature projections and indicate slight to moderate increases in annual precipitation for the eastern US.

Suitable Habitat Modeling

The projections of suitable habitat for tree species come from the USDA Forest Service Climate Change Tree Atlas (Prasad et al. 2007, Iverson et al. 2008). 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 each additional iteration.

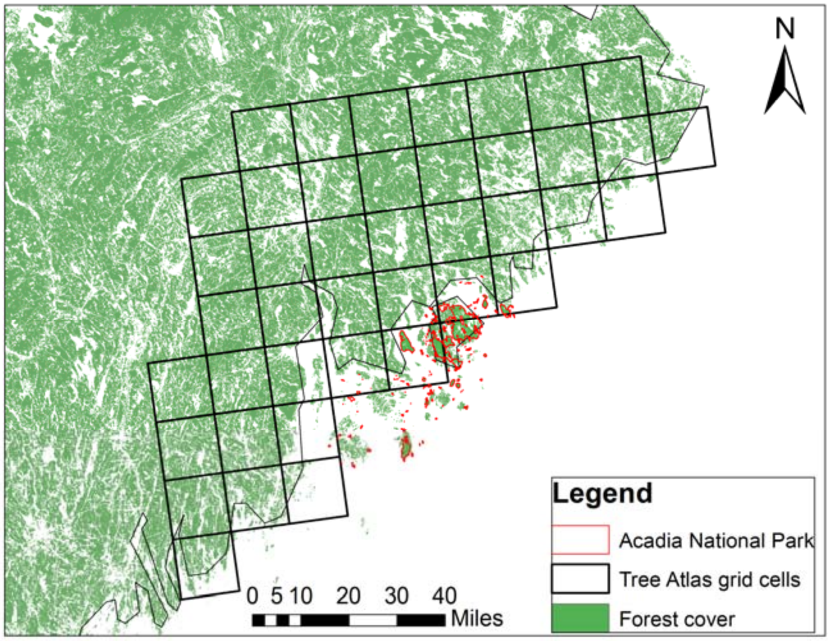

Figure 4. The area of analysis for Acadia National Park included 42 pixels (each 12 x 12 mi, 20 x 20 km) for a total area of 6048 mi^2 (16,800 km^2).

Reading the Complete Output Tables

We compiled summaries of IVs for 134 eastern US tree species for the Acadia National Park region based on 42 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, ratios of future to current IVs at 2040, 2070, and 2100 under the 'least change' and 'most 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 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 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.

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.

Results

Analyses for the Acadia region resulted in 83 tree species with current and/or future habitat suitability (see Appendix 1 for the complete model results for each species). General trends in the data indicate strongly decreasing habitat suitability for 13 species (16% of species, in ‘Extirpated’ and ‘Large Decline’ categories), minor change for 18 species (22% of species, in ‘Small Decrease’, ‘No Change’, and ‘Small Increase’ categories), and large increases or new habitat for 52 species (62% of species, in ‘Large Increase’ and ‘New’ categories) (Table 2).

For the 15 species most abundant on the landscape during the baseline period, seven show large declines and eight species have minor changes in habitat suitability in the future (Figure 5). Boreal conifers, such as balsam fir, spruces, and northern white-cedar have strong decreases in habitat suitability by mid-century under both low and high greenhouse gas emissions scenarios. The temperate conifer species (eastern white pine and eastern hemlock) retain current habitat suitability throughout the century under the ‘least change’ scenario, but both species experience habitat suitability decreases of more than 50% under the ‘most change’ model. The boreal broadleaf species (trembling aspen and paper birch) face habitat suitability declines under both scenarios, though the steepness of the decline depends on the magnitude of warming. Temperate broadleaf species (northern hardwoods such as sugar maple, red maple, American beech, white ash, and red oak) vary between small decreases and small increases in habitat suitability over the coming decades.

Tree species with large increases or new potential habitat include species with current range limits within or south of the Acadia 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 Acadia region by the end of the 21st century. Under the ‘most change’ scenario, 33 southern species gain new suitable habitat in the Acadia region.

