THE VULNERABILITIES OF NORTHEASTERN FISH AND WILDLIFE HABITATS TO CLIMATE CHANGE

A report to the Northeastern Association of Fish and Wildlife Agencies and the North Atlantic Landscape Conservation Cooperative

Manomet Center for Conservation Sciences and the National Wildlife Federation

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EXECUTIVE SUMMARY

- In a project extending from Maine to Virginia and West Virginia, the Northeastern Association of Fish and Wildlife Agencies (NEAFWA), the North Atlantic Landscape Conservation Cooperative (NALCC), Manomet Center for Conservation Sciences (Manomet), and the National Wildlife Federation (NWF) collaborated with other major northeastern stakeholders in safeguarding fish and wildlife and their habitats from climate change. Specifically, NEAFWA, NALCC, Manomet, and NWF completed a three-year effort to evaluate the climate change vulnerabilities of the Northeast's key habitats, and to help increase the capabilities of state fish and wildlife agencies to respond to these challenges.

- The primary objectives of this project were:

  1. To quantify the regional vulnerabilities to climate change of fish and wildlife habitats, and how these vulnerabilities vary spatially across the region.
  2. To project how the status and distributions of these habitats and species may be affected by climate change.
  3. To work with states to increase their institutional knowledge and capabilities to respond to climate change through educational and planning workshops and other events.

- The project began by developing a consistent and uniform approach to evaluating the vulnerabilities of fish and wildlife habitats within and across all 13 states in the Northeast Region and the District of Columbia. This methodological approach is known as the NEAFWA Habitat Vulnerability Model.

- The NEAFWA Habitat Vulnerability Model, based on an Excel spreadsheet platform, comprises four connected modules: Module 1 scores the likely vulnerabilities of non-tidal habitats to future climate change (and the potential interaction between climate and non-climate stressors). Module 1 can be used alone if the objective is limited to only categorizing climate change vulnerabilities, rather than <u>overall</u> future vulnerabilities. Module 2 scores the comparative vulnerabilities of habitats to existing and future, non-climate change stressors. Module 3 combines the results of Modules 1 and 2 to produce an overall evaluation of the habitat's future vulnerability to climate change and to non-climate stressors. Module 4 comprises narratives (see Attachments 3-12) that explain why each of the scores in Modules 1 and 2 were selected.

- Module 3 also groups the model final scores into five categories: critically vulnerable, highly vulnerable, vulnerable, less vulnerable, and least vulnerable. These translate into habitat response categories varying from habitats that are likely to be eliminated from or greatly reduced in the study area (critically and highly vulnerable, respectively) to habitats that may be relatively unaffected (vulnerable), to habitats that may extend or greatly extend their range within the area (less and least vulnerable, respectively).

- Each of the variable scores in Modules 1 and 2 are assigned one of three certainty scores – High, Medium or Low, so that the degree of confidence that the assessors had in their scoring of each variable is explicit. Module 3 also includes a certainty evaluation that categorizes the overall confidence that can be assigned to the Module 3 scores. By comparing these scores it is possible to identify how confident we can be about our model predictions, where the greatest uncertainties lie, and where future studies might be focused to reduce important uncertainties.

- Most categorizations in Modules 1 through 3 are based largely on expert judgment. The primary aim of the narrative (Module 4) that is included in each habitat assessment is to make transparent the rationales and assumptions underlying the scores that were assigned to each variable.

- In selecting habitat types to which to apply the model, the following criteria were used:

    1. We focused on Habitat Systems (Gawler *et al*., 2008).
    2. We applied the model to habitats that were not tidally-influenced (we found that it was not possible to construct a model that could be used both for non-tidal and tidal habitat types and the latter is being included in this project via a separate evaluation approach).
    3. We focused mainly on the more extensive habitats within the region so as to evaluate the vulnerability of the greatest possible extent of the Northeast's habitat area.
    4. We also selected habitats that were more restricted in their distributions but considered by individual states to be important enough to include.
    5. To the extent possible, we attempted to cover all of the major biomes in the northeast – conifer forest, broadleaf forest, grasslands, shrublands, and wetlands.

- A total of 13 habitats were evaluated using the NEAFWA Habitat Vulnerability Model:

    Forests and Woodlands
    Laurentian-Acadian Northern Hardwood Forest
    Appalachian Northern Hardwood Forest
    Central Mixed Oak-Pine Forest
    Northeastern Pine Barrens
    Acadian-Appalachian Montane Spruce-Fir Forest
    Central and Southern Appalachian Spruce-Fir Forest

    Wetlands
    Laurentian-Acadian Wet Meadow-Shrub Swamp

Northern Atlantic Coastal Plain Basin Peat Swamp
Laurentian-Acadian Freshwater Marsh
North-Central Interior and Appalachian Acidic-Peatland
Boreal-Laurentian Bog
Boreal-Laurentian-Acadian Acidic Basin Fen

Grasslands
Acadian-Appalachian Alpine Tundra

- To investigate potential geographical variation in habitat vulnerabilities to climate change across the Northeast Region, the entire region was divided into 4 latitudinal zones, corresponding approximately to the major bioclimatic zones of the region. For each habitat, the model was applied separately in each of the zones in which it occurred. For habitats that were ubiquitous throughout the region (e.g., northern hardwood forest), the result was four sets of vulnerability results, allowing us to compare variation in vulnerability across the region. Some habitats were more restricted in their distributions (e.g., alpine tundra), allowing only 1-3 sets of vulnerability results to be produced.

