PROGRESS REPORT 6 (July through September, 2011)
ACCOMPLISHMENTS AND FUTURE OBJECTIVES OF NEAFWA REGIONAL VULNERABILITY ASSESSMENT PROJECT

Objectives of the project. The overarching goal of the project is to provide vulnerability and adaptation information that will help the northeastern states to plan their conservation of fish and wildlife under a changing climate. It has five specific objectives:

1. To quantify the vulnerabilities to climate change of fish and wildlife and their habitats across the region and thereby identify those habitats and species that are likely to be more or less vulnerable, and how these vulnerabilities vary spatially.

2. To project how these habitats and species will change their status and distributions under climate change.

3. To identify potential adaptation options (including the mitigation of non-climate stressors) that can be used to safeguard vulnerable habitats and species.

4. To identify monitoring strategies that will help track the onset of climate change and the success, or otherwise, of adaptation actions.

5. To work with states to increase their institutional knowledge and capabilities to respond to climate change through educational and planning workshops and other events.

Accomplishments (1) – Terrestrial Habitat Vulnerability Assessment.

Two major accomplishments were achieved during this reporting period:

Runs of Vulnerability Model. The predictive vulnerability model has now been run on six major forest habitat types:

- Alpine tundra
- Acadian-Appalachian Montane Spruce-Fir Forest
- Northern Hardwoods
- Oak-Hickory forests
- Pine Barrens
- Atlantic White Cedar swamps

The draft results of these model runs are shown in the attachments. The results of 5 of these (excepting the alpine tundra) have been submitted to the forest habitat workgroup for review and comment. Comments have been received back on 4 of the 5 habitats submitted for review. The next steps in the completion of these habitat accounts will be to:

- Submit the 6th habitat type to the habitat workgroup for review
- Incorporate the reviewers' comments into the accounts
- Incorporate maps and data from the TNC/NEAFWA habitat map and database into the accounts (see below under GIS)
- Submit the completed accounts to the entire NEAFWA expert panel for additional comments
- Incorporate these comments and finalize the accounts.

GIS Mapping. It has long been our intention that we use the database and habitat maps that are being developed by TNC and NEAFWA for the Northeast Region to explore further the consequences of climate change for northeastern habitats. This habitat map and database has now become available and we are moving forward to incorporate it into our process. To accomplish this, it has been necessary for us to recruit a GIS analyst into the project. We have been fortunate to be able to contract with Bill Van Doren of Greenfield , MA, a GIS practitioner and expert. Van Doren is currently producing data sets and maps from the TNC/NEAFWA database and these will be included as components of the finalized habitat vulnerability accounts.

Accomplishments (2) – Coastal Habitat Vulnerability Assessment. Now that sufficient progress has been made on terrestrial habitat vulnerability assessment, we are turning our attention to coastal habitat types (which are not amenable to investigation using the NEAFWA Habitat Vulnerability Assessment Model). To begin this process, we have convened a small group of state personnel who are interested in and who have been active in evaluating impacts to coastal resources. The members of this group are:

Bill Hyatt (CT DEP)
Karen Bennett (DE DNRC)
Rob Hossler (DE DNRC)
Zoe Johnson (MD DNR)
John O'Leary (MA DFW)
Austen Kane (NWF)
Christopher Hilke (NWF)
Andrew Milliken (USFWS).

The purpose of forming this group was so that Manomet could elicit opinions from state practitioners about what they thought was actually needed in evaluating the vulnerabilities of coastal habitats. In other words, what results and tools would <u>they</u> like to see emerging from this new phase of the work.

We convened our first telephone conversation in early October. The agenda for this call focused on four main questions:

1. What current and previous relevant work has taken place in the NE coastal zone?

2. What was still missing?

3. Which of the identified gaps in our knowledge or capability would the states want filled first?

4. Based on the above, what should be our list of objectives for the NEAFWA project?

Galbraith of Manomet has agreed to write up a short white paper based on the results of this call identifying the ways forward and the work components for this new phased. He will submit this to the panel named above for review and comments. Together, they will then decide on the scope and final list of products for this next phase.

Accomplishments (3) – Securing Additional Funding for Project

The North Atlantic LCC has agreed to contribute additional funding to this project. The additional sum (about $180,000) will be applied to two components: to continue the habitat vulnerability work and capacity building that is taking place ($75k); and to begin to involve NatureServe and its species model to do supporting modeling for species ($100k). The exact outlines of this second component is still being finalized, however, it will support and extend the work that is already taking place on habitat vulnerability assessment.

Accomplishments (4) – Outreach, Education, and Wider Use of the NEAFWA Model

The NEAFWA Habitat Vulnerability Assessment Model has been an important component of various training courses in vulnerability assessment. Organized by a consortium of parties, including NCTC, NWF, Manomet and others, these 3-day courses seek to train state and federal and NGO practitioners in the science of habitat and species vulnerability assessment. Thus far, two such courses have taken place at NCTC in West Virginia, and additional courses are being finalized for Anchorage (November), Seattle (December), Denver and Florida (January). The NEAFWA model has been used at these courses to teach students about habitat vulnerability assessment. This has resulted in the use of the model spreading geographically and it is now being used to envaluate habitat vulnerabilities by the state of Maryland and by the National Park Service in the South Dakota Badlands NP.

Accomplishments (5) – Capacity Building

Over the last three months we have:

- Finalized upland forest expert panel work. Developed a suite of climate-smart guidelines for on-the-ground project implementation applicable to forested habitats across the northeast. Guidelines are currently under panel review.

- Helped carry out NWF/US Fish & Wildlife sponsored Climate Vulnerability Assessment training at NCTC. Shared NCTC skills and knowledge amongst our Department of Fish & Wildlife partners across the northeast.
- Assisted/assisting New Hampshire with the development of a Vulnerability Assessment. Served on the Alpine systems, Grassland/shrubland & Forest systems expert panels.

Future Plans and Timelines. Over the next three months our main goals will be to:

1. Apply the finalized model to at least another 3 terrestrial habitats in the Northeast to estimate their vulnerabilities and likely responses to a changing climate.

2. Finalize our approach to evaluating the vulnerabilities of coastal habitats

3. Begin work on evaluating the vulnerabilities of coastal habitat types.

4. Initiate work on vulnerability assessment and subsequent suite of adaptation strategies for Parker River National Wildlife Refuge as a case study for other NWRs and coastal WMAs across the northeast.

5. Work with NH Fish & Game to develop a coalition in support of state-based conservation funding that can inform efforts throughout the northeast.

6. Hold a webinar showcasing how the emerging Regional Vulnerability Assessment (RVA) can support each northeastern state's vulnerability assessment and, as applicable, adaptation strategy.

7. Brief NEAFWA technical committee chairs on the impact that the RVA will have on their subject matter of interest.

8. Advise NEAFWA on how the RVA can inform the RCN process.

Vulnerability Evaluation: Acadian-Appalachian Alpine Tundra

Vulnerability to Climate Change	**Highly Vulnerable (Zone I)**
Vulnerability to Non-climate Stressors	**Vulnerable (Zone I)**
Overall Future Vulnerability	**Highly Vulnerable (Zone I)**

Habitat Ecology and Distribution

Acadian-Appalachian Alpine Tundra (Figure 1) occurs above tree-line on the highest mountain ranges in the 4 northernmost states of the Northeast Region: The Katahdin Range in Maine, The White Mountains of New Hampshire, the northern Green Mountains in Vermont, and New York's Adirondack Mountains, with its greatest extents in Maine and New Hampshire (Figure 2, Table 1). It constitutes the highest elevation habitat type in the region, being limited to mountain tops and ridges generally above 4,000 feet above sea level (Thompson and Sorenson, 2000; Sperduto and Nichols, 2004; Jenkins, 2010; Barbour and Billings, 1988; Bliss, 1963). It occurs only about 800 feet below the highest elevation in Vermont, about 1,700 feet in New York and Maine, and 2,800 feet in New Hampshire. Therefore, it forms a relatively narrow band of habitat close to the summits of the highest hills in the region.

Figure 1. Acadian-Appalachian Alpine Tundra at about 5,500 feet above sea level on Mount Washington, New Hampshire.

Table 1. Extent of Acadian-Appalachian Alpine Tundra in Region.		
State	**Habitat acres in state**	**% of total habitat in Northeast**
Maine	3,624	44.3
New Hampshire	4,160	50.8
Vermont	115	1.4
New York	285	3.5

Comment [hg1]: Figure 2 will be a map of the distribution of this habitat type from the NEAFWA/TNC habitat map that is currently being finalized. Table 1 will be from the same database and will be the amount of representation (acres) in each of the states in which this habitat occurs.

At its low elevation limit it is bordered by the Krummholz zone of dwarf conifers and, lower still, transitions into Acadian-Appalachian Montane Spruce-Fir Forest (NETHCS, 2008). Floristically, Acadian-Appalachian Alpine Tundra in the Northeast is dominated by dwarf shrubs, graminoids and herbs, none of them reaching more than a few inches in height. These may include highly adapted species such as Bigelow's sedge, highland rush, and mountain sandwort in areas most exposed to the desiccating effects and mechanical damage caused by extreme winds, with the more moist and sheltered soils of snowpatch hollows supporting more lowland species including Canada mayflower, bunchberry and various mosses. The alpine tundra vegetation communities of the Northeast are similar in species composition and growth form, and are southern extensions of, the circumpolar arctic tundra of further north (Bliss, 1963), rather than having close affinities to the alpine communities of the Rocky Mountains.

The geographic distribution of this high elevation habitat is limited by a number of climatic factors. Short growing seasons, low ambient temperatures, intense solar radiation, high precipitation rates, and frequent high wind speeds characterize the climate of the tundra zone in the Northeast. On Mount Washington in New Hampshire, for example, the growing season extends over only four months (from mid-May until early September). The mean January temperature is 4.9 ºF, the mean July temperature is only 48.2 ºF, and average annual precipitation is 214 cm. (Bliss, 1963). The mean monthly wind speed is 35.9 miles/hour, with extreme gusts up to 230 miles/hour (http://www.mountwashington.org/weather/normals.php?MWOSID =22568f2786e8eefe3a1c24648fe46c62). Each month of the year is characterized by high relative humidity of 85-91% (Bliss, 1963).

On the most exposed ridges and summits tundra vegetative cover may be sparse as plants are damaged and killed by wind-driven ice and gravel particles. In such areas, vegetated patches may be separated by bare gravel and rocky patches. In the New York Adirondacks, the largest patches of tundra tend to be found on lee (more sheltered) hilltops and hillsides (Carlson et al., 2011). In the more sheltered snow hollows organic soils are deeper and moister and support a more luxuriant plant community.

Model Results

The results of the model run for Zone I (northern New York, Vermont, New Hampshire, and Maine) are shown in Table 3. Acadian-Appalachian Alpine Tundra does not occur in any of the other three zones.

Comment [hg2]: A map will be provided showing the boundaries of these zones).

Table 3. Vulnerability modeling results.

Zone	Vulnerability to Climate Change	Vulnerability to Non-climate Stressors	Overall Vulnerability	Certainty
Zone I	Highly Vulnerable	Vulnerable	Highly Vulnerable	High

These results indicate that alpine tundra is a particularly vulnerable habitat in the Northeast Region. Its vulnerability is due to several factors: (1) its ability to persist only in areas where harsh climatic conditions prevent colonization by forest; (2) the fact that in this region the habitat type is close to the southern boundary of its current range, where it is limited by climate. Future warming will likely contract this bioclimatic range further north and out of the Region; (3) the relative inability of this habitat type to migrate upslope - it already is limited to close to the summits of the highest mountains in the region; (4) the fact that it is highly fragmented with extensive low elevation areas separating the isolated mountaintop patches of this habitat. This limits its ability to migrate north in response to warming temperatures. The certainty levels for these predictions are High, since we generally know much about the distribution of this habitat type and its climatic-ecological relationships.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fate of the habitat type in the Northeast Region suggests that most, perhaps all, of the habitat type could be eradicated by future climate change. The current adiabatic lapse rate (the rate at which temperature changes with gain in elevation) in the Northeast is about 1°F for every 330 feet vertical gain (Richardson et al., 2004). Consequently, a rise in mean annual temperature of 1°F may be sufficient to elevate the bioclimatic zone in which this habitat exists by about 330 feet, exposing lower elevation tundra patches to colonization by Krummholz vegetation and spruce-fir forest. A 2.5^{o}F temperature rise could eliminate this habitat's bioclimatic zone in Vermont (since it would be shifted upward by more than 800 feet, which is above the level of the highest summit in the Green Mountains). A 5°F increase would eliminate it in New York and Maine, and plus 8.5^{o}F would eliminate it in New Hampshire (Table 4). The most recent and detailed modeling (Hayhoe et al., 2006) indicates that under the low emissions scenario (approximately a doubling of the atmospheric concentrations of greenhouse gases) the 2.5^{o}F and 5°F thresholds may be reached by about 2075. Thus, under a doubling scenario climatic conditions suitable for alpine tundra may be eliminated from all of the northeastern states except New Hampshire within the next 6-7

Comment [hg3]: Table 4 will show tundra habitat that remains in 4 states with 2,4,6, and 8 degrees rise

decades. Under a tripling scenario, the alpine tundra's climatic zone may be eliminated from the entire Northeast by the final few decades of this century.

These results indicate that it is possible that all tundra may be eliminated from the region by future climate change. At the least, they indicate a great reduction in the current extent of the habitat type, with it surviving, at best, only in highly fragmented small patches on the highest summits of the Presidential Range of New Hampshire.

It is possible that we may already be witnessing the first stages in an upward elevational shift in this habitat type in Vermont's Green Mountains, where Beckage et al. (2008) found that the Acadian-Appalachian Spruce-Fir forest has shifted upward by approximately 100m over the 40-year period beginning in 1964, and during which annual average temperatures had risen by about 1.7^{o}F. This could signal the encroachment of forested habitat into the high elevation alpine tundra zone.

Modeling Assumptions

Module 1. Location in geographical range of habitat. Given the high degree of precision and accuracy of the TNC/NEAFWA Northeastern Region Habitat Map, estimating the specific locations of habitats relative to their overall range boundaries is possible with a high degree of confidence. The database and map show that this habitat type is limited to Zone I, and its southern geographic limit is in the central and northern Green Mountains of Vermont and the Adirondack Mountains of New York. All tundra habitat patches in Zone I are within 200km, most within 100km, of this range boundary. Given these facts, we have assigned a score of 5 (most vulnerable) for Variable 1 in Module 1, with a certainty score of High.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Climate is the major limitation on the distribution of this habitat type in the Northeast. Specifically, it only occurs in areas that cannot be colonized by forests because the growing seasons are too brief, the mean annual and summertime temperatures are too low, wind speeds are generally high and often extreme, and extreme winter climatic events frequently occur (Gawler and Cutko, 2010; Sperduto and Nichols, 2004; Thompson and Sorenson, 2000; Bliss, 1963). Of all of the habitats in the Northeast, Acadian-Appalachian Alpine Tundra is adapted to the coldest and most extreme climatic conditions.