Spruce-fir forest in Acadia National Park. These forests are projected to lose substantial suitable habitat in the Acadia region, even under a very low greenhouse gas emissions scenario. Photo by Kathryn Miller, NPS.

Table 2. Potential changes in habitat suitability for 83 tree species in the Acadia National Park region. Species are grouped into eight change classes based on mean model results for the end of the 21st century. See Appendix 1 for scientific names and Appendix 2 for change class definitions.

Extirpated: 4 species modeled to completely lose habitat by 2100

- Tamarack
- White spruce
- Black spruce
- Balsam poplar

Large Decline: 9 species show large declines in habitat suitability

- Balsam fir
- Striped maple
- Yellow birch
- Paper birch
- Black ash
- Red spruce
- Quaking aspen
- Pin cherry
- Northern white-cedar

Small Decrease: 5 species show small decreases in habitat suitability

- Gray birch
- American beech
- Eastern white pine
- Bigtooth aspen
- Eastern hemlock

No Change: 7 species exhibiting very minor changes in habitat suitability

- Red maple
- Mountain maple
- Serviceberry
- White ash
- Red pine
- Pitch pine
- Chokecherry

Small Increase: 6 species have a small increase in suitable habitat in the future

- Sugar maple
- Eastern hophornbeam
- Black cherry
- Northern red oak
- American basswood
- Slippery elm

Large Increase: 5 species have a large increase in suitable habitat

- Silver maple
- American hornbeam
- White oak
- Black willow
- American elm

New under both high and low emissions scenarios: 14 species very rare or currently absent from the region with suitable habitat in the future

- Sweet birch
- Pignut hickory
- Shagbark hickory
- Flowering dogwood
- Black walnut
- Eastern red cedar
- Yellow-poplar
- Blackgum
- Eastern cottonwood
- Scarlet oak
- Chestnut oak
- Black oak
- Black locust
- Sassafras

New under the high emissions scenario: 33 species show potential suitable habitat by the end of the century under the high emissions scenario

- Boxelder
- Pawpaw
- Bitternut hickory
- Pecan
- Shellbark hickory
- Black hickory
- Mockernut hickory
- Sugarberry
- Hackberry
- Eastern redbud
- Common persimmon
- Green ash
- Honeylocust
- American holly
- Sweetgum
- Red mulberry
- Sourwood
- Shortleaf pine
- Loblolly pine
- Virginia pine
- Sycamore
- Southern red oak
- Cherrybark oak
- Shingle oak
- Bur oak
- Blackjack oak
- Chinkapin oak
- Pin oak
- Willow oak
- Post oak
- Baldcypress
- Winged elm
- Cedar elm