- As each habitat type was evaluated, the initial results were submitted to an expert panel for review and comment. These comments were then used to reapply the model and modify the results, where necessary.

- A total of 69,347,600 acres of wetland and upland habitat was evaluated using the NEAFWA Habitat Vulnerability Model. This comprises approximately 60% of the total wildlife habitat (excluding developed areas and agricultural land) in the NEAFWA Region.

- Most of the habitats that were evaluated in this study are likely to suffer range contractions under the changing climate. Eight habitats are at significant risk of being eliminated entirely from the Northeast (Appalachian Spruce-Fir Forest), or of having their current distributions reduced by at least 50% in at least one zone (Alpine Tundra, Montane Spruce-Fir Forest, Northern Hardwood Forest, Appalachian Northern Hardwood Forest, Appalachian Spruce-Fir Forest, Boreal-Laurentian Bog and Acidic Fen, and Acidic Peatland). These are all habitats that are either northern or boreal in their distributions, confined to high elevations or mountain summits, or reach their southernmost extents within the region.

- For many of the habitats that are vulnerable to climate change and that occur in two or more zones (Montane Spruce-Fir Forest, Northern Hardwood Forest, Appalachian Northern Hardwood Forest, Central Oak-Pine Forest) their vulnerabilities increase from north to south, as their bioclimatic range limit is approached.

- Not all of the habitats assessed are equally vulnerable to climate change. While some are highly vulnerable, others (Atlantic White Cedar Swamps, Pine Barrens, Emergent Marshes and Shrub Swamps) are much less so. This is because these habitats are not northern in distribution and extend far to the south of the Northeast Region into areas where the climatic conditions are already similar to those projected for the region in the future, their dominant and/or foundational species may not be particularly vulnerable to climate change, and many of them are not particularly sensitive to the types of ecological disruptions that can be expected to occur under the changing climate, for example drought and more frequent or severe wildfires.

- Some habitats may benefit from the changing climate. Better-adapted species and habitats will expand their distributions into these areas from which they may have previously been excluded by competition. For example, Central Oak-Pine Forest is likely to expand its range into areas that are currently dominated by northern hardwood plant species.

- Non-climate stressors that already impact many habitats will continue to be important stressors in the future. For example, invertebrate pests already adversely impact some forest types, such as hemlock stands or Central-Southern Appalachian Spruce-Fir Forests. In some areas, these pests are a major determinant of the condition and distribution of these habitats. The same applies to over-abundance of white-tailed deer in northeastern forests and their effects on the habitat through grazing and browsing, or the invasion of native plant communities by exotic species. While climate change may increasingly exert adverse effects on these habitats, current stressors will continue to be important, conceivably more important in some cases.

- Climate change and non-climate stressors may interact to affect habitat distributions. The most obvious examples are the "beneficial" effects that climate change may have on the life cycles of pest species. Some forest pests are already benefiting from the changed climatic conditions. Under warming winter temperatures, hemlock wooly adelgid, for example, is shifting its range northwards and impacting hemlock stands that were previously not vulnerable to it. The spread and impacts of other stressors, such as white-tailed deer, emerald ash borer and balsam wooly adelgid, are limited by climate. Climate change introduces the potential of their impacts being increased and extended in the region.

- In some cases, the responses of human communities to the changing climate may be as important for habitats as climate change itself. However, projecting how societies might respond to, for example, the increasing frequencies and intensities of wildfires in forest habitats, or view the potential need for more controlled burns in such areas, or respond to increasing algal blooms in lakes that are used for recreation (as well as providing habitat for sensitive aquatic species) are highly uncertain and possibly more obscure than questions about how climate change may directly impact species and habitats.

Chapter 1. Introduction

Climate change and its impacts on species and ecosystems are already being experienced in the Northeast Region (NECIA, 2007, Hayhoe *et al*., 2008, Sallenger *et al*, 2012). Moreover, the rate at which the climate is changing has accelerated over the last three decades (IPCC, 2007). Across North America accelerating climate change has resulted in impacts to fish and wildlife and their habitats: sea levels are rising, threatening coastal ecosystems; fish migrations, bird breeding seasons, plant flowering seasons, freeze-ups and ice-outs, and peak flows in streams and rivers are all happening significantly earlier or later than they once did; and the ranges of mobile organisms such as birds and, unfortunately, pests have extended northward (Parmesan and Galbraith, 2004; Schneider and Root, 2002; Walther *et al*., 2002; Parmesan and Yohe, 2003; Root *et al*., 2003; Parmesan, C. 1996; Beckage *et al*.; 2008, Galbraith, 2010). Due to our lack of success in mitigation, and the resulting continued high global emission rates of greenhouse gases, it is likely that impacts to northeastern ecological systems will continue to grow in extent and severity.