Currently, this habitat type may be locally sensitive to extreme climatic events – such as damage due to ice storms or blowdown, which may be ameliorated under a warming climate. However, it is also possible that the warming climate may be accompanied by longer, more frequent and severe droughts that could affect the critical water relations on which this mist-shrouded habitat depends. This could result in at least local habitat loss.

Based on these data and considerations, we have determined that this habitat type should score 5 for variables 2 and 3 (degree of cold adaptation and vulnerability to extreme weather events) of Module 1. Given our extensive knowledge of the relationship between

climate and distribution and ecology of this habitat type, we have also determined that our level of certainty for these scores should be High.

Module 1. Vulnerability to maladaptive human responses. Although much of this habitat type occurs at relatively inaccessible high elevations and more remotes areas, it does come under anthropogenic stresses. In areas like the Presidential Range of New Hampshire, the Adirondacks of New York and Vermont's Green Mountains, localized but severe mechanical damage is inflicted on tundra habitats by overuse by walkers. This pressure may be expected to increase in the future if higher ambient temperatures in the valleys encourage even more walkers and hikers to recreate in the high country. We have, accordingly, scored this variable 3 (Less Vulnerable) in Zone I, but have assigned a certainty score of only Medium to reflect the considerable uncertainties that beset projections of future human behavior.

Module 1. Location relative to highest elevation. We know that this habitat type occurs only on the highest mountains and at the upslope limit of the height of the land in Zone I. Therefore, there is only a very limited opportunity for upslope migration of this habitat type relative to the projected temperature and bioclimatic envelope shifts, especially in New York, Vermont, and Maine. We therefore assigned vulnerability scores for this variable of 5 for Zones I and II, respectively, with High certainties.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type is relatively low. This is largely because the current distribution of the habitat type is so tightly determined by a severe climate. Any climatic amelioration is likely to shift the competitive balance in favor of the Krummholz zone and spruce-fir forest. It is difficult to see how the tundra habitat could adapt to warmer conditions when it is being invaded by conifer forest. Accordingly, we have scored this variable as 5 (unlikely to be significant) with a certainty score of Medium (since our understanding of the true adaptive capacity of this habitat may well be incomplete.

Module 1. Dependence on specific hydrologic conditions. Since this is not a wetland or aquatic habitat, it is not dependent on specific hydrologic conditions. We have , accordingly, scored this variable as 1 (Less Dependent), with a certainty score of High.

Module 1. Vulnerability of Foundation/Keystone species to climate change. This habitat type is floristically complex and diverse and probably lacks single species that could be viewed as foundational or keystone. We have, accordingly scored its vulnerability as 1 (Foundation/Keystone species unlikely to be vulnerable), but have assigned a certainty score of only Medium, to reflect that we may not know as much about the keystone/foundational relationashipes within this community type as we would wish.

Module 1. Constraints on latitudinal range shifts. In Zone I, Acadian-Appalachian Alpine Tundra exists on isolated mountain tops that are widely separated by intervening and extensive tracts of lower-lying ground. It is inconceivable that this habitat will be able to

shift north into such expanses of unsuitable land. We have accordingly scored the vulnerability of this habitat type as Highly Constrained, with a certainty score of High.

Module 1. Likelihood of managing/alleviating climate change impacts. The ecological processes that govern the distribution of this habitat type are extremely slow, making the responsiveness to management actions extend far beyond normal policy and management timescales. Also, the severe weather conditions on the mountain tops on which this habitat exists, their remoteness, and the difficulties of access do not render them suitable targets for management activities, beyond limiting human access. Accordingly, we have scored the vulnerabilities to this variable as 5 (unlikely that management actions would be feasible) and assigned a certainty score of High.

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. Much of this habitat exists in protected and remote areas where current non-climate stressors are limited to recreational overuse by humans. It is feasible that this overuse could increase in response to a warming climate. Also, areas of tundra could come under threat from wind energy development along mountain ridges. However, it is also likely that, given the relatively inaccessible locations of this habitat and its severe weather conditions, such impacts would be local in extent, rather than widespread. Accordingly, we scored the potential for this as 1 (Low Potential) with a certainty score of only Medium, to reflect significant uncertainties.

Module 2. Current extent of habitat. Based on what we know about the distribution of this habitat type, it exists in more or less highly fragmented and usually small patches throughout Zone I. Accordingly we have scored this variable in Module 2 as 5 (Highly Limited in Distribution and Fragmented), with a certainty score of High .

Module 2. Current extent trend. Since this habitat type exists largely in the Northeast on remote, inaccessible, or protected land, current loss rates are minor. For this reason we have scored this variable as 1 (Stable or increasing), with a certainty score of High.

Module 2. Likely future extent trend. We consider it unlikely that the few and minimal stressors that currently affect this habitat type will increase in their effects markedly in the future and result in large habitat loss. Thus, we have conservatively assigned a vulnerability score of 2 (Some Losses) with a certainty score of Medium.

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being little affected by non-climate stressors. Much of the habitat is on remote or protected areas. However, some habitat loss/damage is being caused by recreational overuse. However, this is localized in extent and we have assigned a score for this variable of 1 (Least affected), with a certainty score of High.

Module 2. Likely future stressor trends. It is feasible that recreational overuse and wind energy development could increase in their effects on tundra habitat in the future. However, it is unlikely that these effects will be extensive. For this reason, we score this variable as 3 (Some Increase). With a certainty score of High.

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Vulnerability Evaluation: Acadian-Appalachian Montane Spruce-Fir Forest

Vulnerability to Climate Change	**Vulnerable (Zone I); Highly Vulnerable (Zone II)**
Vulnerability to Non-climate Stressors	**Vulnerable (Zone I); Highly Vulnerable (Zone II)**
Overall Future Vulnerability	**Vulnerable (Zone I); Critically Vulnerable (Zone II)**

Habitat Ecology and Distribution

Acadian-Appalachian Montane Spruce-Fir Forest (Figure 1) occurs in five of the 13 northeastern states: Maine, New Hampshire, Vermont, New York, and Massachusetts (Figure 2, Table 1), with its greatest extents in Maine, New Hampshire and New York (Table 1). It is generally limited to elevations above 2,500-3,000 feet (Table 2). Further south it is replaced by Central and Southern Appalachian Spruce-Fir Forest (NETHCS, 2008). At lower elevations (<2,500 feet) it transitions into northern hardwood forest, while at higher elevations (approximately above 3,500 feet) it may transition through a Krummholz zone into alpine grass and forb meadows. Floristically, it is typically dominated by red spruce and balsam fir, with a sparse understory of striped maple, mountain ash, and hobblebush. The ground layer is usually sparse and dominated by mosses, particularly sphagnum species, and lichens. It provides breeding habitat for a number of vertebrate species that are highly limited in their distributions in the Northeast, including Blackpoll, Cape May and Bay-breasted Warblers, and Bicknell's Thrush (currently petitioned for listing under the federal Endangered Species Act and listed as a Species of Special Concern in Maine, New Hampshire, Vermont, and New York).

Comment [hg1]: Figure 2 will be a map of the distribution of this habitat type from the NEAFWA/TNC habitat map that is currently being finalized. Table 1 will be from the same database and will be the amount of representation (acres) in each of the states in which this habitat occurs.

The geographic distribution of this cold-adapted habitat is limited by a number of climatic, edaphic and anthropogenic factors, including temperature - the spruce-fir/deciduous forest ecotone in the Northeast is correlated with a mean July temperature of approximately 17 °C, and treeline with a mean July temperature of approximately 13 °C. (Cogbill and White, 1991), cloud cover, wind, winter snowpack, storm damage, acidic soils, and disturbance history (Cogbill and White, 1991; Thompson and Sorenson, 2000; Jenkins, 2010). Climatic fluctuations over the last millennium have already resulted in marked range shifts in this habitat type as it shifted its range southwards during the summer cooling of the Little Ice Age (Figure 3). Current and future warming may throw this process into reverse.

Figure 1. Appalachian-Acadian Montane Spruce-Fir Forest at about 3,500 feet on Mount Mansfield, Vermont. The spruce-fir forest is the dark green band of trees immediately below the rocky summit ridge and above the light green northern hardwood forest. As in many such high elevation areas in the Northeast, this site and habitat type is fragmented by a downhill ski development.

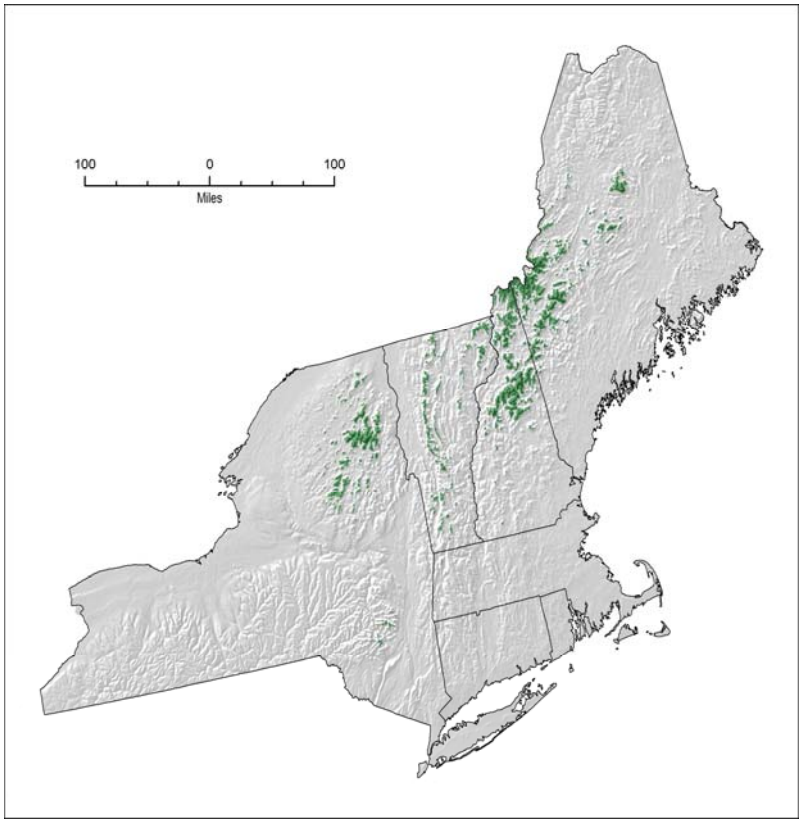

Figure 2. Distribution of Acadian-Appalachian Montane Spruce-Fir forest in Northeast Region (citation)

Figure 3. Southward shifts in distribution of spruce-fir forest in the Northeast from 1,000 and 500 years ago (left and middle) to the present day based on the pollen record (Jacobson et al. 2009).

Table 1. Extent of Acadian-Appalachian Montane Spruce-Fir forest in Region (citation).

State	Habitat acres in state	% of total habitat in Northeast
Maine	417,364	38.5
New Hampshire	351,295	32.4
Vermont	101,697	9.4
New York	213,413	19.7
Massachusetts	605	0.1

Table 2. Elevational ranges (feet above sea level) of Acadian-Appalachian Montane Spruce-Fir Forests in five northeastern states.

	Elevation Range (feet above sea level)	Reference
Maine	2,700-3,700	Gawler and Cutko, 2010
Northern Vermont	2,600-3,500	Thompson and Sorenson, 2000
Southern Vermont	2,800-3,500	Thompson and Sorenson, 2000
New Hampshire	2,500-4,000	Sperduto and Nichols, 2004.
Massachusetts	>3,000	MNHESP, 2010
New York	>3,000	Edinger et al., 2002

Model Results

The results of the model runs for Zones I (northern New York, Vermont, New Hampshire, and Maine) and II (Central Vermont and New Hampshire south to Massachusetts) are shown in Table 3.

Comment [hg2]: A map will be provided showing the boundaries of these zones).

Table 3. Vulnerability modeling results.

Zone	Vulnerability to Climate Change	Vulnerability to Non-climate Stressors	Overall Vulnerability	Certainty
Zone I	Vulnerable	Vulnerable	Vulnerable	High
Zone II	Highly Vulnerable	Highly Vulnerable	Critically Vulnerable	High

These results indicate that the vulnerability of this habitat type varies geographically in the Northeast, with higher risk from future climate change and non-climate stressors in the more southern patches (Zone II). The higher vulnerability in Zone II is due to several factors: (1) the fact that in this area the habitat type is in closer proximity to the southern boundary of its current range, where it is likely to be limited by climate. This assumes that the current southern distribution of this habitat is largely due to climate, rather than to land use. While this habitat was undoubtedly logged during the first half of the 20th Century it has been left comparatively undisturbed since then (Thompson and Sorenson, 2000) and most of the surviving patches are now in protected areas. Also, while acidic deposition may have locally affected the health of some forest patches, there is no evidence, thus far, of more widespread effects on distribution (Thompson and Sorenson, 2000); (2) the relative inability of this habitat type to migrate upslope (mountains are lower in elevation in Zone II); (3) the fact that large lower elevation areas separate the isolated mountaintop patches of this habitat in Zone II, limiting its ability to contract to the north; (4) its distribution is already highly limited and fragmented in Zone II. The certainty levels for these predictions are High, since we generally know much about the distribution of this habitat type and its climatic-ecological relationships.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fates of the habitat type in both zones suggests that most, perhaps all, of the habitat type in Zone II, could be eradicated by future climate change. In the more northern zone (Zone I), losses may still be widespread and severe, but the habitat may survive, particularly on the higher and northernmost mountains such as the higher Adirondacks, the White Mountains and the Katahdin Massif. Even in these areas, however, significant loss of habitat and its replacement by lower elevation habitat types may be expected. These projections assume, however, that atmospheric concentrations of greenhouse gases do not greatly exceed a doubling above pre-industrial levels. If the concentrations are closer to or exceed a tripling we could see much greater losses in Zone I.

Comment [hg3]: When the Northeastern habitat map is available it may be possible to map these refugia

These projections are similar to those proposed by Iverson et al. (2007) who modeled the complete or almost complete elimination of red spruce and balsam fir in the Northeast, except for in the northernmost mountains of ME, NH and VT and under the lowest estimate of future warming.

Modeling Assumptions

Module 1. Location in geographical range of habitat. Given the high degree of precision and accuracy of the TNC/NEAFWA Northeastern Region Habitat Map, estimating the specific locations of habitats relative to their overall range boundaries is possible with a high degree of confidence. The database and map show that the southern geographic limit for this habitat type is in the Berkshire Mountains in Massachusetts. All of the habitat patches in Zone II are, therefore, within 200km of this range boundary. In contrast, this habitat in Zone I is at greater distances than 200km from the southern habitat boundary.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Climate is the major limitation on the distribution of this habitat type in the Northeast. Specifically, it only occurs in areas where growing seasons are shortest, where mean annual and summertime temperatures are lowest, where extreme winter climatic events frequently occur, and where snowpack is deepest (Cogbill and White, 1991; Gawler and Cutko, 2010; Sperduto and Nichols, 2004; and Thompson and Sorenson, 2000). Of all of the forested habitats in the Northeast, Acadian-Appalachian Montane Spruce-Fir Forest is adapted to the coldest and most extreme climatic conditions.