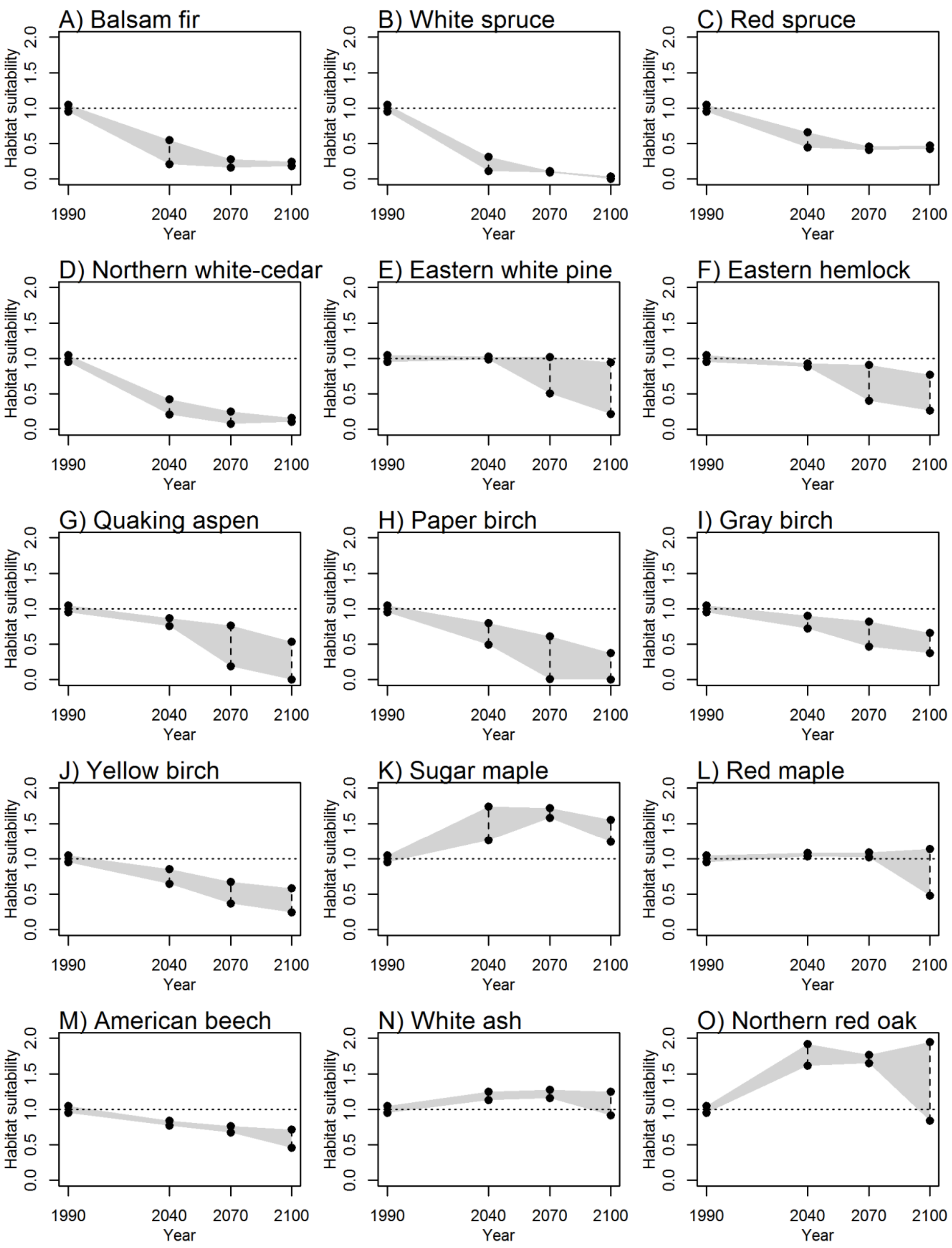

Figure 5. Projected changes in habitat suitability for 15 common tree species in the region. Projections are for three future periods, compared with late 20th century habitat. Y-axis is the ratio of future to late 20th century habitat suitability (2.0 = doubling of suitable habitat; 0.5 = 50% reduction in habitat).

Discussion

Suitable habitat for tree species in eastern North America is projected to shift north. The results presented here, specifically decreases in suitable habitat for many cold-adapted boreal tree species and the expansion of habitat 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; Potter et al. 2010, Beckage et al. 2008). Even under the 'least change' scenario there are major shifts in habitat suitability, including major declines for common boreal tree species in the park (e.g., fir, spruce, aspen, and paper birch). The magnitude and rate of change will depend on many local scale factors which may either accelerate or inhibit changes in forest composition. Furthermore, detecting early signs of these changes will require focused monitoring efforts.

Changes in climate and forest composition will have cascading effects on other resources, park operations, and visitor experiences. Species such as spruce grouse and 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 rapid decline in the current overstory and increasing storms may exacerbate trail maintenance backlogs in the future.

Large white pine tree in Acadia National Park. Future suitable habitat for white pine in the Acadia region depends greatly on the magnitude of climate change, with greater potential habitat loses associated with greater warming. Photo by Kathryn Miller, NPS.