The changing climate poses significant challenges to the future conservation of fish and wildlife in the Northeast: how do we protect valued resources against a climatic background that can no longer be assumed to be stable? How well will our "traditional" conservation tools (e.g., place-based protection) continue to work? What new management tools will we need? How do we plan future acquisitions? How will the changing climate interact with the other stressors that are already impacting wildlife resources? The most urgent question, and the one that needs answering before the others can be fully addressed, is: which species and habitats are likely to be vulnerable to, or benefit from, the changing climate?

In a project extending from Maine to Virginia and West Virginia, the Northeastern Association of Fish and Wildlife Agencies (NEAFWA), the North Atlantic Landscape Conservation Cooperative (NALCC), Manomet Center for Conservation Sciences (Manomet), and the National Wildlife Federation (NWF) are collaborating with other major northeastern stakeholders to protect fish and wildlife and their habitats from climate change. Specifically, NEAFWA, NALCC, Manomet, and NWF have completed a three-year effort to evaluate the vulnerabilities of the Northeast's most important habitats[1], and to help increase the capabilities of state fish and wildlife agencies to respond to these challenges. This regional effort is the first of its kind in the country, and is an essential step toward the implementation of effective "climate-smart" conservation of ecosystems.

This NEAFWA/NALCC Regional Habitat Vulnerability Assessment Project (the NEAFWA project) is intended to address important gaps in our knowledge by building and applying a consistent and uniform approach to evaluating the vulnerabilities of fish

[1] In a parallel effort funded by the NALCC, NatureServe is evaluating the vulnerabilities of selected plant and wildlife species in the Northeast to future climate change.

and wildlife habitats within and across all 13 states in the Northeast Region[2] and the District of Columbia. Extending over more than 260,000 miles (an area equal or larger than many countries, France, Germany, or Spain, for example) this region is topographically and ecologically highly diverse, includes coastal, inland and freshwater aquatic habitats, and ranges from over 6,000 feet above sea level in the Appalachian Mountains to low-lying coastal plain. Given its size, its north-south orientation, and its elevational range, the region supports a high diversity of major plant community types and ecological habitats[3]. These range from treeless arctic-alpine tundra at the highest elevations, to boreal conifer forests, to various deciduous forest types at lower elevations, to freshwater wetlands, to coastal habitats, including intertidal beaches and marshes.

The overarching goal of the NEAFWA project was to provide vulnerability information that will help the northeastern states plan their conservation of fish and wildlife under a changing climate. To meet this ambitious goal, it had three main specific objectives:

- To quantify the regional vulnerabilities to climate change of fish and wildlife habitats, and how these vulnerabilities vary spatially across the region.

- To project how the status and distributions of these habitats and species may be affected by climate change.

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

Achieving these objectives was contingent on developing an understanding of the comparative vulnerabilities of ecological resources to climate change. Over the last five years significant progress has been made in assessing the vulnerabilities of organisms and habitats to the changing climate. While the Northeast pioneered and led much of this vulnerability assessment work[4], our knowledge was still confined to individual states. However, for the most effective conservation of many resources we need to be able to take a regional view. Specifically, we need to be able to evaluate the vulnerabilities of valued resources, and understand how these vulnerabilities may vary across the region. This last is important: if it is determined that a habitat, for example, is threatened in a particular state, any conservation action that might be proposed needs to be weighed against that habitat's vulnerability elsewhere in the region.

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[2] Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Virginia, West Virginia, Delaware, Maryland and Pennsylvania.

[3] In this project we are using the terms plant community and habitat interchangeably. Also, plant community/habitat names are those that are currently being finalized in NEAFWA's Northeastern Terrestrial Habitat Classification System taxonomy and cross-walk project.

[4] This work has resulted in important vulnerability assessments being performed by northeastern states, leading to the development and publication of two groundbreaking sets of national vulnerability assessment guidelines (AFWA, 2010; Glick *et al*., 2010)

To achieve these important objectives it was necessary to develop and apply a habitat vulnerability assessment model consistently across the region and within the individual states. In this report we describe how this predictive model (the NEAFWA Habitat Vulnerability Model) was developed and the results that were obtained when the model was applied to major northeastern habitat types.

In the remainder of this report we summarize our current scientific understanding about how the climate in the Northeast region is projected to change over the rest of this century (Chapter 2); how the NEAFWA Habitat Vulnerability Model was developed (Chapter 3); how habitats were selected for analysis, and the results of applying the model to major habitat types in the northeast (Chapters 4 and 5).

Chapter 2. Climate Change in the Northeast Region

Climate modeling analyses for the Northeast Region of the United States have projected major changes over the rest of this century (e.g., Hayhoe *et al*. 2006). They also indicate that the magnitudes of these changes are likely to vary spatially across the region (e.g., Hayhoe *et al*. 2006; IPCC, 2007; Karl *et al*., 2009; Sallenger *et al*., 2012). Exposures[5] of systems or species will, therefore, also vary temporally and geographically. Therefore, if the vulnerabilities of ecological resources across the entire Northeast Region to climate change are to be understood, the magnitudes and geographical variations in future exposure must be taken into account (Parmesan and Galbraith, 2004; Glick *et al*., 2010).