With a moist elevation-temperature lapse rate of 1.0ºF for every 330 feet in the Northeast (Richardson et al., 2004), and the fact that all of this habitat in Zone II occurs within a few hundred to a thousand feet of the highest elevations (<4,000 feet), there is less potential for upward migration under a warming climate. It would require a mean annual temperature increase of only about 4-5ºF to entirely eliminate the climatic envelope in which most of this habitat exists in southern VT, NH, and Massachusetts. The most recent and detailed modeling (Hayhoe et al., 2006) indicates that under the low emissions scenario (approximately a doubling of the atmospheric concentrations of greenhouse gases) this threshold may be reached by about 2075. Under a tripling scenario, it will be reached and exceeded by 2050. This underlines the great vulnerability of this habitat type in Zone II. However, given that the mountains of Zone I are higher (>5,000 feet) and because the habitat type occurs at somewhat lower elevations, the same temperature trends may have less affect (though, the habitat is still relatively vulnerable).

Currently, this habitat type may be locally sensitive to extreme climatic events – such as damage due to ice storms or blowdown, which may be ameliorated under a warming climate. However, it is also possible that the warming climate may be accompanied by longer, more frequent and severe droughts that could affect the critical water relations on which this mist-shrouded habitat depends. This could result in at least local habitat loss.

Based on these data and considerations, we have determined that this habitat type should score high for variables 2 and 3 (degree of cold adaptation and vulnerability to extreme

weather events) for Zone II, but somewhat less highly for Zone I. Given our extensive knowledge of the relationship between climate and distribution and ecology of this habitat type, we have also determined that our level of certainty for these scores should be High.

It is possible that we may already be witnessing upward elevational shifts in this habitat type in Vermont's Green Mountains, where Beckage et al. (2008) found that the lower limit of this community type had shifted upward by approximately 100m over the 40-year period beginning in 1964, and during which annual average temperatures had risen by about 1.7^{o}F. Based on bioclimatic modeling, Prasad et al., (2007) found in the U.S. Forest Service Climate Change Tree Atlas project that the two dominant tree species in this habitat (Balsam Fir and Red Spruce) will be eliminated entirely from southern New England, except under the least sensitive GCM (PCM) and lowest IPCC emissions scenario (B1). Prasad *et al*. (2007) assign model reliability scores of High for both species.

Module 1. Vulnerability to maladaptive human responses. Much of this habitat type exists at present in protected areas (e.g., Green Mountain National Forest, White Mountains National Forest, Baxter State Park, Adirondacks State Park) and in areas that are too remote or high in elevation to be the focus of much anthropogenic exploitation. Therefore, we anticipate that human responses to climate change within this altitudinal zone will be relatively minor. It is possible that we will see, for example, current downhill ski areas diversifying their recreational options to include mountain biking and other activities as snow cover becomes less dependable, but these effects will likely be confined to already existing developments. Given that snowfall and snowpack are likely to decrease under a warming climate, it is also unlikely that new ski developments will be built. Indeed, it may be that existing sites may be forced by changing economics to close. We have, accordingly, scored this variable low (=1) in both zones. Nevertheless, it is possible that human recreational use of this habitat may increase as the temperatures rise. It is difficult to evaluate how likely this is. We have therefore assigned certainty scores of only Medium to these variables.

Module 1. Location relative to highest elevation. In Zones I and II we know that the upslope limit of this habitat type is determined by the height of the land. The highest elevation mountain where this habitat occurs in Massachusetts is only 3,491 feet; in Southern Vermont and New Hampshire it is about the same. Therefore Zone II provides little opportunity for upslope migration of this habitat type relative to the projected temperature and bioclimatic envelope shifts. With higher mountains, Zone I has greater potential for this. We therefore assigned vulnerability scores for this variable of 3 and 5 for Zones I and II, respectively with High certainties.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type is relatively low. This is largely because of two factors: (a) its regeneration time (the period between a major disturbance that results in habitat loss and recovery back to a mature stand) is long. Recovery times after fire in the Northeast can be as long as 200 years. This protracted recovery period makes the habitat vulnerable

to repeat disturbances. (b) Tree growth rates, reproductive potentials, and recruitment are all slow because of the ecological, biochemical and biophysical constraints imposed by short growing seasons and low temperatures. These limitations also may act to reduce adaptive capacity. Accordingly, we have scored this variable as 5 (unlikely to be significant) with a certainty score of Medium (since our understanding of the true adaptive capacity of this habitat may well be incomplete.

Module 1. Dependence on specific hydrologic conditions. Since this is not a wetland or aquatic habitat, it is not dependent on specific hydrologic conditions.

Module 1. Vulnerability of Foundation/Keystone species to climate change. The two main foundation species in this habitat are red spruce and balsam fir. These are both trees that are highly adapted to short growing seasons and extreme weather conditions. Prasad et al. (2007) has shown that they are likely to be highly vulnerable to a warming climate in the Northeast. We have, accordingly scored their vulnerability as High, with a certainty score of Medium (to reflect the fact that we may not know as much about the ability of these species to survive warming as we would wish).

Module 1. Constraints on latitudinal range shifts. In Zone II, Acadian-Appalachian Montane Spruce-Fir Forest exists on isolated mountain tops that are widely separated by intervening and extensive tracts of lower-lying ground. For example, the northernmost patch of habitat in Massachusetts at Mount Greylock is separated from the next patch to the north in the Green Mountains of Vermont by approximately 70 miles of lower-lying ground. It is highly unlikely that this habitat will be able to shift north into such expanses of unsuitable land. In Zone I the patches of this habitat are larger, more contiguous and extend to somewhat lower elevations, especially in the higher mountain ranges of the White Mountains (New Hampshire), the Adirondacks (New York), and Katahdin (Maine). In these areas there may be less of a constraint on northward latitudinal shifts as the forest may be able to colonize sites that are currently Krummholz or tundra. We have accordingly scored the vulnerability of this habitat type as Highly Constrained in Zone II and Somewhat Constrained in Zone I, with certainty scores of Medium to reflect the conjectural nature of these scores.

Module 1. Likelihood of managing/alleviating climate change impacts. We have scored this variable as Not Feasible for both zones. This reflects the fact that the ecological processes that govern the distribution of this habitat type are extremely slow, making the responsiveness to management actions extend far beyond normal policy and management timescales. Also, the severe weather conditions on the mountain tops on which this habitat exists, their remoteness, and the difficulties of access do not render them suitable targets for management activities. Accordingly, we have scored the vulnerabilities to this variable in both zones as High (unlikely that management actions would be feasible), with certainty scores of medium (since predicting human actions in response to the changing climate is fraught with uncertainties).

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. While most of this habitat exists in protected areas where stressors such as habitat

destruction and logging are minimal, and few other stressors are currently impacting this habitat type, it is possible that stressors such as invasive pests (mountain pine beetle, for example) could spread into the Northeast and adversely affect the habitat. Also, fire is currently not an important stressor in this habitat. However, with longer, more frequent and more severe droughts accompanying climate change, it may become much more important. Accordingly, we scored the potential for this as High, although we have assigned a certainty score of only Medium, to reflect significant uncertainties.

Module 2. Current extent of habitat. Based on what we know about the distribution of this habitat type, it exists in more or less highly fragmented and usually small patches throughout the Northeast (though less so in the more northern mountain areas). Accordingly we have scored this variable in Module 2 as Highly Limited in Distribution and Fragmented, with a certainty score of High for Zone II, and scores of Less Limited Distribution and Somewhat Less Fragmented and High for Zone I.

Module 2. Current extent trend. Since this habitat type exists largely in the Northeast on protected land, current loss rates are minor. For this reason we have scored this variable as More Limited Losses, with certainty scores of High in both zones.

Module 2. Likely future extent trend. We consider it unlikely that the few and minimal stressors that currently affect this habitat type will increase in their effects much in the future. However, one major uncertainty in this is the future of windpower development in the Northeast. These are often sited on exposed and high elevation summits and ridges – typical locations for Acadian-Appalachian Montane Spruce-Fir Forest. If windpower continues to increase in its importance in the future, we could imagine habitat losses due to the construction of the infrastructure associated with some developments. Also, an increased frequency of wild fires could also result in future losses. We have conservatively assigned vulnerability scores of Some Losses with certainty scores of Medium for both zones.

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being little affected by non-climate stressors. Much of the habitat is on protected areas and previous major stressors- for example downhill ski developments, are no longer increasing. Windpower developments have fragmented some of this habitat type in Zone I, but at present this is limited in extent.

Module 2. Likely future stressor trends. It is feasible that pest species and wild fires could increase in their impacts in the future under a changing climate. For this reason, we score this variable as Some Increase. Our certainty score is only Low to reflect the hugh degree of uncertainty that surrounds this prediction.

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Vulnerability Evaluation: Central Mixed Oak-Pine Forests

Vulnerability to Climate Change	**Least Vulnerable (Zones I, II, III); Vulnerable (Zone IV)**
Vulnerability to Non-climate Stressors	**Less Vulnerable (Zones I and II); Vulnerable (Zones III and IV)**
Overall Future Vulnerability	**Least Vulnerable (Zones I, II); Less Vulnerable (Zone III); Vulnerable (Zone IV)**

Habitat Ecology and Distribution

Central Mixed Oak-Pine Forest comprises a mosaic of variants, depending on soil, climate, slope, and land use history. The canopy is typically dominated by either, red, white or black oaks, with pine species codominating in the northern part of the range or on drier, rockier soils (Figure 1). Other widespread canopy species include hickories, tuliptree, ashes, and, previously, American chestnut. The variability in this forest type is reflected in the Northeastern Habitat Classification (NETHCS, 2008) which identifies three main matrix or large patch community types: Northeastern Interior Dry Mesic Oak Forest (matrix), Central Appalachian Dry Oak-Pine Forest (matrix) and Central Appalachian Pine-Oak Rocky Woodland (large patch). Although there are other variants, these three cover most of the northeastern “oak-hickory” or “mixed deciduous” forests.

In comparison with northern hardwood forests, central mixed oak-pine forests are typical of warmer climatic conditions and a longer growing season. They also generally occur further south and on sunnier, warmer aspects. Generally lower in elevation than northern hardwoods, this habitat type can occur from close to sea level up to about 3,000 feet in the southern states and a few hundred feet at the more northern limits of its distribution (Collins and Anderson, 1994; Fike, 1999; Thompson and Sorenson, 2000; Edinger et al., 2002; Harrison, 2004; Sperduto and Nichols, 2004; Gawler and Cutko, 2010; MNHESP, 2010; VANHP, 2011). Above these elevations and at more northern latitudes, the mixed oak- pine forests transition into northern hardwoods, with the oaks and hickories characteristic of the former being replaced with maple, beech, white pine, etc. In the southeastern states this matrix habitat type is replaced by matrix forests dominated by conifers, primarily loblolly and shortleaf pine.

Figure 1. Central Mixed Oak-Pine Forest on well-drained south-facing slope in southern New Hampshire. Canopy dominated by red oak, red maple and shagbark hickory.

This habitat type occurs mainly in the southern and central states of the Northeast Region (Figure 2), but also extends up into the southern parts of Vermont, New Hampshire and Maine. Its greatest extents are in Virginia, West Virginia and Pennsylvania (Table 1)

Table 1. Extent of Central Mixed Oak-Pine Forest in Region.

State	Habitat acres in state	% of total habitat in Northeast
Maine	4,783	<0.1
New Hampshire	15,153	0.1
Vermont	25,055	0.1
New York	2,128,254	8.9
Massachusetts	291,155	1.2
Connecticut	993,362	4.2
Rhode Island	180,463	0.8
Pennsylvania	7,761,385	32.6
Maryland	819,272	3.4
District of Columbia	1,552	<0.1
Delaware	8,394	<0.1
New Jersey	582,997	2.4
Virginia	5,036,716	21.2
West Virginia	5,948,013	25.0

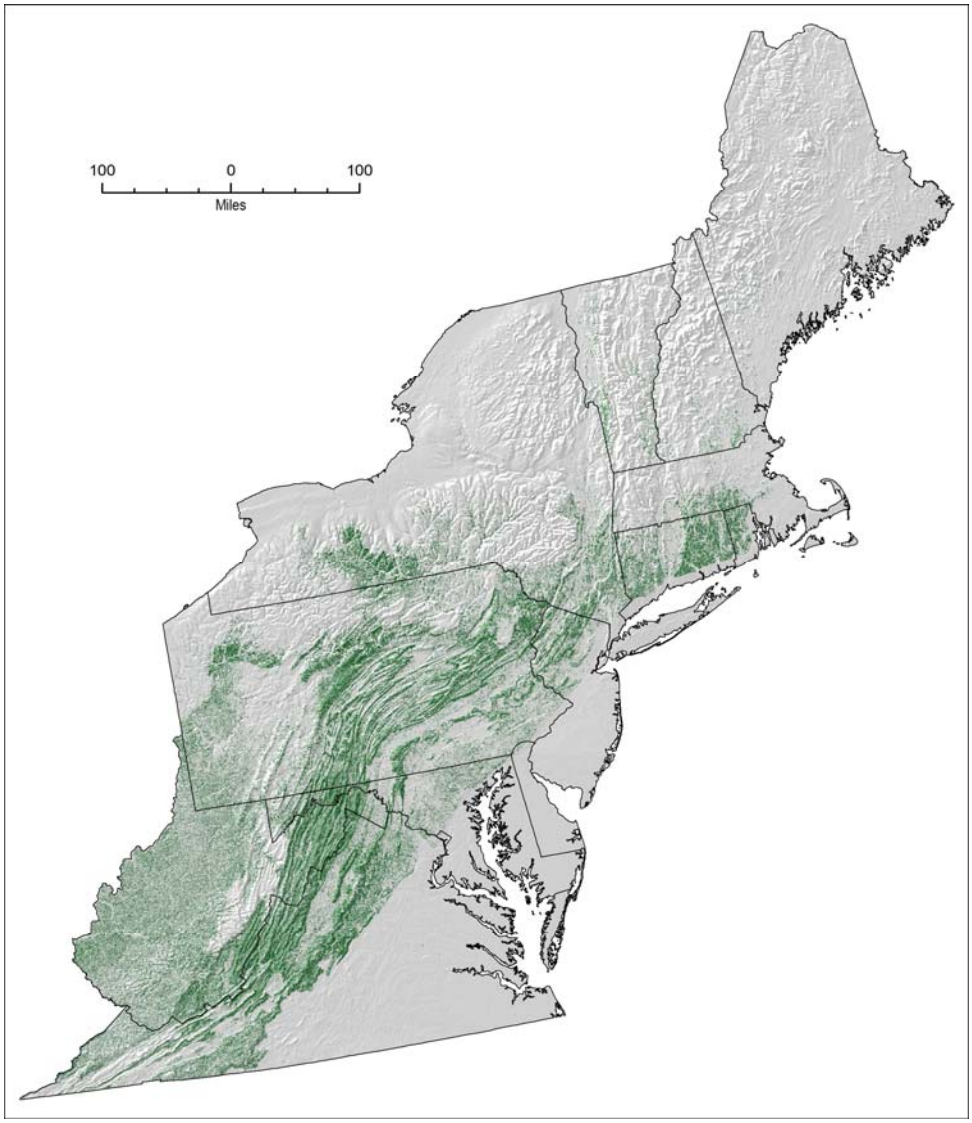

Figure 2. Distribution of Central Mixed Oak-Pine forests in the Northeast Region (citation)

The climatic regime within which this forest type exists is primarily temperate, with relatively long growing seasons (>200 days), mean July temperatures ranging from 21 to 27°C, and mean January temperatures of about 0°C (Greller, 1988). Precipitation across the range of this forest type ranges between 80 and 120 cm/year (Greller, 1988). The northern range limit of this forest is correlated with decreasing summer warmth, while the southern limit is correlated with high summer temperatures (28°C) and infrequent frosts

(Greller, 1998). Thus, the distribution of Central Mixed Oak-Pine Forest is partly a function of a mild, temperate climate, though modified extensively by land use (see below).