Modifying Factors

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. Forests in Acadia are generally only beginning to reach mature age and structural stages (Miller et al. 2010) and thus individual trees may continue to reside in the canopy for many decades. Current overstory composition is one of the strongest predictors of understory seedling and sapling composition in northern forests, likely due in part to local seed dispersal (Fisichelli et al. 2013b). This 'possession is nine-tenths of the law' effect may allow poorly performing northern tree species to persist and regenerate because the seeds of better adapted tree species are not yet present. 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 Acadia for many decades after the habitat becomes suitable due to habitat fragmentation and dispersal limitations (Ibanez et al. 2008, Scheller and Mladenoff 2008). Outer islands within the park may also show slower rates of change due to dispersal barriers. Lastly, the complex topography and proximity to the ocean are likely to 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, may inhibit the ability of tree species to expand their ranges in response to climate change (Dukes et al. 2009; Matthews et al. 2011). Introduced insects such as hemlock woolly adelgid (*Adelges tsugae*), emerald ash borer (*Agrilus planipennis*), and gypsy moth (*Lymantria dispar*) continue to impact large swaths of eastern forest and limit the potential pool of tree species. For Acadia, the balsam woolly adelgid (*Adelges piceae*) may accelerate the decline of northern species (balsam fir) while the appearance of the Asian long-horned beetle (*Anoplophora glabripennis*) could slow the expansion of temperate hardwood species. Nonnative earthworms and overabundant white-tailed deer (*Odocoileus virginianus*) alter understory conditions and the competitive dynamics among regenerating seedlings (Rooney & Waller 2003; Fisichelli et al. 2013c). 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). 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).

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.

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; Kreyling et al. 2012). 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).

Detecting Change

Detecting early indications of forest response to climate change can include measuring shifts in phenology, establishment, recruitment, survival, and local tree range margins. Documentation of tree expansion at leading edge range limits is far more common than that of contraction at trailing edges (Jump et al. 2009). Seedling establishment beyond the local range limit of adult trees can occur relatively rapidly, whereas detectable range shifts of trailing edge populations likely will be slower to develop, due to the longevity of overstory trees (Crawford 2008; Peñuelas et al. 2007). For Acadia, this means that the expansion of warm-adapted tree species already present on the landscape may become detectable before the decline of boreal tree species. Local ecotonal boundaries, where competing tree species are growing at/near their ecophysiological tolerances, are the likely locations to exhibit such early signs of climate-mediated change. This may manifest as local expansions of temperate tree regeneration into boreal forest patches (Fisichelli et al. 2013a). 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 also 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. Lastly, habitat suitability models and other projections of change should be revisited and reassessed as local field data become available.

Adaptation Strategies for Forests

National Parks are located within a matrix of other federal, state, tribal, and private lands. Effective climate adaptation will require collaboration with managers from neighboring jurisdictions. Climate change adaptation strategies can be lumped into various categories such as resistance, response, and transformation strategies (Millar et al. 2007). The most appropriate strategies depend on management objectives and goals, though many common approaches exist that 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 (Kareiva et al. 2008, NFWPCAP 2012). Promoting heterogeneity in forest types and age structure and greater biodiversity within and across stands is likely to foster an enhanced landscape-scale capacity to adapt to climate change.

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

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 the forest. Any management aimed at shaping the future composition of the forest should focus on the understory regeneration layers during this ‘reorganization phase’ (Gunderson & Holling 2002). For example fire management could be utilized to prepare seedbed conditions for target species adapted to regenerate after fires.

Forest understory in Acadia National Park. Performance of seedlings and saplings in the forest understory can be used as a bellwether of future change. For example growth rates and abundance changes across local ecotones can indicate potential directions of forest change. Photo by Kathryn Miller, NPS.

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, boreal conifers (balsam fir and black spruce) in Acadia 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 these species are likely to become more susceptible to other pests and pathogens as the climate shifts beyond the historical range of variability.