This chapter and Attachment 1 to this report reviews information from the literature (and some new analyses) describing how the exposures of northeastern species and systems may change and vary geographically over this century. This is not intended to be an exhaustive analysis of future climate change. Rather, it uses mostly existing data, and was intended to provide project expert panel and habitat workgroup members, who were assessing vulnerabilities, with background information describing likely climate futures. As they evaluated vulnerability assessments for selected habitats across the region, workgroup members were able to use the figures and tables presented in this report to assess how climatic changes and exposures may vary across the region. The data were gathered from two sources – the Northeast Climate Impacts Assessment (NECIA), and the web-based tool, ClimateWizard. NECIA (2007) was a major effort to describe plausible climate futures in the Northeast by statistically downscaling 3 Global Circulation Models (GCMs) to a $1/8^{o}$ scale. The results were presented in a project report (NECIA, 2007), several scientific papers (e.g., Hayhoe *et al* 2006 and 2007), and in an interactive website (http://www.northeastclimatedata.org/). ClimateWizard is a web-based interactive tool (http://www.climatewizard.org/) developed by The Nature Conservancy and the Universities of Washington and Southern Mississippi. It uses various combinations of the output of 16 GCMs to statistically downscale information to a 12km grid scale. Both sources provide the most recent and thorough downscaled analyses of how the climate may change in the Northeast Region over the remainder of this century.

To summarize the detailed results presented in Attachment 1: the future climate projected for the Northeast Region from currently available modeling results is one where the region is hotter by several degrees C, where precipitation will have increased by up to about 15%, where less precipitation will fall as snow and more as rain, where extreme climatic events (droughts, storms) will have increased in their frequency, intensity, and duration, where plant growing seasons will have lengthened by up to about 50 days, and where sea levels will have risen by up to a meter or more. Specifically, the following changes are projected by 2070-2099:

[5] The exposure of an ecological resource (i.e., plant, animal, or community) to climate change refers to the direction and magnitude of change that the resource will experience (Glick *et al*., 2010).

1. The annual average temperature across the region will increase by 2-5^{o}C (3.6-9.0^{o}F) depending on the emissions scenario.

2. The annual average temperature increase will have seasonal and geographical components, being greatest in the winter months and at higher latitudes.

3. The annual average precipitation across the region will increase by about 7-15%, depending on the emissions scenario.

4. The number of extreme heat days per year (>50^{o}C, 90^{o}F) will increase from the current 10 to 20-40 days depending on the emissions scenario.

5. The annual number of freeze days (days when temperature <^{o}C, 32^{o}F) will decrease across region by about 20-30%.

6. The length of the plant growing season (days between last and first killing frosts) will extend by 30-50 days, depending on the emissions scenario, and the plant hardiness zones will advance north.

7. The area of the region that is typically snow covered in winter will contract north to the northernmost parts of Vermont, New Hampshire and Maine.

8. Soil moisture content (percent saturation) will decrease, particularly during the summer months (by about 1-2%).

9. Evapotranspiration rates in the region will increase in the spring and summer by 1-2% depending on the emissions scenario.

10. Under the A1FI emissions scenario, the frequency of short-term droughts (1-3 months in duration) will increase from the current 13 per 30 yr period to about 22 per 30 yr period. The frequencies of medium term droughts (3-6 months duration) will increase from the current 0.6 per 30 yr period to 2.2 per 30 yr period. Long-term droughts (>6 months duration) will increase from 0.3 per 30 yr period to about 0.4. Much smaller changes are projected under the B1 scenario.

11. Sea levels in much of the Northern Hemisphere have been rising over the last century. The observed rate at any point on the coast is a function of the current rate of sea level rise (SLR), oceanic currents, and crustal processes, particularly coastal subsidence or elevation. The future rate of SLR is expected to accelerate due mainly to the steric expansion of the sea water (under increasing air temperatures) and to an acceleration in the melt rates of ice caps and glaciers. Our best estimate of the future degree of SLR due to the changing climate is that global sea levels will rise by the end of this century by between 1 meter and 2 meters (Pfeffer *et al*., 2008; Rahmstorf, 2007). The likely extent of SLR can be estimated at any point on the coast by adding these future estimates to the current observed rate of SLR. Current rates of SLR in the Northeast Region decrease

> from south to north and between about 2 mm/yr and 5 mm/yr. By 2100 this translates into a total rise of 231 mm to 258 mm, with a midpoint of 242 mm. Assuming a global SLR due to climate change of 1 meter, future SLR across the region will vary from 1.23 meters to about 1.26 meters. The highest projections are for the southernmost states (Sallenger *et al*., 2012).