In the past, the distribution of this forest type was greatly affected by logging and agriculture (Sutton and Sutton, 1985), making its pre-colonial distribution difficult to discern. Currently, the main stressors on this forest type include habitat loss and fragmentation through residential and commercial development, overgrazing by browsers (particularly white-tailed deer), and forest pests, such as gypsy moths (which have now spread south from their point of introduction in Massachusetts to inhabit the entire Northeast). Fire in central mixed oak-pine forests is relatively rare due to fire suppression; however, given that oak species can sprout and regrow after burning, the habitat is not as intolerant of fire as northern hardwood forests. In at least the more northern states in the region, fire may play a role in maintaining this habitat type by preventing the establishment of the more fire-sensitive trees characteristic of the northern hardwood forests (Gawler and Cutko, 2010; Thompson and Sorenson, 2000; Sperduto and Nichols, 2004).

Model Results

The results of the model runs for Zones I, II, III, and IV are shown in Table 2.

Comment [hg1]: A map will be provided showing the boundaries of these zones).

Table 2. Central Mixed Oak-Pine Forest vulnerability modeling results.

Zone	**Vulnerability to Climate Change**	**Vulnerability to Non-climate Stressors**	**Overall Vulnerability**	**Certainty**
Zone I	Least Vulnerable	Less Vulnerable	Least Vulnerable	High
Zone II	Least Vulnerable	Less Vulnerable	Least Vulnerable	High
Zone III	Least Vulnerable	Vulnerable	Less Vulnerable	High
Zone IV	Vulnerable	Vulnerable	Vulnerable	High

These results indicate that the vulnerability of this habitat type varies geographically in the Northeast, with lowest vulnerabilities from future climate change and non-climate stressors in the three more northern zones (Zones I, II, III), and the habitat being most at risk in the southernmost zone (IV). The lower vulnerabilities in Zones I and II are due to two main factors: (1) this is primarily a southern habitat type that extends far south of the current distribution in these zones and into areas where the climate is warmer and closer to that expected under climate change. Thus, climate change is likely to result in an extension of suitable growing conditions in these two northern zones; (2) there is much room for expansion into areas currently occupied by a more climate-vulnerable hardwood forest type, northern hardwoods. The certainty levels for these predictions are High, since we generally know much about the distribution of this habitat type and its climatic-ecological relationships.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fates of the habitat type across all zones suggests that under a doubling of the atmospheric concentrations of greenhouse gases this habitat type will greatly extend its range throughout the northern and central states in the region. However, in the more southern states (mainly Virginia and West Virginia) it may be replaced in at least some areas (though probably not on higher ground) by more heat-tolerant conifer forests dominated by loblolly and shortleaf pines. These projections assume that atmospheric concentrations of greenhouse gases do not greatly exceed a doubling above pre-industrial levels. If the concentrations are closer to or exceed a tripling we could see much greater losses in all zones.

These projections are similar to those arrived at in the U.S. Forest Service modeling study of forest types under a changing climate (Prasad, et al. 2007-ongoing).Under a doubling of atmospheric greenhouse gases, this study modeled an extension of the three dominant oak species (red, white and black) northward into areas in Maine, New Hampshire, Vermont, New York, and Massachusetts that are currently occupied by northern hardwood species. They also project, under a doubling of greenhouse gases, that the range of this habitat type would contract northward in low-lying areas of Virginia, and be replaced by conifer-dominated forest.

Modeling Assumptions

Module 1. Location in geographical range of habitat. For Zones I, II, and III we scored this habitat type as 1 (further than 200km of its southern range boundary). Given the high degree of precision and accuracy of the TNC/NEAFWA Northeastern Region Habitat Map, estimating the specific locations of habitats relative to their overall range boundaries is possible with a high degree of confidence. This database and map (and the maps in Prasad et al., 1988-ongoing) show that within the Northeast Region, Central Mixed Oak-Pine Forest is mainly southern in its distribution, extending from Virginia and West Virginia north to central New England and New York State. South of Virginia and West Virginia, the Central Mixed Oak-Pine Forest biome is replaced by conifer-dominated forests. North of central New England and New York State, it transitions into northern hardwood forests. All of this habitat type in Zones I, II, and III is, therefore, well beyond 200km of its southern range boundary. In contrast, this habitat in Zone IV is within 200km of its southern range boundary.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* This is mainly a southern and central forest type that is characteristic of more temperate areas than northern hardwoods and montane spruce-fir forests. It is likely that the dominant trees are at least partly adapted to warmer growing conditions than more northern forest types, and are more tolerant of the types of extreme events that may occur in southern and central areas of the Northeast under climate change (mainly droughts). Accordingly, we have scored it as 1 (important constituent species tolerant of warmer temperatures) for degree of cold adaptation in all four zones. We have scored this habitat type as 3 (less

vulnerable to extreme climatic events) in all four zones for sensitivity to extreme climatic events (while its vulnerability to ice storms, extreme snow fall, etc. may decrease under a changing climate, it will still be exposed to windstorms and drought).

Given our extensive knowledge of the relationship between climate and distribution and ecology of this habitat type, we have also determined that our level of certainty for these scores should be High.

Module 1. Vulnerability to maladaptive human responses. We have scored this variable as 3 (Less Vulnerable) for all four zones. Though it is unlikely that this habitat type is neither highly vulnerable nor not vulnerable to maladaptive human responses to climate change, it will likely have some vulnerability. Increasing temperatures and drought could increase the fire risk in this habitat, which could result in conversion to conifer-dominated forest in more frequently burnt areas in the southern zones. Also, as the temperature warms, the higher elevation areas that are currently under this forest type may become more attractive for human settlement, resulting in increased fragmentation. This again could increase the risk of human-caused fires.

Given that human responses are probably even more difficult to predict accurately than ecological responses, we have assigned certainty scores of only Medium to this variable for all zones.

Module 1. Location relative to highest elevation. In all four Zones Central Mixed Oak-Pine Forest is a low to mid elevation community type and it has, therefore, a high potential for upslope migration under a warming climate. We have, accordingly score this variable as 1 (low elevation habitat that should be able to migrate upslope) for all four zones. We have assigned certainty scores of High to all of these vulnerability rankings since we know much about the topography of the region and the relationship between elevation and habitat range.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type should score 1 (intrinsic adaptive capacity is high) for all four zones. This is because the habitat type exists in large patches with relatively low levels of fragmentation and with a relatively high degree of contiguity across topographically diverse landscapes. Also, for much of its range, it is tolerant of the higher temperatures and precipitation that is projected under a changing climate. We have assigned certainty scores of Medium for all four zones, since our understanding of the true adaptive capacity of this habitat may well be incomplete.

Module 1. Dependence on specific hydrologic conditions. Since this is not a wetland or aquatic habitat, it is not dependent on specific hydrologic conditions.

Module 1. Vulnerability of Foundation/Keystone species to climate change. Central Mixed Oak-Pine Forest is a community dominated by foundational tree species that are tolerant of the types of climatic changes that are projected for the future (warmer temperatures, longer growing seasons, higher precipitation, etc.). Thus, it is likely that

climate change will result throughout much of the central and northern northeastern states in an improvement of growing conditions for this habitat. Accordingly we have scored this variable as 1 for all zones, with a certainty score of High.

Module 1. Constraints on latitudinal range shifts. Throughout the four zones, the central mixed oak-pine forests have small, if any, regional constraints of their ability to shift northward. This would require them to invade and replace existing forest habitats, mainly northern hardwoods – which is likely to occur under climate change. There may be local constraints on these latitudinal shifts, for example, urban areas, waterbodies, but these are unlikely to be significant at a regional scale. We have, therefore, assigned a score of 1 (low level of constraint) to this variable, with a certainty score of High.

Module 1. Likelihood of managing/alleviating climate change impacts. Central mixed oak-pine forests have been the focus of intensive human management since the European colonization. Managing such forests for specific ends (timber, recreation, hunting, etc.) is well-understood. This experience provides great potential for managing them for resilience to the changing climate. We have scored this variable as 1 (management feasible) in all four Zones, with certainty scores of medium (since predicting human actions in response to the changing climate is fraught with uncertainties).

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. It is possible that climate change could exacerbate the effects of non-climate stressors that already impact this habitat type. For example, the ranges of pests and invasive species that are currently limited by temperature (kudzu, gypsy moth or other invertebrate pests, for example) could extend further and adversely affect the habitat. Also, browsing on oak seedlings by white-tailed deer is a major stressor on this forest type in some areas where deer densities are close to or above carrying capacity. Deer overwinter survival is a function of temperature and snowpack. If survival is improved by increasing winter temperatures and contracting snowpack, it could have adverse effects on the recruitment and regeneration of oak seedlings. Accordingly we scored the potential for this as High (5), although we have assigned a certainty score of only Medium, to reflect significant uncertainties.

Module 2. Current extent of habitat. Based on what we know about the distribution of this habitat type, we assigned a score of 3 (less limited in distribution and level of fragmentation) for all four zones. We assigned certainty scores of High to all these scores since much is known and mapped about the distribution of the habitat throughout the Northeast.

Module 2. Current extent trend. Much of the losses that are occurring to this habitat across the Northeast are likely to be local in scale and due to (e.g.) relatively small-scale residential and commercial developments. Large-scale losses (as were experienced during the conversion to farmland no longer occur. Indeed, much farmland in the more northern states has been rapidly reverting back to oak-hickory forests). Accordingly, we have assigned to this variable a score of 3 (Limited Losses) for all four zones. We assigned

certainty scores of High to all these scores since much is known and mapped about the distribution of the habitat throughout the Northeast.

Module 2. Likely future extent trend. We consider it unlikely that the stressors that currently affect this habitat type will greatly increase in their effects in the future. It is unlikely, however, that such increases would be major, given that this habitat type is currently effectively managed against these stressors. We have, therefore assigned a score of 3 (some losses) for all four zones, with certainty scores of Medium.

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being affected by a number of non-climate stressors, including habitat destruction and fragmentation, overgrazing by ungulates, particularly white-tailed deer, and invasion by pest species and non-native plants. However, these effects are generally local in nature, not widespread across the region, and while some of them may affect the composition and structure of the communities, they do not usually result in large-scale community loss. For these reasons we have scored this variable as 3 (Less Affected) with a certainty score of Medium (to reflect the fact that there is some uncertainty about the magnitude of losses due to these stressors).

Module 2. Likely future stressor trends. It is likely that the changing climate may act to exacerbate the effects of current non-climate stressors. For example, warmer winters are likely to increase the overwinter survival and densities of deer (with increased grazing or browsing effects). Similarly, increased drought frequency may result in a more frequent and intense fires, and the warmer winters will be likely to result in further spread in temperature-limited pests and non-native plants. We consider that these stressor increases are likely to be most marked in the southern zones, but less so in the north where the forest type will be extending its range and the ambient temperatures not so high. Accordingly, we have scored this variable as 1 (little or no increase) for Zones I and II, and as 3 (some increase) for Zones III and IV.

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Vulnerability Evaluation: Northern Hardwood Forests

Vulnerability to Climate Change	**Less Vulnerable (Zone I); Vulnerable (Zones II and III); Highly Vulnerable (Zone IV)**
Vulnerability to Non-climate Stressors	**Less Vulnerable (Zone I); Vulnerable (Zones II, III), Highly Vulnerable (Zone IV)**
Overall Future Vulnerability	**Less Vulnerable (Zone I); Vulnerable (Zones II and III); Critically Vulnerable (Zone IV)**

Habitat Ecology and Distribution

Northern Hardwood Forest (Figure 1) is a widespread matrix community that occurs in various forms across most of the northeastern region from Maine south to Pennsylvania and northern New Jersey, and to Virginia and West Virginia (Figure 2). It reaches its southernmost limit in North Carolina (Sutton and Sutton, 1985, Prasad et al. 2007-ongoing), where it meets the conifer forest matrices of the more southern states.

Figure 1. Northern Hardwood Forest at about 500 feet above sea level in southern Vermont. Major tree species on this west-facing slope are red maple, black birch, beech, and white pine. A recent lightning-caused fire scar is visible in the upper left.