Conclusions

Northern forests are changing and these changes are due in large part to direct and indirect effects of climate change. Stewarding NPS forests for continuous change is a challenge for park managers; however, understanding projected rates and direction of forest change should facilitate monitoring and management efforts on park lands. Although there are uncertainties in the rate of climate change, primarily due to uncertainties concerning future greenhouse gas emissions and discrepancies among general circulation models, many patterns are already apparent in both climate and biotic responses. Climate change science and our understanding of impacts are rapidly evolving. As climate change continues and forest responses accelerate, management will need to shift from actions which are no longer effective to new strategies which achieve desired conditions in a continuously changing world.

View of Jordan Pond from Penobscot Mountain, Acadia National Park. Climatic conditions outside the historical range of variability will result in forest changes beyond the magnitude observed in the past. Photo by Andrew Vincello, NPS.

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Appendix 1. Climate change tree atlas habitat suitability output for 83 tree species in the region including Acadia National Park. Ratio of future to baseline (1961-1990) habitat is shown for three time periods, 2040 (2010-2039), 2070 (2040-2069), and 2100 (2070-2099), and two climate projections, the PCM B1 and Had A1FI, which represent the 'least change' and 'most change' scenarios, respectively. Species are sorted by scientific name. 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.

					Ratio of Future to Baseline Suitable Habitat									
		Baseline			2040		2070		2100			Modifying Factors		
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	Model Reliability	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Positive Traits	Negative Traits	Adapt Score
Abies balsamea	Balsam fir	667	536	High	0.55	0.21	0.28	0.16	0.25	0.18	Lg. Dec.	COL	INS FTK DRO	2.7
Acer negundo	Boxelder	0	1	Medium	3.00	9.00	5.00	7.00	1.00	17.00	New-High	SES DISP DRO COL SES	FTK	7.4
Acer pensylvanicum	Striped maple	16	26	High	0.62	0.27	0.27	0.00	0.27	0.00	Lg. Dec.	COL SES	DRO	5.1
Acer rubrum	Red maple	426	473	High	1.03	1.08	1.09	1.02	1.14	0.48	No Change	SES ESP ESP COL DISP		8.5
Acer saccharinum	Silver maple	14	11	Medium	2.27	4.27	2.45	6.82	2.45	9.09	Lg. Inc.	DISP SES COL	DRO FTK	5.6
Acer saccharum	Sugar maple	61	100	High	1.26	1.74	1.58	1.72	1.55	1.24	Sm. Inc.	COL ESP		5.8
Acer spicatum	Mountain maple	4	0	High	NA	NA	NA	NA	NA	NA	No Change	COL VRE ESP	DRO FTK	5.9
Amelanchier sp.	Serviceberry	4	1	Medium	0.00	0.00	1.00	0.00	0.00	0.00	No Change	COL SES	DRO	4.8
Asimina triloba	Pawpaw	0	0	Low	NA	NA	NA	Inf	NA	Inf	New-High	COL	DRO	3.7
Betula alleghaniensis	Yellow birch	65	82	High	0.85	0.65	0.67	0.37	0.59	0.24	Lg. Dec.	DISP	FTK INS DISE	3.4
Betula lenta	Sweet birch	0	23	High	1.39	1.87	1.70	2.26	2.17	0.65	New-Both	DISP	FTK COL INS DISE	3.2