The combination of these conditions could, result in a northeastern climate that bears little resemblance to that which currently prevails in the region, but is instead closer to the climate currently experienced further south, for example in North or South Carolina (NECIA, 2007). Obviously, this change could have major implications for plant and animal communities.

Chapter 3. Development and Structure of the NEAFWA Habitat Vulnerability Model

The Model Development Process

It was recognized early in the process of planning the development and application of the NEAFWA Habitat Vulnerability Model that the active participation of representatives from the state fish and wildlife agencies was essential. Not only are the state agencies the sources of much of our knowledge about the ecologies, management, and threats to northeastern habitats and species, they also comprise the professionals and experts tasked with planning and implementing future conservation. Consequently, the model was built utilizing an expert panel-based approach. Beginning in 2010, the director of each fish and wildlife agency in the northeastern states was asked to identify potential panel members (where possible, we attempted to recruit experts in upland, freshwater aquatic and coastal habitats and their species). Manomet then contacted directly all of the proposed panel members and invited them to participate in the panel. The result of this process was an expert panel of 27 members from 12 of the 13 northeastern states. While the panel members comprised mainly representatives from state fish and wildlife agencies, biologists from NGOs (Table 1) also participated.

Once the expert panel had been formed, Hector Galbraith of Manomet then led the process of building a draft model, based on his work building vulnerability models for other assessments (see Galbraith and Price, 2010), and his knowledge of other models. Having built a draft model, Galbraith then carried out test runs on several habitat types. He provided the results to a subgroup of members of the expert panel for review and comment. Based on these comments the model was revised and run once more on the test habitats. The results were then submitted to the entire expert panel for review and comment. Armed with verbal and written comments, Galbraith again modified the model to arrive at the final working version.[6]

Informing the Expert Panel

Most of the expert panel members were not climate change experts and it was necessary to provide them with background information that would help them to participate in the evaluation of habitat vulnerabilities. Manomet supplied the expert panel members with information packages to inform them about how the climate is likely to alter in the Northeast, and the implications for ecosystem change and adaptation:

[6] The resulting model addresses non-tidal habitats only. Tidal habitats (i.e., below the high tide mark) have been addressed in a parallel effort.

1. An analysis of how the climate has already changed in the Northeast and how it is likely to change further over the remainder of this century (similar to Attachment 1 to this report).

2. An analysis of how the climatic changes have already impacted ecological resources in North America and how they might affect ecological resources in the Northeast in the future.

3. A statement of main objectives of the NEAFWA Project.

The Role of the Expert Panel in Applying the Model

Once the model had been developed, the expert panel had two further roles. The first was to help in the selection of habitat types for analyses, and the second to help guide, review, and evaluate the results of the modeling runs. These are described in detail in Chapters 4 and 5, respectively.

Table 1. Expert Panel Participants.

	Participant	Affiliation
Maine	Steve Walker	Inland Fisheries and Wildlife
	Phillip deMaynadier	Inland Fisheries and Wildlife
	Andrew Cutko	Natural Areas Program
New Hampshire	Pam Hunt	NH Audubon
	Matt Carpenter	NH Fish and Game
Vermont	John Austin	VT Fish and Wildlife
	Eric Sorenson	VT Fish and Wildlife
Massachusetts	Caleb Slater	MA Fisheries and Wildlife
	John Scanlon	MA Fisheries and Wildlife
Connecticut	Neal Hagstrom	CT DEP
	Ann Kilpatrick	CT DEP
	Mark Johnson	CT DEP
	Min Huang	CT DEP
New York	Zoe Smith	Wild. Conservation Society
	Tracey Tomajer	NY DEC
New Jersey	Kris Schantz	NJ DFW
Pennsylvania	David Day	Fish and Boat Commission
Virginia	David Norris	DGIF
	Paul Bugas	DGIF
	Chris Burkett	DGIF
West Virginia	Elizabeth Byers	WV DNR
	Kerry Bledsoe	WV DNR
	Paul Johansen	WV DNR
Maryland	Dana Limpert	MD DNR
Delaware	Robert Hossler	DE DFW
	Karen Bennett	DE DFW
	Desmond Kahn	DE DFW

Model structure

The NEAFWA Habitat Vulnerability Model, based on an Excel spreadsheet platform, comprises four connected modules (Figure 1 and Attachment 2 [the Excel spreadsheet that accompanies this report]): Module 1 comprises 11 variables and scores the likely vulnerabilities of non-tidal habitats to future climate change (and the potential interaction between climate and non-climate stressors). Module 1 can be used alone if the objective is limited to only categorizing climate change vulnerabilities, rather than overall future vulnerabilities. Module 2 has 5 variables and scores the comparative vulnerabilities of habitats to existing and future, non-climate change stressors. Module 3 combines the results of Modules 1 and 2 to produce an overall evaluation and a score of the habitat's future vulnerability to climate change and to non-climate stressors. Module 3 also groups these scores into five categories: critically vulnerable, highly vulnerable, vulnerable, less vulnerable, and least vulnerable. These translate into habitat response categories varying from habitats that are likely to be eliminated from or greatly reduced in the study area (critically and highly vulnerable, respectively) to habitats that may be relatively unaffected (vulnerable), to habitats that may extend or greatly extend their range within the area (less and least vulnerable, respectively).