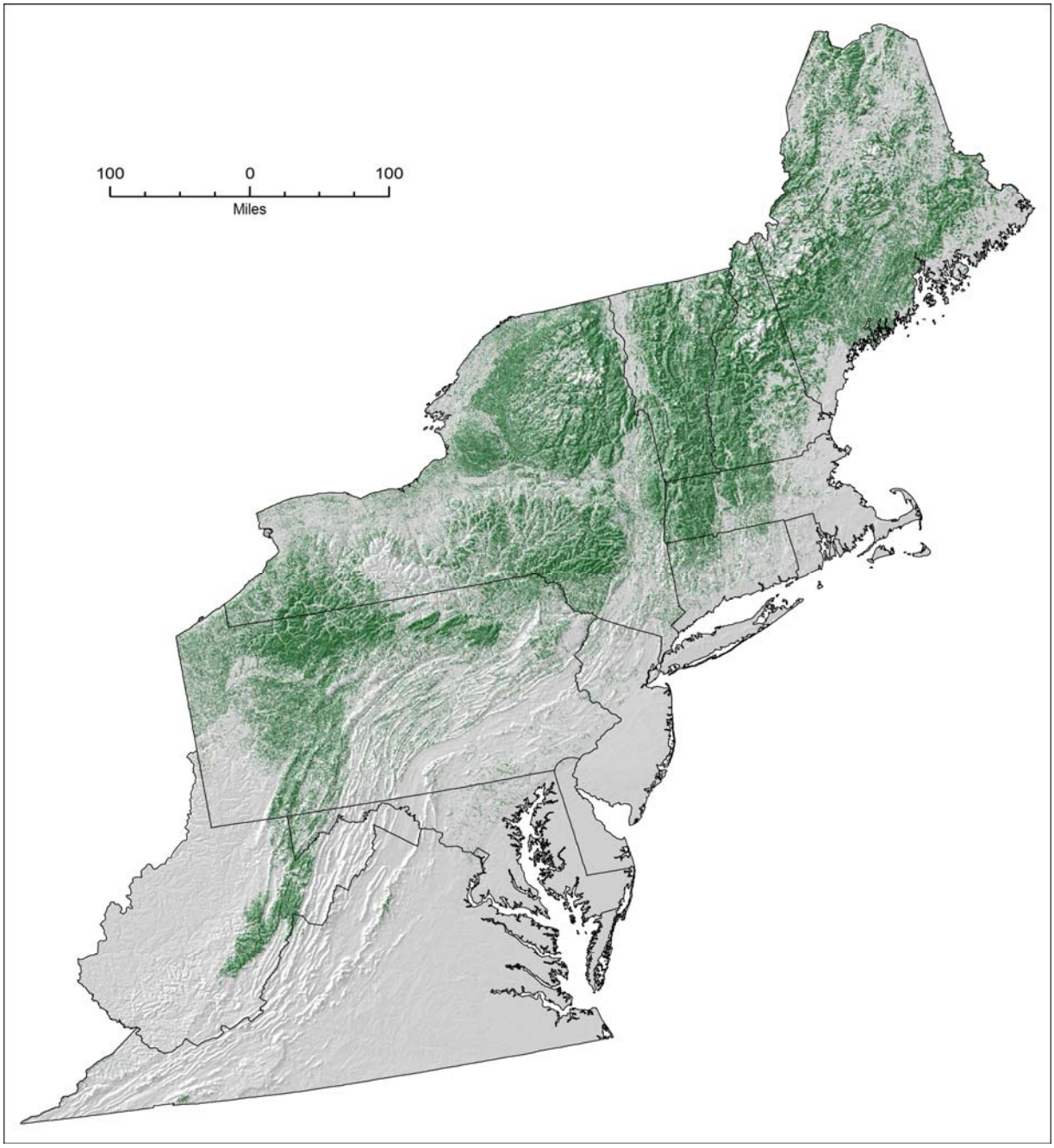

Figure 2. Current distribution of Northern Hardwood Forest in the Northeast. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

The three states with the greatest extents of Northern Hardwood Forest are, in descending order of importance, New York, Pennsylvania, and Maine. Together, these hold over 60% of the total area of this habitat type in the Northeast (Table 1). Other states with large extents include New Hampshire, Vermont, and West Virginia.

Table 1. Extent of Northern Hardwood Forest in Region.		
State	**Habitat acres in state**	**% of total habitat in Northeast**
Maine	8,396,387	20.5
New Hampshire	3,307,458	8.1
Vermont	3,886,727	9.5
New York	13,207,973	32.2
Massachusetts	1,616,631	3.9
Connecticut	589,515	1.4
Rhode Island	11,956	<0.1
Pennsylvania	8,331,053	20.3
New Jersey	127,473	0.3
Maryland	283,669	0.7
Virginia	157,029	0.4
West Virginia	1,130,329	2.8
Delaware	3,630	<0.1
District of Columbia	1,289	<0.1

The composition of this forest type varies with elevation and latitude (Sutton and Sutton, 1985). In the northern states (ME, NH, VT, NY, and MA), the canopy is usually dominated by beech, yellow birch, eastern hemlock, or white pine and is designated Laurentian-Acadian Northern Hardwood Forest or Laurentian-Acadian Pine-Hemlock Forest (NETHCS, 2008). Further south, it typically has greater cover of more southern tree species, such as red oak or tuliptree, and is designated Appalachian Northern Hardwood Forest (NETHCS, 2008). This forest type can occur in the more northern states from near sea level to about 2,500 feet. Above this height, it may transition to Acadian-Appalachian Montane Spruce-Fir Forest. In more southern states it occurs mainly at higher elevations. In Virginia, it typically occurs only at elevations above 3,000 feet (VANHP, 2011). At low elevations it may transition into lowland forest communities such as Southern and Central Oak-Pine Forests.

The shrub layer of Northern Hardwood Forest may be dominated by striped maple, hobblebush, and beech, sugar maple and yellow birch saplings. The herbaceous layer may contain a variety of species, including Canada mayflower and shining clubmoss. Northern hardwood forests provide habitat for many of the wildlife species that are thought of as characterizing the northeastern forest biota, including many warblers, tanagers, up to five species of thrushes, up to six species of woodpeckers, flying squirrels, fishers, black bears, and moose (Sutton and Sutton, 1985).

The geographic distribution and composition of this forest type is influenced by a number of climatic, edaphic and anthropogenic factors, including temperature (the upper elevational limit of the northeastern northern hardwood forest is correlated with a mean July temperature of approximately 17 °C), growing season length (<150 days with temperatures below freezing), wind damage, winter snowpack, and disturbance history

(Cogbill and White, 1991; Collins and Anderson, 1994; Fike, 1999; Thompson and Sorenson, 2000; Edinger et al., 2002; Harrison, 2004; Sperduto and Nichols, 2004; Jenkins, 2010; Gawler and Cutko, 2010; MNHESP, 2010; VANHP, 2011).

A number of stressors have affected the distribution and condition of northern hardwood forests in the Northeast over the last three centuries. Logging and conversion to agriculture have been major stressors. Vermont and New Hampshire, for example, were, prior to European colonization, extensively covered in this forest type (then including American chestnut). Logging and conversion reduced this cover from about 80% to 20% between 1800 and the late 19th century. However, as agricultural use diminished thereafter, a rapid recovery back to 80% cover took place, demonstrating the resilience and potential for rapid recovery of this habitat type.

Currently, the main stressors on this forest type include habitat loss and fragmentation for residential and commercial development, overgrazing by browsers (particularly white-tailed deer), and forest pests (including gypsy moth, hemlock wooly adelgid, and beech scale disease). In areas closer to human habitation or powerline cuts, non-native plant species, including Japanese barberry, Japanese knotweed, glossy buckthorn, etc. can form dense growths in the herbaceous layer. Fire in northern hardwood forests is relatively rare due to the low inherent flammability of the forest, and the prevailing wet or damp conditions. Consequently, the community type is not fire-adapted, especially in the more northern states where fire sensitive trees such as eastern hemlock, beech and sugar maple may dominate.

Model Results

The results of the model runs for Zones I, II, III, and IV (Figure 3) are shown in Table 2.

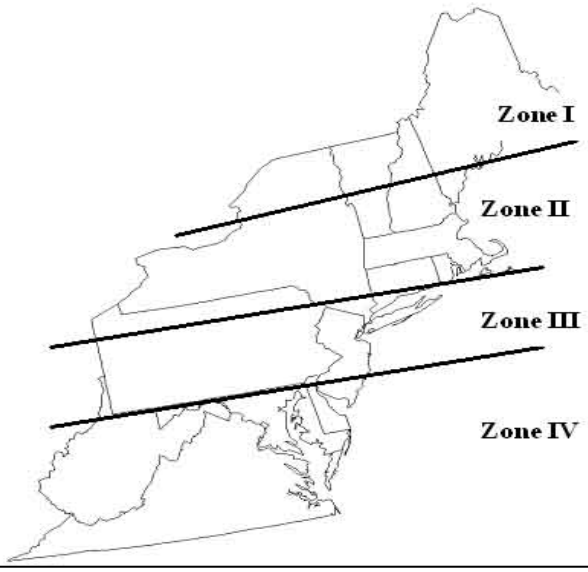

Figure 3. The four latitudinal zones used in the analyses.

Table 2. Northern Hardwood Forest vulnerability modeling results.				
Zone	**Vulnerability to Climate Change**	**Vulnerability to Non-climate Stressors**	**Overall Vulnerability**	**Certainty**
Zone I	Less Vulnerable	Less Vulnerable	Less Vulnerable	High
Zone II	Vulnerable	Vulnerable	Vulnerable	High
Zone III	Vulnerable	Vulnerable	Vulnerable	High
Zone IV	Highly Vulnerable	Highly Vulnerable	Critically Vulnerable	High

These results indicate that the vulnerability of this habitat type varies geographically in the Northeast, with higher risks from future climate change and non-climate stressors in the more southern zones (Zones II and II, and, particularly, Zone IV). The higher vulnerabilities in these Zones are due to several factors: (1) the fact that in this area the habitat type is in closer proximity to the southern boundary of its current range, where it may be limited by climate. This assumes that the current southern distribution of this habitat is at least partly due to climate, rather than entirely to land use; (2) the relative inability of this habitat type to migrate upslope (mountains are lower in elevation in Zones II and III, and the habitat type occurs close to the highest elevations in Zone IV); (3) the fact that extensive lower elevation areas separate the isolated mountaintop patches of this habitat in Zones III and IV, limiting its ability to contract to the north. The certainty levels for these predictions are High, since we generally know much about the distribution of this habitat type and its climatic-ecological relationships.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fates of the habitat type across all zones suggests that under a doubling of the atmospheric concentrations of greenhouse gases most of the habitat type in Zone I could survive. Indeed, new areas of habitat might be created as northern hardwood forests move upslope to replace the more vulnerable Acadian-Appalachian Montane Spruce-Fir forests. In Zones II and III habitat losses might be more widespread, but substantial areas of Northern Hardwood forests are likely to survive at higher elevations or north-facing colder slopes. In Zone IV, the losses are likely to be even more severe with most or perhaps all of the habitat type being replaced by more warmth-tolerant communities dominated by oaks and hickories. These projections assume, however, that atmospheric concentrations of greenhouse gases do not greatly exceed a doubling above pre-industrial levels. If the concentrations are closer to or exceed a tripling we could see much greater losses in all zones.

The above projections are similar to those arrived at in the U.S. Forest Service modeling study of forest types under a changing climate (Prasad, et al. 2007-ongoing). This found that under a doubling of greenhouse gases the range of this habitat type in the Northeast would contract northward out of Virginia and much of West Virginia and become limited to the more northern states, particularly New York, Vermont, New Hampshire, and

Maine. Under a tripling of greenhouse gases, Prasad et al. (2007-ongoing) project that this habitat type may become limited to our Zone I.

Large-scale range contractions are not the only effect that climate change may have on this habitat type. Some of the tree species that characterize the community in many areas may be particularly sensitive to increasing warmth – more so than others. Eastern hemlock and sugar maple are examples. It is likely that these vulnerable species may be lost across the range of the habitat, leaving a less diverse habitat type (though still recognizable as Northern Hardwood Forest) in place.

Modeling Assumptions

Module 1. Location in geographical range of habitat. Given the high degree of precision and accuracy of the TNC/NEAFWA Northeastern Region Habitat Map, estimating the specific locations of habitats relative to their overall range boundaries is possible with a high degree of confidence. The database and map show that the southern geographic limit for this habitat type is in the higher elevations areas of Virginia and West Virginia. Sutton and Sutton (1985) and Prasad et al. (2007-ongoing) extend this range into North Carolina). All of this habitat type in Zone IV is, therefore well within 200km of habitat's southern range boundary. In contrast, this habitat in Zones III, II, and I is at increasingly greater distances than 200km from the southern habitat boundary.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.*
It is likely that climate is an important limitation on the distribution of this habitat type in the Northeast. Specifically, it typically occurs in mid-high elevation areas or in more northern latitudes where growing seasons are relatively short, where mean annual and summertime temperatures are low, where winters are relatively severe, and where snowpack is deep. (Gawler and Cutko, 2010; Sperduto and Nichols, 2004; and Thompson and Sorenson, 2000). Of all of the forested habitats in the Northeast, Northern Hardwood Forest is second only to Montane Spruce-Fir Forest in its adaptation to cold, extreme climatic conditions.

With an elevation-temperature lapse rate of 1.0ºF for every 330 feet in the Northeast (Richardson et al., 2004), and the fact that all of this habitat in Zone IV occurs within a few hundred to a thousand feet of the highest elevations (<4,000 feet), there is less potential for upward migration under a warming climate. It would require a mean annual temperature increase of only about 3-4ºF to entirely eliminate the climatic envelope in which most of this habitat exists in West Virginia and Virginia. Also, much of this climatic envelope may be eliminated in Pennsylvania, New Jersey, and southern New York. The most recent and detailed modeling (Hayhoe et al., 2006) indicates that under the low emissions scenario (approximately a doubling of the atmospheric concentrations of greenhouse gases) this threshold may be reached by about 2050. Under a tripling scenario, it may be reached and exceeded a decade earlier. This underlines the vulnerability of this habitat type in Zone IV. However, given that the habitat type occurs at somewhat lower elevations, in larger and more contiguous patches, and has more

potential to migrate upslope in Zones I, II, and III, the same temperature trends may have less affect (though, the habitat is still relatively vulnerable).

It is possible that we may already be witnessing upward elevational shifts in this habitat type in Vermont's Green Mountains, where Beckage et al. (2008) found that the upper limit of this community type had shifted upward by approximately 100m over the 40-year period beginning in 1964, and during which annual average temperatures had risen by about 1.7^{o}F.

Currently, this habitat type may be locally sensitive to extreme climatic events – such as damage due to ice storms or blowdown, which may be ameliorated under a warming climate. However, it is also possible that the warming climate may be accompanied by longer, more frequent and severe droughts that could affect the critical water relations on which this mist-shrouded habitat depends. This could result in at least local habitat loss.

Based on these data and considerations, we have determined that this habitat type should score 3 for variables 2 and 3 (degree of cold adaptation and vulnerability to extreme weather events) for all four Zones. This is intended to reflect that this habitat is limited to cool (rather than cold environments) across its range and that while it may be vulnerable to extreme weather events, such events are less frequent in the lower elevation areas occupied by Northern Hardwood Forests. Given our extensive knowledge of the relationship between climate and distribution and ecology of this habitat type, we have also determined that our level of certainty for these scores should be High.

Module 1. Vulnerability to maladaptive human responses. For Zones I, II and III. We have scored this variable as 3 (Less Vulnerable). This is intended to reflect the assumption that because much of the habitat is at higher elevations and in areas less valued by humans for residential and commercial use, human responses to climate and ecological change may be relatively limited. For Zone IV we have scored this variable as 1, reflecting the fact that in this zone the habitat type occurs mainly in the more remote areas where human use is even more limited. Given that human responses are probably even more difficult to predict accurately than ecological responses, we have assigned certainty scores of only Medium to this variable for all zones.