		Baseline			Ratio of Future to Baseline Suitable Habitat							Modifying Factors		
					2040		2070		2100					
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	Model Reliability	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Positive Traits	Negative Traits	Adapt Score
Betula papyrifera	Paper birch	164	131	High	0.80	0.50	0.61	0.01	0.37	0.00	Lg. Dec.	FRG DISP ESP	FTK COL INS DRO	3.4
Betula populifolia	Gray birch	85	82	Medium	0.90	0.72	0.82	0.46	0.66	0.38	Sm. Dec.	DISP ESP	FTK COL INS DISE	3.6
Carpinus caroliniana	American hornbeam	1	1	Medium	0.00	5.00	1.00	16.00	2.00	29.00	Lg. Inc.	COL SES	FTK DRO	5.1
Carya cordiformis	Bitternut hickory	0	0	Low	NA	NA	NA	Inf	NA	Inf	New-High	DRO	COL	5.6
Carya glabra	Pignut hickory	0	0	High	Inf	Inf	Inf	Inf	Inf	Inf	New-Both	ESP	INS DRO	4.7
Carya illinoensis	Pecan	0	0	Low	NA	NA	NA	NA	NA	Inf	New-High		FTK INS COL	2.2
Carya laciniosa	Shellbark hickory	0	0	Low	NA	NA	NA	Inf	NA	Inf	New-High	COL	FTK ESP	3.7
Carya ovata	Shagbark hickory	0	0	Medium	Inf	Inf	Inf	Inf	Inf	Inf	New-Both		INS FTK	4.4
Carya texana	Black hickory	0	0	High	NA	NA	NA	NA	NA	Inf	New-High		ESP COL	4.1
Carya tomentosa	Mockernut hickory	0	0	High	NA	NA	NA	Inf	Inf	Inf	New-High		FTK	5.4
Celtis laevigata	Sugarberry	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High	COL SES	FTK	4.6
Celtis occidentalis	Hackberry	0	0	Medium	NA	NA	NA	Inf	Inf	Inf	New-High	DRO	FTK	5.7
Cercis canadensis	Eastern redbud	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High			4.9
Cornus florida	Flowering dogwood	0	0	High	Inf	Inf	Inf	Inf	Inf	Inf	New-Both	COL		5.0
Diospyros virginiana	Common persimmon	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High	COL ESP		5.8
Fagus grandifolia	American beech	117	156	High	0.84	0.77	0.76	0.67	0.72	0.46	Sm. Dec.	COL	INS FTK	3.6
Fraxinus americana	White ash	66	105	High	1.13	1.25	1.16	1.28	1.25	0.91	No Change		INS FTK COL	2.7
Fraxinus nigra	Black ash	18	32	High	0.63	0.59	0.50	0.00	0.41	0.06	Lg. Dec.		INS COL DISP DRO SES FTK	1.7

		Baseline			Ratio of Future to Baseline Suitable Habitat							Modifying Factors		
					2040		2070		2100					
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	Model Reliability	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Positive Traits	Negative Traits	Adapt Score
													ESP	
Fraxinus pennsylvanica	Green ash	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High		INS FTK COL	4.0
Gleditsia triacanthos	Honeylocust	0	0	Low	NA	Inf	Inf	Inf	Inf	Inf	New-High		COL	5.5
Ilex opaca	American holly	0	0	High	NA	NA	NA	NA	NA	Inf	New-High	COL ESP	FTK	4.5
Juglans nigra	Black walnut	0	0	Medium	NA	Inf	Inf	Inf	Inf	Inf	New-Both	SES	COL DRO	4.0
Juniperus virginiana	Eastern red cedar	1	0	Medium	Inf	Inf	Inf	Inf	Inf	Inf	New-Both	DRO	FTK COL INS	3.9
Larix laricina	Tamarack (native)	40	44	High	0.52	0.14	0.18	0.00	0.07	0.00	Extirpated		FTK COL INS	3.1
Liquidambar styraciflua	Sweetgum	0	1	High	0.00	0.00	0.00	76.00	7.00	208.00	New-High	VRE ESP	FTK COL DRO	4.1
Liriodendron tulipifera	Yellow-poplar	0	0	High	NA	Inf	Inf	Inf	Inf	Inf	New-Both	SES DISP ESP	INP	5.3
Morus rubra	Red mulberry	0	0	Low	NA	Inf	NA	Inf	Inf	Inf	New-High	COL DISP	FTK	4.7
Nyssa sylvatica	Blackgum	0	0	High	NA	Inf	Inf	Inf	Inf	Inf	New-Both	COL FTK		5.9
Ostrya virginiana	Eastern hophornbeam	18	31	Medium	0.68	0.84	0.71	1.16	0.77	2.00	Sm. Inc.	COL ESP SES		6.4
Oxydendrum arboreum	Sourwood	0	0	High	NA	NA	NA	NA	NA	Inf	New-High	COL ESP		6.9
Picea glauca	White spruce	51	54	Medium	0.31	0.11	0.09	0.11	0.04	0.00	Extirpated		INS	3.9
Picea mariana	Black spruce	35	43	High	0.26	0.00	0.00	0.00	0.00	0.00	Extirpated	COL ESP DISP	FTK INS DRO	4.3
Picea rubens	Red spruce	262	173	High	0.66	0.45	0.46	0.41	0.47	0.42	Lg. Dec.	ESP COL	FTK SES	2.9
Pinus echinata	Shortleaf pine	0	0	High	NA	NA	NA	Inf	NA	Inf	New-High	ESP	COL INS DRO	3.6
Pinus resinosa	Red pine	23	26	Medium	1.08	1.81	1.46	0.58	1.42	0.58	No Change		INS COL DISP	3.9
Pinus rigida	Pitch pine	4	4	High	0.00	0.00	0.00	0.50	0.00	0.00	No Change		COL INS	3.8