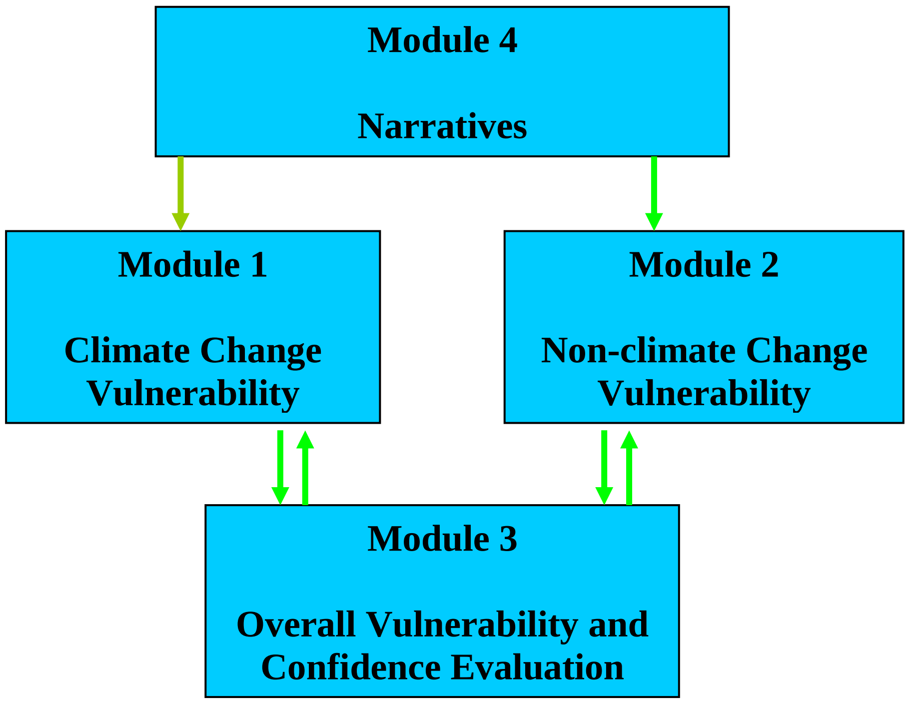

Figure 1. Structure of the NEAFWA Habitat Vulnerability Model.

Additionally, each of the variable scores in Modules 1 and 2 are assigned one of three certainty scores – High, Medium or Low, so that the degree of confidence that the assessors had in their scoring of each variable is explicit. Module 3 also includes a certainty evaluation that categorizes the overall confidence that can be assigned to the Module 3 scores. By comparing these scores it is possible to identify how confident we can be about our model predictions, where the greatest uncertainties lie, and where future studies might be focused to reduce important uncertainties.

Most categorizations in Modules 1 through 3 are based largely on expert judgment. The primary aim of the narrative (Module 4) that that is included in each habitat assessment is to make transparent the rationales and assumptions underlying the scores that were assigned to each variable.

Model Variables

This section lists the variables that make up the Excel-based model. In the actual model itself, these variable descriptions, together with advice on assigning scores, are included as drop-down text boxes so that the model is as "stand-alone" as possible.

Module 1 – location in geographical range of habitat. Habitats close to the southern extremes of their distributions and that may be close to the southern edges of their ranges of climatic tolerances, may be more vulnerable to a warming climate than habitats that are further north of these bioclimatic edge zones. However, it is also important to recognize that the current distributions of habitats are also affected by non-climatic factors, especially anthropogenic influences. Any such confounding factors should be taken into account when evaluating how close habitats currently may be to their southern climate-limited distributions. Habitats closer to the northern edge of their current limit (e.g., oak-hickory, warmer-water aquatic habitats) may benefit from a warming climate by being able to follow the shifting climatic zones northward.

Module 1 – degree of cold adaptation. Some plant and animal communities are cold-adapted (e.g., hemlock stands, coldwater streams, high elevation forests, habitats limited to "frost pockets"). These are likely to be more vulnerable to increasing temperatures.

Module 1 – sensitivity to extreme climatic events. Some habitats may be more vulnerable than others to extreme climatic events or climate-induced events (fire, drought, floods, ice storms, windstorms). Such events are projected to become more frequent and/or intense under climate change.

Module 1 – vulnerability to maladaptive human responses. Some habitats are likely to be more vulnerable to the human responses to climate change, than to climate change itself. For example, the construction of sea walls in response to rising sea levels will have major impacts on the ability of the coastline to migrate inland, thereby jeopardizing coastal habitats. Also, reservoir drawdowns to eliminate increased algal blooms (caused by rising temperatures) could result in the elimination of hypolimnia and associated fish species.

Module 1 – location relative to highest elevation. The highest elevations in the Northeast extend up to about 6,000 feet above sea level. Montane habitats that are limited to high elevations (within 1,000 feet of the summits) are likely to be highly vulnerable to climate change since they may not be able to respond by simply migrating upslope (there is very little or no "upslope" in these cases). Middle elevation habitats may also be adversely impacted, but less so, and low elevation habitats may be least affected, as they have the potential to extend their ranges upslope.