Module 1. Location relative to highest elevation. In all four Zones it is known that the upslope limit of this habitat type is determined by elevation. In Zones I and II where the elevation range exceeds 4,000 feet, there is potential for this habitat type to migrate upslope to replace the more climate-sensitive Montane Spruce-Fir forests and we have assigned a vulnerability score of 1 to reflect this. In Zones III and IV we have assigned vulnerability scores of 3 and 5, respectively, to reflect the fact that in these more southern areas where the habitat naturally occurs at higher elevations (particularly Zone IV) there is less potential for this upslope migration. We have assigned certainty scores of High to all of these vulnerability rankings since we know much about the topography of the region and the relationship between elevation and habitat range.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type decreases from north to south, from Zone I to Zone IV. We assume this because the habitat type becomes much less widespread, more patchy, and more confined to isolated small patches at high elevations from north to south. This allows the habitat less opportunity to expand and contract across the landscape in the southern zones. Accordingly, we have scored this variable as 5 (unlikely to be significant) for the two southernmost zones (III and IV), but as I (likely to be significant) for the two northernmost zones (I and II), with certainty scores of Medium (since our understanding of the true adaptive capacity of this habitat may well be incomplete).

Module 1. Dependence on specific hydrologic conditions. Since this is not a wetland or aquatic habitat, it is not dependent on specific hydrologic conditions.

Module 1. Vulnerability of Foundation/Keystone species to climate change. Northern Hardwood Forest is a relatively diverse community with the canopy dominated by a varied range of tree species depending on climate, land-use, elevation, aspect, etc. Unlike Montane Spruce-Fir Forest, its biomass is not dominated by one or two Foundation species and the potential for climate change to exert a disproportionate effect across the range of the habitat through its impacts on such a species is more limited. Thus, we have scored this variable as 1 for all zones, with a certainty score of Medium. Nevertheless, it is likely that at the scale of smaller patches climate change could exert an effect through one or two dominant species. For example, eastern hemlock is usually confined to shaded cooler areas within the northern hardwood complex and in such areas it can dominate the canopy. It is likely that in such areas climate change could eliminate hemlock cover. This does not automatically mean that the matrix habitat type will be eliminated, as other species in the northern hardwoods may simply colonize the area being vacated by the hemlocks.

Module 1. Constraints on latitudinal range shifts. In Zone IV, Northern Hardwood Forest exists as isolated patches at higher elevations, widely separated by intervening and extensive tracts of lower-lying ground. Further north the patches of this habitat are larger, more contiguous and extend to lower elevations. In these areas there may be less of a constraint on northward latitudinal shifts as the forest may be able to migrate north (and upslope) to colonize sites that are currently spruce-fir forest. We have accordingly scored the vulnerability of this habitat type as Highly Constrained in Zone IV, Somewhat Constrained in Zones III and II, and a low level of constraint in Zone I. We have assigned certainty scores of Medium to reflect the somewhat conjectural nature of these scores.

Module 1. Likelihood of managing/alleviating climate change impacts. Northern hardwood forests have been the focus of intensive human management since the European colonization. Managing such forests for specific ends (timber, recreation, hunting, etc.) is well-understood. This experience provides great potential for managing them for resilience to the changing climate. We have scored this variable as 1 (management feasible) in Zones I, II, and III. However, for Zone IV we have scored it as Not Feasible. This is intended to reflect the fact that in this zone, northern hardwood forests are less accessible to management activities, given their locations at high

elevations and in more remote areas, with certainty scores of medium (since predicting human actions in response to the changing climate is fraught with uncertainties).

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. It is possible that climate change could exacerbate the effects of non-climate stressors that already impact this habitat type. For example, the ranges of pest species that are currently limited by temperature (e.g., hemlock wooly adelgid) could extend further north and upslope and adversely affect the habitat. Also, fire is currently not an important stressor in this habitat. However, with longer, more frequent and more severe droughts accompanying climate change, it may become much more important. Accordingly, we scored the potential for this as High, although we have assigned a certainty score of only Medium, to reflect significant uncertainties.

Module 2. Current extent of habitat. Based on what we know about the distribution of this habitat type, the following scores were assigned to this variable: for Zone I we assigned a score of 1 (widespread and contiguous distribution with only limited fragmentation); for Zones II and III we assigned a score of 3 (somewhat limited in distribution and with a higher degree of fragmentation); for Zone IV we assigned a score of 5 (Highly limited in distribution and highly fragmented). We assigned certainty scores of High to all these scores since much is known and mapped about the distribution of the habitat throughout the Northeast.

Module 2. Current extent trend. Much of the losses that are occurring to this habitat across the Northeast are likely to be local in scale and due to (e.g.) relatively small-scale residential and commercial developments. Large-scale losses (as were experienced during the conversion to farmland no longer occur. Indeed, much farmland in the more northern states has been rapidly reverting back to northern hardwood forests). Accordingly, we have assigned to this variable a score of 3 (Limited Losses) for Zones II, III, and IV and a score of 1 (Stable or Increasing) for Zone I. We assigned certainty scores of High to all these scores since much is known and mapped about the distribution of the habitat throughout the Northeast.

Module 2. Likely future extent trend. We consider it likely that the stressors that currently affect this habitat type will increase in their effects in the future (see below). These increases are likely to result in some habitat loss (particularly in the central and southern states where the stressors are already exerting effects). It is unlikely, however, that such losses would be major, given that this habitat type is currently effectively managed against these stressors. We have, therefore assigned a score of 3 (some losses) for Zones II, III, and IV. For Zone I we have assumed that the trends that are currently been seen (stable forests and some reforestation) will continue and we have assigned a score of 1 to this zone.

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being affected by a number of non-climate stressors, including invertebrate pest outbreaks, fire, invasive plant species, habitat destruction and fragmentation, and overgrazing by ungulates, particularly white-tailed deer. However, these effects are

generally local in nature, not widespread across the region, and while some of them may affect the composition and structure of the communities, they do not usually result in large-scale community loss. For these reasons we have scored this variable as 3 (Less Affected) with a certainty score of Medium (to reflect the fact that there is some uncertainty about the magnitude of losses due to these stressors).

Module 2. Likely future stressor trends. It is likely that the changing climate may act to exacerbate the effects of current non-climate stressors. For example, warmer winters are likely to increase the overwinter survival and densities of deer (with increased grazing or browsing effects). Similarly, the warmer winters will be likely to result in further spread in temperature-limited pests such as hemlock wooly adelgid. Also, while fire is not a great problem currently in the northern hardwoods, it is possible that the drying out and more frequent and intense droughts predicted by the climate models could result in a greater frequency, scale, and intensity of wildfire. Since northern hardwood forests are not adapted to fire, and are sensitive to it, this could result in increased damage to the habitat type (with, potentially, its replacement by more fire-tolerant grasslands, shrublands, or weed-dominated woodlands. For these reasons, we score this variable as 3 (Some Increase in effects over the next few decades. We assign a certainty score of only Medium to this because, the actual magnitudes of these exacerbations (particularly of fire) could be greater than we currently anticipate.

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Vulnerability Evaluation: Pitch Pine Barrens

Vulnerability to Climate Change	**Least Vulnerable (Zones II, III, and IV)**
Vulnerability to Non-climate Stressors	**Vulnerable (Zones II, III, and IV)**
Overall Future Vulnerability	**Less Vulnerable (Zones II, III, and IV)**

Habitat Ecology and Distribution

Northeastern pitch pine barrens comprise two more or less distinct plant communities: Northern Atlantic Coastal Plain Pitch Pine Barrens; and Northeastern Interior Pine Barrens (NETHCS, 2008). Both community types are similar in that they occur mainly on gravelly or sandy, xeric, nutrient-poor soils, with canopies that are dominated by pitch pine (red oak, white pine, and gray birch are common associates in the canopy of interior pine barrens), with scrub oak, highbush and lowbush blueberry and huckleberry dominating the shrub layer (Figure 1).

Figure 1. New Jersey Coastal Plain Pitch Pine Barren. Pitch pine dominates the canopy, while pitch pine and scrub oak saplings are predominant in the shrub layer.

Pitch pine barrens occur in 8 of the 13 northeastern states with the greatest extents in New Jersey, Massachusetts, and New York (Figure 2 and Table 1). Coastal plain pitch pine barrens are well represented as a large patch community in southern Maine, Massachusetts, and New Jersey, with the most extensive example being the New Jersey Pine Barrens. Interior pitch pine barrens occur mainly as isolated communities on glacial outwash plains in New England and New York (NETHCS, 2008), and as isolated and small patches on low elevation rocky summits in Vermont (Thompson and Sorenson, 2000) and New Hampshire (Sperduto and Nichols, 2004). Pitch pine barrens reach their southernmost distributional limits in the southern states of the Northeast Region, being replaced on xeric soils further south by longleaf and shortleaf pine-dominated communities (Barbour and Billings, 1988).

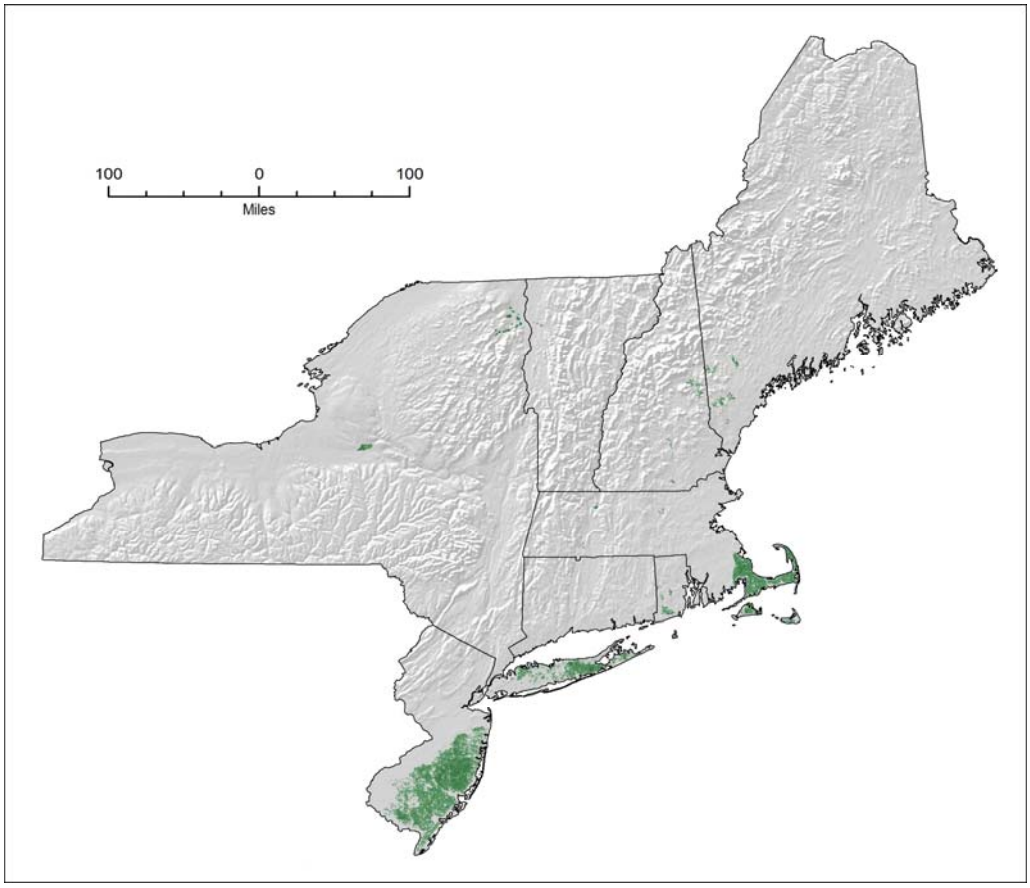

Figure 2. Distribution of pitch pine barrens in the 13 northeastern states (TNC/NEAFWA habitat database and map).

Table 1. Extent of Pitch Pine Barrens in Region.		
State	**Habitat acres in state**	**% of total habitat in Northeast**
Maine	9,155	1.7
New Hampshire	5718	1.1
Vermont	534	0.1
New York	82,929	15.5
Massachusetts	103,336	19.3
Connecticut	146	<0.1
Rhode Island	6,011	1.1
New Jersey	326,476	61.1

Both community types are maintained by fire, with oaks outcompeting pitch pine in the canopy in areas with longer fire return intervals. Fire suppression can lead to the pitch pine-dominated community being replaced by a canopy dominated by white pines, hemlocks, red and black oaks, with red maples in wetter areas. This has already occurred in Vermont where little of the pitch pine-dominated original community survives (Thompson and Sorenson, 2000), Maine (Gawler and Cutko, 2010), New Hampshire (Sperduto and Nichols, 2004), and Massachusetts (MNHESP, 2010). Controlled burning and clear cutting (which also favors the regeneration of pitch pines over deciduous trees) are now being used to manage and maintain this habitat in many northeastern states.

Previously, pitch pine forests were cut extensively for fuel and building materials, particularly in New Jersey (Collins and Anderson, 1994). This probably helped maintain dominance by pitch pines. Currently, any such exploitation of this habitat is small scale.

Model Results

This habitat type does not occur in Zone I. The results of the model runs for Zone II (Central New York, Central Vermont and New Hampshire, Southern Maine south to Massachusetts, Connecticut and Rhode Island), Zone III (Pennsylvania, New Jersey, southern New York), and Zone IV (Virginia, West Virginia, Maryland, Delaware, and Washington DC) are shown in Table 2.

Comment [hg1]: A map will be provided showing the boundaries of these zones).

Table 2. Vulnerability modeling results.				
Zone	**Vulnerability to Climate Change**	**Vulnerability to Non-climate Stressors**	**Overall Vulnerability**	**Certainty**
Zone II	Least Vulnerable	Vulnerable	Less Vulnerable	High
Zone III	Least Vulnerable	Vulnerable	Less Vulnerable	High
Zone IV	Least Vulnerable	Vulnerable	Less Vulnerable	High

These results indicate that the vulnerability of this habitat type to climate change is both low and relatively constant across the Northeast. The low vulnerability of this habitat is due to a number of its characteristics: first, it is largely a "southern" and low elevation habitat type, flourishing in areas where temperatures are generally high, winters are mild and short, and growing seasons are long – the climatic characteristics that the changing climate is likely to spread northwards in the Northeast. Second, this habitat is not particularly vulnerable to the drought conditions that might prevail in the Northeast under a changing climate. Indeed, it is a xeric habitat and flourishes in areas where such conditions already prevail. Lastly, the types of stochastic events that might characterize the changed climatic conditions, particularly an increased frequency and intensity of wildfires, may actually benefit this habitat type by encouraging the regeneration and growth of pitch pine. Thus, climate change could benefit Pine Barrens in the Northeast.

The vulnerability of this habitat to non-climate stressors is higher than its vulnerability to climate change stresses. This habitat is already being impacted in many areas by loss and fragmentation due to commercial/residential development, and fire suppression. These stressors may continue to increase in their effects in the future. If human communities react to climate change by vigorously suppressing fires, pitch pine barrens might in some areas (particularly those closer to human habitat where fires might be most suppressed) see an increasing dominance by oaks and a diminished presence of pitch pines.