		Baseline			Ratio of Future to Baseline Suitable Habitat							Modifying Factors		
					2040		2070		2100					
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	Model Reliability	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Positive Traits	Negative Traits	Adapt Score
Pinus strobus	Eastern white pine	212	253	High	1.03	0.99	1.02	0.51	0.94	0.22	Sm. Dec.	DISP	DRO FTK INS	3.3
Pinus taeda	Loblolly pine	0	0	High	NA	NA	NA	Inf	NA	Inf	New-High	ESP	INS INP DRO COL	3.4
Pinus virginiana	Virginia pine	0	0	High	NA	NA	NA	Inf	NA	Inf	New-High		COL POL	3.8
Platanus occidentalis	Sycamore	0	0	Medium	NA	NA	NA	Inf	Inf	Inf	New-High			4.8
Populus balsamifera	Balsam poplar	11	2	High	0.00	0.00	0.00	0.00	0.00	0.00	Extirpated	FRG VRE	COL DRO	4.0
Populus deltoides	Eastern cottonwood	0	0	Low	Inf	Inf	Inf	Inf	Inf	Inf	New-Both	SES	INS COL DISE FTK	3.9
Populus grandidentata	Bigtooth aspen	58	55	High	1.11	0.93	1.02	0.56	1.02	0.00	Sm. Dec.	FRG DISP	COL DRO FTK	5.1
Populus tremuloides	Quaking aspen	116	120	High	0.87	0.76	0.77	0.19	0.53	0.00	Lg. Dec.	SES FRG ESP	COL DRO FTK	4.7
Prunus pensylvanica	Pin cherry	14	21	Medium	0.38	0.71	0.62	0.52	0.48	0.00	Lg. Dec.	SES FRG FTK	COL	4.2
Prunus serotina	Black cherry	26	56	High	1.20	1.41	1.25	1.93	1.36	1.29	Sm. Inc.	DRO ESP	INS FTK COL	3.0
Prunus virginiana	Chokecherry	7	0	Low	Inf	Inf	Inf	NA	Inf	NA	No Change		COL	3.8
Quercus alba	White oak	2	5	High	9.60	15.20	13.20	27.20	18.00	36.20	Lg. Inc.	ESP ESP SES FTK	INS DISE	6.1
Quercus coccinea	Scarlet oak	0	0	High	Inf	Inf	Inf	Inf	Inf	Inf	New-Both	VRE ESP ESP	INS DISE FTK	4.6
Quercus falcata var. falcata	Southern red oak	0	0	High	NA	NA	NA	NA	NA	Inf	New-High	SES		5.3
Quercus falcata var. pagodaefolia	Cherrybark oak	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High		INS FTK	3.9
Quercus imbricaria	Shingle oak	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High	ESP	COL	4.9