Module 1 – intrinsic adaptive capacity. While all habitat types are likely to have characteristics that may enable them to withstand the effects of a changing climate, their adaptive capacities (their ability to cope *in situ* with climatic stress) will vary among and within habitat types. This capability will depend on their intrinsic and extrinsic characteristics and their condition:

1. The physical diversity within which a habitat exists may affect its resilience and adaptive capacity: habitats with diverse physical and topographical characteristics (variety in aspects, slopes, geologies and soil types, elevations) may be more able to survive climate change than habitats that are less varied, since the former, by existing across widely differing conditions, may be at lower risk to being eliminated by any future climatic conditions.
2. Some habitats may be intrinsically more resistant to stressors because (for example) they have more rapid regeneration times and/or are dominated by species closer to the end of the life-history continuum. Habitats in which the recovery period from the impacts of stressors is shorter (<20 years) may have greater intrinsic adaptive capacities than slower developing habitats (recovery times of >20 years). For example, high elevation spruce-fir forest may take 2-3 hundred years to recover from fire or pest impacts. This may render them intrinsically more vulnerable to the potential intervening effects of climate change than are habitats that have shorter recovery periods (e.g., grasslands or shrub habitats).
3. The current conditions of habitats will also affect their adaptive capacities. Habitats that support their full complement of species (or close to that), have high biodiversity. If they are relatively free from non-climate stressors, such as fragmentation, invasive species, etc., they are likely to be both more resistant and resilient to the effects of a changing climate. In contrast, habitats that are in "poorer" condition with comparatively impoverished species representation and biodiversity, or that are being impacted by other stressors, may be less resilient and have lower adaptive capacity.

Module 1 – dependence on specific hydrologic conditions. Some habitats are confined to areas with specific and relatively narrow hydrologic conditions. For example, vernal pools may be confined to areas with abundant winter snow cover and poor soil drainage characteristics. This produces isolated ephemeral pools when snow melts in spring. Boreal bogs, peatlands, high Alleghany wetlands, and coastal plain ponds may be other examples. Changes in precipitation amount, type (snow vs. rain) and phenology are projected by all climate change models (though the directions and degree of change vary across models) potentially threatening these ecohydrologic habitat types.

Module 1 – vulnerability of foundation/keystone species to climate change. Foundation species are those that have substantial influences on community structure as a consequence of their high biomass. Examples are abundant tree species in a forest, such as red spruce in high elevation conifer forest, or oak species in a mixed oak-hickory forest. Keystone species are those that exert strong effects on the structures of their communities, despite a low biomass. In the Northeast, white-tailed deer may be a keystone species in areas where densities are high due to their selective browsing on tree saplings. Beaver are certainly a keystone species, creating and maintaining wetland habitat. If either foundation or keystone species in a habitat are particularly vulnerable to climate change the whole habitat type may be in jeopardy.

Module 1 – constraints on latitudinal range shifts. Habitats that are comparatively free to shift latitudinally across landscapes are likely to be less vulnerable to the changing climate than habitats that are otherwise constrained. Examples of the latter might be habitats that are fragmented and separated by extensive urban areas, large water bodies or mountain ranges**.**

Module 1 – likelihood of managing or alleviating climate impacts. How we are able to manage impacts of climate change on habitats is likely to become an important factor in conserving resources. However, some habitats may be less easy to manage than others. For example, managing the impacts of climate change on early seral or riverine habitats may be easier (through using fire, plantings, water level control, dam removal, etc.) than managing habitats that are more intrinsically vulnerable to climate change (e.g., intertidal or high elevation habitats). Also, for some habitat types (forests, for example), we have already developed effective management tools, and these could be applied and/or modified for management under climate change.

Module 1 - potential for climate change to exacerbate impacts of non-climate stressors. For some habitats and species it is likely that significant impacts of climate change will be expressed through their exacerbating or mitigating effects on current or future non-climate stressors. The effects of drawing down reservoir levels to eliminate algal blooms (caused by increasing water temperatures) on hypoliminia and their inhabitants are an example. Another is the potential exacerbatory effects of warming temperatures on cold-limited pest species or invasives (e.g., hemlock wooly adelgid). This variable captures the potential effects of this interaction between climate change and non-climate change stressors**.**

Module 2 – current extent of habitat type. Habitats that are currently widespread in their extents and relatively unfragmented are more likely to be able to withstand and persist into the future despite non-climate stressors, than are habitats that are rarer, more fragmented, or less widespread.

Module 2 – current extent trend. Habitats that have low current rates of loss or fragmentation to non-climate stressors may be less vulnerable to both climate and non-climate stressors in the future than habitats that are currently undergoing major losses due to these factors.

Module 2 – likely future extent trend. Habitats that are likely to experience stabilization or a decline in future rates of loss are likely to be able to persist better than habitats where rates of loss are likely to increase.