Overall, we have scored this habitat as being Less Vulnerable. This reflects the continuing and future risks posed by non-climate stressors and the potential benefits that might be introduced by climate change.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fate of the habitat type in all four zones suggests that Zone I, the northernmost zone in which pine barrens do not currently exist, might be colonized as climatic conditions become more suitable for them. However, such colonization may be limited since soil type and drainage ultimately limit the distribution of this habitat. In Zones II, III, and IV, where Pine Barrens currently exist, it is unlikely that we will see major changes in distribution and extent. Again, surface geology and soil type limit the spread of this habitat type and, while the changing climatic conditions may benefit the habitat, it is unlikely that this will be expressed in a major extension into new areas, though local extensions might occur. These projections are similar to those proposed by Prasad et al. (2007) whose modeling projects little change in the distribution of pitch pine-dominated forest under high and low emissions scenarios and using a range of climate models.

Modeling Assumptions

Module 1. Location in geographical range of habitat. Given the high degree of precision and accuracy of the TNC/NEAFWA Northeastern Region Habitat Map, estimating the specific locations of habitats relative to their overall range boundaries is possible with a high degree of confidence. The database and map show that the southern geographic limit

for this habitat type is in Zone IV. All habitat patches in this southernmost zone are within 200kms of the habitat range boundary. In contrast, in Zones III and II this habitat is at greater distances than 200km from the southern habitat boundary.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Pine Barrens are not a cold-adapted habitat nor dominated by plant species that can tolerate particularly cold conditions. In fact, it is a southern habitat type that occurs in warmer climates with temperate or mild winter conditions and long, dry summers (such as are found in its main strongholds in New Jersey and southeastern Massachusetts). It is also not likely to be vulnerable to the types of extreme events that climate change might make more frequent, particularly drought. Indeed the habitat type is already characteristic of drought prone areas and its affinity for xeric, highly drained soils preadapts it to the types of changes that climate change might introduce.,

Based on these data and considerations, we have determined that this habitat type should score low (a score of 1) for variables 2 and 3 (degree of cold adaptation and vulnerability to extreme weather events) for Zones IV, III, and II. Given our extensive knowledge of the relationship between climate and distribution and ecology of this habitat type, we have also determined that our level of certainty for these scores should be High.

Module 1. Vulnerability to maladaptive human responses. Fire suppression is currently the major anthropogenic stressor on this community type – leading to replacement of a pine-dominated by an oak-dominated canopy. It is possible that this stressor could become even more severe and widespread as climate change-induced droughts result in a higher risk of wildfires. This might not pose a threat to the habitat type, but societies might respond to this elevated risk by increased fire suppression efforts (particularly in areas with higher residential densities). Alternatively, it could result in communities becoming less willing to tolerate controlled burns (which could spark wildfires). Both of these effects could result in the replacement of pitch pine dominated woodland being replaced with a scrub oak dominated habitat. We have, accordingly, scored this variable medium (=3) in all three zones to reflect the risk that local adverse impact could occur to this habitat type. It is possible that we overestimate or underestimate the risk that fire suppression poses to this habitat (predicting societal responses to the changing climate are fraught with uncertainty). We have therefore assigned certainty scores of only Medium to these variables.

Module 1. Location relative to highest elevation. Pine Barrens are a low elevation habitat. And have the ability to move upslope in response to a changing climate (if the xeric, gravelly or sandy soils are available). We therefore assigned a vulnerability score of 1 (should be able to move upslope) for this variable in all three zones (II, III, and IV), and High certainty scores.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type should score 1 (intrinsic adaptive capacity is high) for all three zones. This is because the habitat type exists in large patches with relatively low levels of fragmentation and with a relatively high degree of contiguity across

topographically diverse landscapes. Also, for much of its range, it is tolerant of the higher temperatures projected under a changing climate. We have assigned certainty scores of Medium for all three zones, since our understanding of the true adaptive capacity of this habitat may well be incomplete.

Module 1. Dependence on specific hydrologic conditions. Since this is not a wetland or aquatic habitat, it is not dependent on specific hydrologic conditions.

Module 1. Vulnerability of Foundation/Keystone species to climate change. The foundation species in this habitat is pitch pine. This tree is already adapted to the sorts of climatic conditions that might be intensified or made more widespread by climate change. Also, pitch pines depend on fire to maintain their dominance in the canopy, which may benefit them under longer, drier, and hotter summers. We have, accordingly scored the vulnerability as 1 (unlikely to be vulnerable), with a certainty score of Medium (to reflect the fact that we may not know as much about the ability of this species to survive warming as we would wish).

Module 1. Constraints on latitudinal range shifts. The current distribution of this habitat type is constrained by climatic conditions (dry, warmer summers and milder winters) and by soil type (adapted to xeric, gravelly or sandy soils). With climate change, the climatic conditions that favor Pine Barrens may spread further north or more inland in the Northeast Region. However, the availability of the Pine Barrens to exploit this and extend their range may be constrained by the distribution of suitable soil types. If the soils occurring in areas where the climate is becoming more suitable for Pine Barrens are not xeric, gravelly, or sandy, the habitat type is not likely to be able to extend. Thus, surface geology is likely to be an important limitation on how readily this habitat is able to colonize new areas under climate change. We have accordingly scored the vulnerability of this habitat type as 3 (somewhat constrained), with certainty scores of Medium to reflect the conjectural nature of these scores.

Module 1. Likelihood of managing/alleviating climate change impacts. Pine Barrens have been the focus of intensive human management since the European colonization. Managing such forests for specific ends (timber, recreation, hunting, etc.) is well-understood. This experience provides great potential for managing them for resilience to the changing climate. We have scored this variable as 1 (management feasible) in all three Zones, with certainty scores of High.

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. Much of this habitat exists in protected areas where stressors such as habitat destruction and logging are minimal, and few other stressors are currently impacting this habitat type. It is possible that stressors such as invasive pests could spread into the Northeast and adversely affect the habitat. However, we judge this potential to be low. Accordingly, we scored the potential for this as 1 (low potential), although we have assigned a certainty score of only Medium, to reflect significant uncertainties about future colonization by invasives.

Module 2. Current extent of habitat. This is a large patch habitat that occurs in large, relatively unfragmented blocks across its range. Accordingly we have scored this variable in Module 2 as Widespread and contiguous, with certainty scores of High for all three Zones.

Module 2. Current extent trend. The losses to this habitat type that are occurring across the Northeast are local in scale and due to relatively small-scale residential and commercial developments. In the Massachusetts coastal plain, for example, residential development and fire suppression is resulting in the fragmentation of this habitat type and its replacement by an oak-dominated community. Accordingly, we have assigned to this variable a score of 3 (Limited Losses) for all three zones. We assigned certainty scores of High to all these scores since much is known and mapped about the distribution of the habitat throughout the Northeast.

Module 2. Likely future extent trend. While it is likely that the types of effects detailed in *Current extent trend* above may continue to occur in the future, we consider it unlikely that this will result in a marked acceleration in the future trend. Indeed, since much of the land that can be developed has already been so, and since much or the large patches of this habitat type occur on protected land, the trend may decrease. We have conservatively assigned vulnerability scores of 3 (Some Losses) with certainty scores of Medium for all three zones.

Module 2. Current impacts of non-climate change stressors. While this habitat is being affected by at least one non-climate stressor (fire suppression), its effects are local in scale. Indeed, controlled burning and clear cutting are reversing the effects of fire suppression in some areas. Accordingly, we have scored this variable in Module 2 as 3 (Less affected) for all three zones, with certainty scores of Medium.

Module 2. Likely future stressor trends. It is feasible that residential/commercial development and fire suppression could increase in their impacts in the future. For this reason, we score this variable as 3 (Some Increase) for all three zones. Our certainty score is Medium to reflect the degree of uncertainty that surrounds this prediction.

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Vulnerability Evaluation: Northern Atlantic Coastal Plain Basin Peat Swamp

Vulnerability to Climate Change	**Less Vulnerable (Zones II, III, and IV)**
Vulnerability to Non-climate Stressors	**Less Vulnerable (Zones II, III, and IV)**
Overall Future Vulnerability	**Less Vulnerable (Zones II, III, and IV)**

Habitat Ecology and Distribution

Atlantic white cedar-dominated swamps (Figure 1) occur in most of the U.S. Atlantic coastal states from Maine south to South Carolina, and in the Gulf of Mexico in Florida, Mississippi and Louisiana (Figure 2. Prasad et al. 2007; Barbour and Billings, 1988). Throughout this extensive range they are floristically quite similar, with the main differences between the northern and southern extremes being that in the northern and Mid-Atlantic States Atlantic white cedar dominates the canopy, while in the Gulf of Mexico other species may share co-dominance (Barbour and Billings, 1988). In the Northeast Region, where it is classified as Northern Atlantic Coastal Plain Basin Peat Swamp (NETHCS, 2008), this wetland type occurs in 8 of the 13 states (Figure 3 and Table 1) in Zones II, III, and IV. New Jersey supports the majority of this habitat type at almost 60%, with Massachusetts supporting a further 20%.

Figure 1. Atlantic white cedar swamp in New Jersey showing sparse shrub layer and hummock-hollow growth of sphagnum spp.

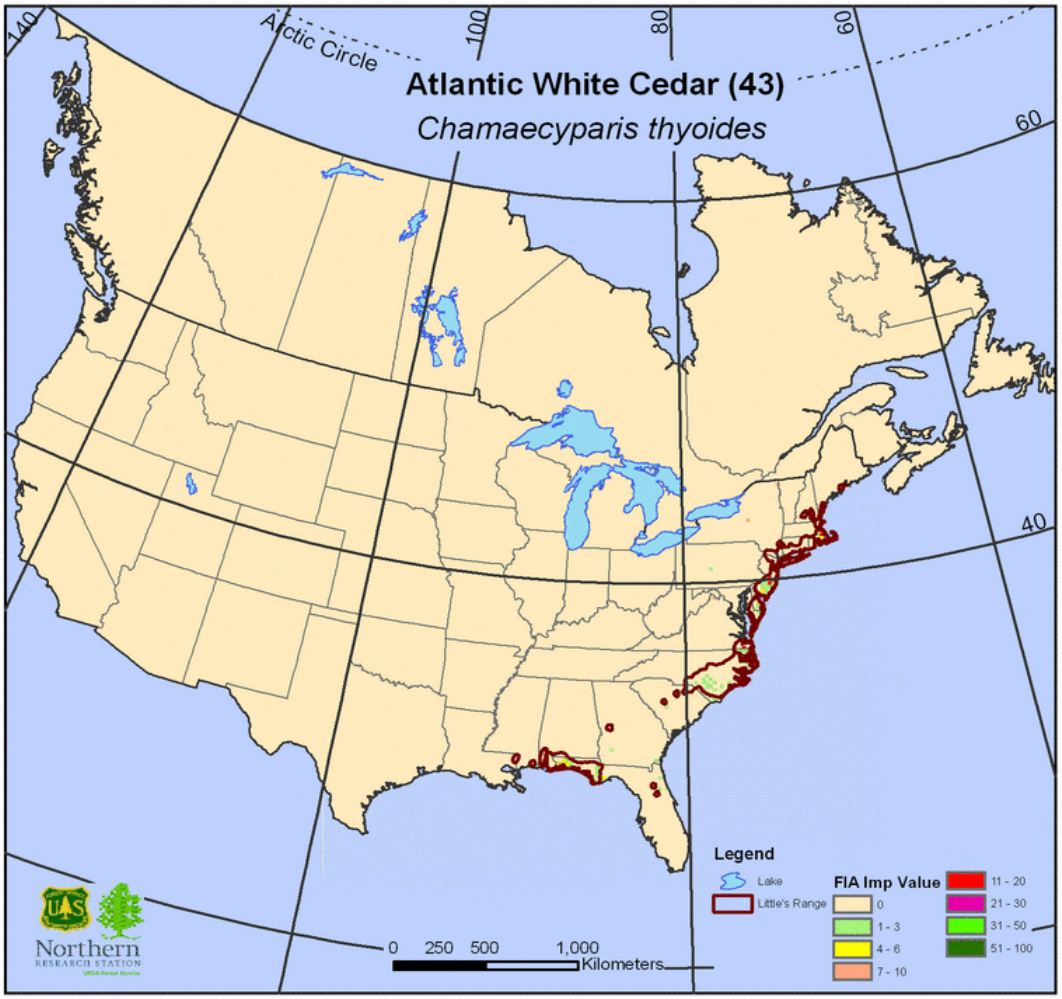
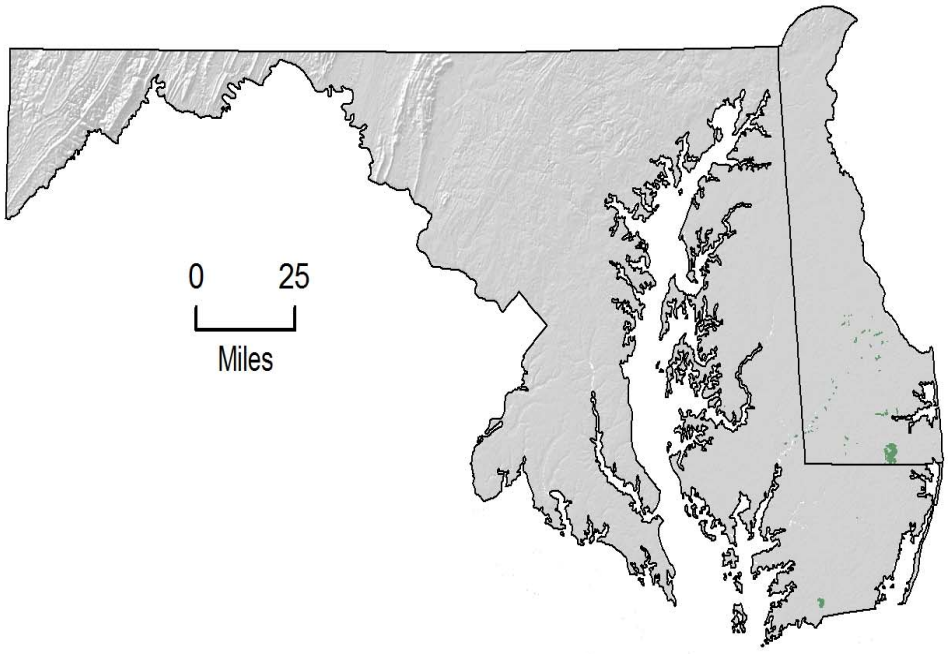