		Baseline			Ratio of Future to Baseline Suitable Habitat							Modifying Factors		
					2040		2070		2100					
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	Model Reliability	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Positive Traits	Negative Traits	Adapt Score
Quercus macrocarpa	Bur oak	0	0	Medium	NA	Inf	NA	Inf	NA	Inf	New-High	DRO FTK		6.4
Quercus marilandica	Blackjack oak	0	0	Medium	NA	NA	NA	NA	NA	Inf	New-High	DRO SES FRG VRE	COL FTK	5.6
Quercus muehlenbergii	Chinkapin oak	0	0	Medium	NA	NA	NA	Inf	NA	Inf	New-High	SES		4.8
Quercus palustris	Pin oak	0	0	Medium	NA	NA	NA	Inf	Inf	Inf	New-High		FTK COL INS DISE	2.8
Quercus phellos	Willow oak	0	0	Medium	NA	NA	NA	NA	NA	Inf	New-High	SES SES	COL	4.7
Quercus prinus	Chestnut oak	0	0	High	NA	Inf	Inf	Inf	Inf	Inf	New-Both	SES VRE ESP FTK	INS DISE	6.1
Quercus rubra	Northern red oak	77	98	High	1.61	1.92	1.77	1.65	1.95	0.84	Sm. Inc.		INS	5.4
Quercus stellata	Post oak	0	0	High	NA	NA	NA	Inf	NA	Inf	New-High	DRO SES FTK	COL INS DISE	5.7
Quercus velutina	Black oak	0	0	High	Inf	Inf	Inf	Inf	Inf	Inf	New-Both	DRO ESP	INS DISE	4.9
Robinia psuedoacacia	Black locust	0	0	Low	Inf	Inf	Inf	Inf	Inf	Inf	New-Both		COL INS	3.8
Salix nigra	Black willow	1	1	Low	1.00	12.00	4.00	23.00	7.00	38.00	Lg. Inc.		COL FTK DRO	2.8
Sassafras albidum	Sassafras	0	0	High	Inf	Inf	Inf	Inf	Inf	Inf	New-Both		COL FTK	4.2
Taxodium distichum	Baldcypress	0	2	Medium	0.00	0.50	0.00	1.00	0.00	12.50	New-High	DISP	FTK	3.9
Thuja occidentalis	Northern white-cedar	175	197	High	0.43	0.21	0.25	0.08	0.16	0.11	Lg. Dec.	COL	FTK	4.2
Tilia americana	American basswood	6	9	Medium	0.33	0.44	0.44	2.22	0.33	2.56	Sm. Inc.	COL	FTK	4.6
Tsuga canadensis	Eastern hemlock	135	199	High	0.93	0.88	0.91	0.40	0.77	0.27	Sm. Dec.	COL	INS DRO	2.7
Ulmus alata	Winged elm	0	0	High	NA	NA	NA	Inf	NA	Inf	New-High		INS DISE	3.6
Ulmus americana	American elm	11	30	Medium	1.07	1.80	1.37	2.07	1.47	2.77	Lg. Inc.	ESP	DISE INS	4.0

					Ratio of Future to Baseline Suitable Habitat									
		Baseline			2040		2070		2100			Modifying Factors		
Scientific Name	Common Name	Actual (FIA)	Current (modeled)	Model Reliability	PCM B1	Had A1FI	PCM B1	Had A1FI	PCM B1	Had A1FI	Change Class	Positive Traits	Negative Traits	Adapt Score
Ulmus crassifolia	Cedar elm	0	0	Low	NA	NA	NA	NA	NA	Inf	New-High		DISE	3.3
Ulmus rubra	Slippery elm	6	0	Medium	NA	Inf	Inf	Inf	Inf	Inf	Sm. Inc.	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

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