Figure 2. Distribution of Atlantic white cedar swamp in North America (Prasad et al. 2007).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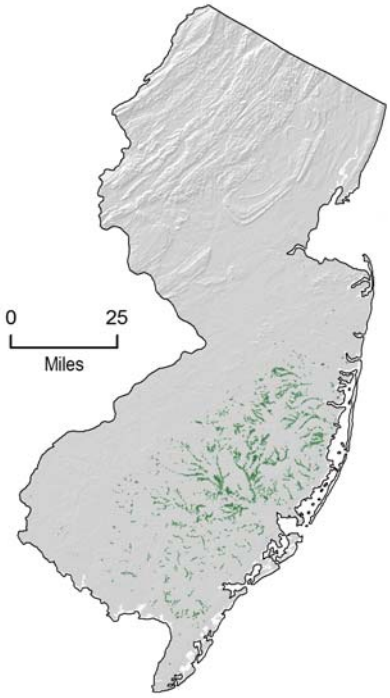
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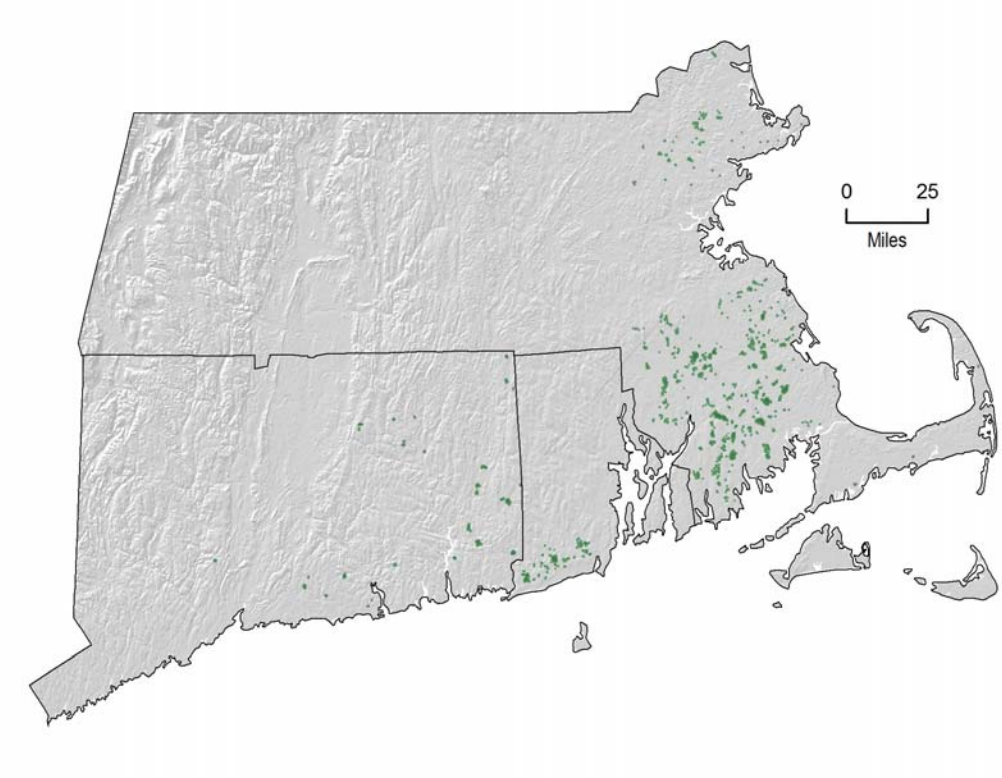

Table 1. Extent of Northern Atlantic Coastal Plain Basin Peat Swamp (Atlantic white cedar swamp) in Northeast Region.		
State	**Habitat acres in state**	**% of total habitat in Northeast**
Maine	654	1.1
New Hampshire	1,157	1.9
New York	97	0.2
Massachusetts	11,834	19.9
Connecticut	2,480	4.2
New Jersey	35,681	59.9
Delaware	4,877	8.2
Maryland	998	1.7
Rhode Island	1,750	2.9

In the Northeast, this habitat type is confined to acidic peat soils (or thin peat soils overlying alluvial mineral soils) that are saturated for most of the year, and flooded for half or more of the year (MNHESP, 1988). The canopy is dominated by Atlantic white cedar, though other tree species such as red maple may also occur (especially in areas that are not subject to burning or other disturbance). The shrub layer is typically sparse and may be dominated by highbush blueberry, sweet pepperbush, and others. The ground cover is often a hummock-hollow growth of sphagnum mosses (MNHESP, 1998).

This community type benefits from regular disturbance, particularly fire (Laderman, 1989). In areas where fire does not occur often enough, or is suppressed, the Atlantic white cedar dominance gives way to fire-intolerant species such as red maple. Development of a mature Atlantic white cedar swamp requires a fire return rate of about 100-200 years, while the development of a community dominated by larger Atlantic white cedars requires a return rate of 200-400 years. In areas where fire is suppressed and red maple achieves a high representation, it may alter the soil chemistry: red maples have deeper root systems than Atlantic white cedar and are able to "pump up" nutrients from deeper mineral soils and reduce soil acidity, thereby rendering the area less suitable for Atlantic white cedars (P. Swain, Massachusetts DFW, *pers comm*.).

Atlantic white cedar germination and establishment is affected by surface hydrology: in areas where soils are too dry (on the tops of hummocks, for example) or wet for too long a period (at the bottom of hollows or more hydric areas) germination may be poor (http://www.na.fs.fed.us/pubs/silvics_manual/volume_1/chamaecyparis/thyoides htm). Thus, the establishment and growth of this forest type is at least partly a "goldilocks" compromise – neither too wet nor too dry but just right. Lavagnino et al (2009) have shown that the germination and growth of Atlantic White Cedars in New Jersey are negatively correlated with the Palmer Drought Severity Index, but not correlated with temperature.

Model Results

This habitat type does not occur in Zone I. The results of the model runs for Zone II (Central New York, Central Vermont and New Hampshire, Southern Maine south to Massachusetts, Connecticut and Rhode Island), Zone III (Pennsylvania, New Jersey, southern New York), and Zone IV (Virginia, West Virginia, Maryland, Delaware, and Washington DC) are shown in Table 2.

Comment [hg1]: A map will be provided showing the boundaries of these zones).

Table 2. Vulnerability modeling results.

Zone	Vulnerability to Climate Change	Vulnerability to Non-climate Stressors	Overall Vulnerability	Certainty
Zone II	Less Vulnerable	Less Vulnerable	Less Vulnerable	High

Zone III	Less Vulnerable	Less Vulnerable	Less Vulnerable	High
Zone IV	Less Vulnerable	Less Vulnerable	Less Vulnerable	High

These results indicate that the vulnerability of this habitat type to climate change is low across all three zones. The low vulnerability of this habitat is due to a number of its characteristics: for example, it is largely a "southern" and low elevation habitat type, flourishing in areas where temperatures are generally high, winters are mild and short, and growing seasons are long – the climatic characteristics that the changing climate is likely to spread across the Northeast. Secondly, few important stressors on this habitat currently exist and the potential for climate change to exacerbate these is low. Lastly, the adaptive capacity of the habitat type is high. Thus, climate change is unlikely to adversely impact this habitat type in the Northeast. Consequently, we have scored this habitat as being Less Vulnerable.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fate of the habitat type suggests that Zone I, the northernmost zone in which Atlantic white cedar forests do not currently exist, might be colonized as climatic conditions become more suitable for them. However, such colonization, if it occurs, is likely to be limited since soil type and drainage ultimately limit the distribution of this habitat. In Zones II, III, and IV, where Atlantic white cedar forests currently exist, it is unlikely that we will see major changes in distribution and extent. Again, surface geology and soil type limit the spread of this habitat type and, while the changing climatic conditions may benefit the habitat, it is unlikely that this will be expressed in a major extension into new areas, though local extensions might occur. These projections are similar to those proposed by Prasad et al. (2007) whose modeling projects little change in the distribution of Atlantic white cedar under high and low emissions scenarios and using a range of climate models.

Modeling Assumptions

Module 1. Location in geographical range of habitat. Given the high degree of precision and accuracy of the TNC/NEAFWA Northeastern Region Habitat Map and the larger scale habitat maps that are available (e.g., Prasad et al. 2007), the southern extent of this habitat type can be fixed with considerable certainty to be in the Gulf of Mexico, more than 600 miles south of the southern border of the Northeast Region. Therefore, all habitat patches in Zones II, III, and IV in the Northeast Region are more than 200km from the southernmost extent of this habitat type.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Atlantic white cedar swamps are not a cold-adapted habitat nor dominated by plant species that can tolerate particularly cold conditions. In fact, it is a southern habitat type that occurs in warmer climates with temperate or mild winter conditions and long, dry summers (such as are found in its main strongholds in New Jersey and southeastern

Massachusetts). We have, accordingly, scored this variable as 1 for all three zones, with a certainty score of High.

This habitat could, however, be vulnerable to extreme climatic events, for example prolonged, more frequent and more severe droughts, which could result in soil drying and impaired germination and growth of tree seedlings. However, this habitat type could have a relatively high resistance to drought because: (a) they have great longevity, with trees living for 200-300 years; (b) they begin to reproduce in only their 3rd or 4th years of growth; (c) their fecundity is high with seed densities in soils in suitable habitats as high as 20 millions/hectare (Fowells, 1965). Therefore, Atlantic white cedars have the capacity to withstand sporadic events such as droughts. For this reason we have scored this variable as moderate (3) for all three zones. We have allocated a certainty score of Medium (2) to this estimate to reflect the fact that we are unable to predict with any certainty the scales and magnitudes of climate change-induced droughts that may occur in the future, and conditions could be worse or better for Atlantic white cedars than we assume here.

Module 1. Vulnerability to maladaptive human responses. This habitat type is currently not greatly affected in the Northeast Region by human activities – the soils on which it grows are too wet for development and the commercial value of the timber is low. Also, many of the patches of this habitat occur on protected areas or are protected by state wetland regulations. We do not anticipate that humans will increase their interference with this habitat type under a changing climate and we score this variable as Low (1), with a certainty score of Medium (2). This last reflects the fact that anticipating societal responses to the changing climate and how these responses might affect ecosystems is problematic.

Module 1. Location relative to highest elevation. Atlantic white cedar swamp is a low elevation habitat which, theoretically, has the ability to move upslope in response to a changing climate (if the necessary soil type is available). We therefore assigned a vulnerability score of 1 for this variable in all three zones (II, III, and IV), and High certainty scores.

Module 1. Intrinsic adaptive capacity. Atlantic white cedars are likely to have a high adaptive capacity to sporadic climate change-induced events like droughts and wildfires. This is because: (a) they have great longevity, with trees living for 200-300 years; (b) they begin to reproduce in only their 3rd or 4th years of growth; (c) their fecundity is high with seed densities in soils in suitable habitats as high as 20 millions/hectare (Fowells, 1965). Therefore, Atlantic white cedars have the capacity to withstand sporadic events such as droughts.

Module 1. Dependence on specific hydrologic conditions. Atlantic white cedar swamp is a wetland habitat type and depends on specific hydrologic conditions for germination and growth. Thus it is sensitive to hydrologic variability. We have accordingly scored this variable as 5 for all three zones, with certainty scores of High.

Module 1. Vulnerability of Foundation/Keystone species to climate change. The foundation species in this habitat is Atlantic white cedar. This tree is already adapted to the sorts of climatic conditions that might be intensified or made more widespread by climate change. However, it could be vulnerable to extreme events, such as drought. As already described above, this is a species with a high reproductive rate and prolonged life. Therefore it may be well adapted to surviving such stochastic events. We have, accordingly scored its vulnerability as 1 (unlikely to be vulnerable), but have assigned a certainty score of only Medium (to reflect the fact that we may not know as much about the ability of this species to survive warming as we would wish).

Module 1. Constraints on latitudinal range shifts. The current distribution of this habitat type is constrained by a combination of anthropogenic factors (previous habitat destruction); climatic factors (warmer wetter summers and milder winters); and by soil type (the habitat flourishes only on peaty, relatively saturated soils). With climate change, the climatic conditions that favor white cedar swamps may become more widespread in the Northeast Region. However, the availability of the habitat to exploit this and extend its range may be constrained by the distribution of suitable soil types. If the soils occurring in areas where the climate is becoming more suitable are not hydric or peaty enough, the habitat type is not likely to be able to extend. We have accordingly scored the vulnerability of this habitat type as 3 (somewhat constrained), with certainty scores of Medium to reflect the conjectural nature of these scores.

Module 1. Likelihood of managing/alleviating climate change impacts. Human societies do not have a history of managing this habitat type. This is probably because it is basically a wetland and its fate under humans has typically been drainage and conversion to more “useful” habitat. It is difficult to be confident that we would be able to manage this habitat successfully under a changing climate because so much of the health of the habitat type depends on surface soils type and hydrology, factors that are likely to not be amenable to effective and practical management regimes. We have scored this variable as 5 (management unlikely to be feasible) in all three Zones, but with certainty scores of only Medium (to reflect considerable uncertainty about how effective human management of this habitat could be).

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. Much of this habitat exists in protected areas where stressors such as habitat destruction and logging are minimal, and few other stressors are currently impacting this habitat type. It is possible that stressors such as invasive pests could spread into the Northeast and adversely affect the habitat. However, we judge this potential to be low. Accordingly, we scored the potential for this as 1 (low potential), although we have assigned a certainty score of only Medium, to reflect significant uncertainties about future colonization by invasives.

Module 2. Current extent of habitat. This is a habitat that occurs in small to medium sized blocks on the landscape and is highly fragmented in its distribution. Accordingly we have scored this variable in Module 2 as Limited in Distribution and Highly Fragmented in all three zones, and with certainty scores of High.

Module 2. Current extent trend. Any current losses to this habitat type across the Northeast are likely to be small and local in scale and due to relatively small-scale drainage and conversion. Accordingly, we have assigned to this variable a score of 1 (Stable or Increasing) for all three zones. We assigned certainty scores of High to all these scores since much is known and mapped about the distribution of the habitat throughout the Northeast.

Module 2. Likely future extent trend. While it is likely that the types of effects detailed in *Current extent trend* above may continue to occur in the future, we consider it unlikely that this will result in a marked acceleration in the future trend. Indeed, since much of the land that can be easily developed has already been so, and since much or the large patches of this habitat type occur on protected land, the trend may decrease. We have conservatively assigned vulnerability scores of 1 (Stable or Increasing) with certainty scores of Medium for all three zones.

Module 2. Current impacts of non-climate change stressors. While this habitat may be being affected by at least one non-climate stressor (fire suppression), its effects are minimal or local in scale. Accordingly, we have scored this variable in Module 2 as 1 (Least affected) for all three zones, with certainty scores of High.

Module 2. Likely future stressor trends. It is feasible that habitat destruction for residential/commercial development and fire suppression could increase in their impacts in the future. However, we anticipate that such effects, if they occur, are likely to continue to be small scale and local. For this reason, we score this variable as 1 (Little or no increase) for all three zones. Our certainty score is Medium to reflect the degree of uncertainty that surrounds this prediction.

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