Module 2 – Current impacts of non-climate change stressors. Many habitat types are already being affected by non-climate change stressors. The impacts on wetlands of reclamation or drought are examples, as are the impacts on forests of invasives, fires, or the cyclic outbreaks of pest species. Habitats that are already being adversely affected by these or other existing stressors may be intrinsically more vulnerable to a changing climate than are habitats that are not so affected.

Module 2 – likely future stressor trends. Habitats that are likely to experience a stabilization or decrease in non-climate stressor intensities in the future are likely to be able to persist better than habitats where such stressor trends are likely to remain stable or to increase.

Certainty Evaluation

As described above, each of the model variable scores was assigned a certainty score: High, Medium, or Low. These approximate confidence levels of >70%, 30-70%, and <30%. They are based on the 5-category scale developed by Moss and Schneider (2000) for the Intergovernmental Panel on Climate Change Third Assessment Report. It was believed by the NEAFWA Habitat Vulnerability Model developers, however, that using a 5-category scoring system would imply a greater level of certainty precision than was defensible, and it was, therefore, collapsed into a 3-category scale. The NEAFWA model not only assesses the certainty associated with the individual variable scores, at the conclusion of each habitat evaluation it also uses these scores to estimate the overall level of certainty.

Wider Application of the NEAFWA Habitat Vulnerability Model

Since the finalization and application of the NEAFWA Habitat Vulnerability Model in the Northeast Region, it has been adopted and used further afield and by individual states. It has been successfully used by the National Parks Service to evaluate habitat vulnerabilities in the Badlands of South Dakota, and is currently being used to evaluate habitat vulnerabilities in a number of states including New York, New Jersey, Maryland, and Vermont. It is also being used by the U.S. Forest Service to evaluate the vulnerabilities of habitats in the Colorado Front Range. This confirms that the basic framework and approach of the model are flexible enough to be applied in widely differing landscapes.

Chapter 4. Habitat Selection

Building on previous work carried out in the NEAFWA Region, we based our habitat selection and taxonomy on the habitat classification system and nomenclature developed by NatureServe (Gawler *et al*., 2008). By doing so, we intended to eliminate, to the extent possible, confusion that exists across the region in habitat naming.

Given the time and resources available, it was obviously not feasible to apply the NEAFWA model to all of the more than 140 different habitat types that exist in the Northeast Region (Gawler *et al*., 2008). Also, to do so would have involved a large amount of spurious precision: our knowledge about how the future climate will change, and our knowledge about how species and systems will respond, is uncertain enough that we cannot discriminate between the likely vulnerabilities of habitats that may have different classifications, but that are ecologically and/or floristically very similar. Therefore, we had to be selective in our choice of habitats for analysis. We applied five criteria in the selection of habitats:

- Habitat Systems (Gawler *et al*., 2008) were the foci of our analyses.
- We applied the model to habitats that were not tidally-influenced (we found that it was not possible to construct a model that could be used both for non-tidal and tidal habitat types and the latter is being included in this project via a separate evaluation approach).
- We focused mainly on the more extensive habitats within the region so as to evaluate the vulnerability of the greatest possible extent of the Northeast's habitat area.
- We also selected habitats that were more restricted in their distributions but considered by individual states to be important enough to include.
- To the extent possible, we attempted to cover all of the major biomes in the northeast – conifer forest, broadleaf forest, grasslands, shrublands, and wetlands.

Habitat Selection Process

The expert panel (Chapter 3) played an important role in the selection of the habitats for analysis. Manomet developed a preliminary list of target habitats (based on the criteria above) and submitted it for comment to all members of the panel. After receiving comments, Manomet modified and finalized the list. These modifications typically were to include habitat types that individual states or groups of states considered to be important, given their conservation mandates.

Habitats Evaluated

Based on the above process, 13 habitats were evaluated:[7]

Forests and Woodlands
Laurentian-Acadian Northern Hardwood Forest
Appalachian Northern Hardwood Forest
Central Mixed Oak-Pine Forest
Northeastern Pine Barrens
Acadian-Appalachian Montane Spruce-Fir Forest
Central and Southern Appalachian Spruce-Fir Forest

Wetlands
Laurentian-Acadian Wet Meadow-Shrub Swamp
Northern Atlantic Coastal Plain Basin Peat Swamp
Laurentian-Acadian Freshwater Marsh
North-Central Interior and Appalachian Acidic-Peatland
Boreal-Laurentian Bog
Boreal-Laurentian-Acadian Acidic Basin Fen

Grasslands
Acadian-Appalachian Alpine Tundra

[7] Cold water fish habitat and three tidally- influenced habitats are being evaluated using separate but parallel approaches. Their results are being reported separately. Thus, a total of 17 habitat types were evaluated.

Chapter 5. Model Application and Results

Model Application – latitudinal zones

One of the major objectives of applying the NEAFWA Habitat Vulnerability Model was to investigate potential geographical variation in habitat vulnerabilities to climate change across the Northeast Region. To accomplish this, the entire region was divided into 4 latitudinal zones (Figure 2).

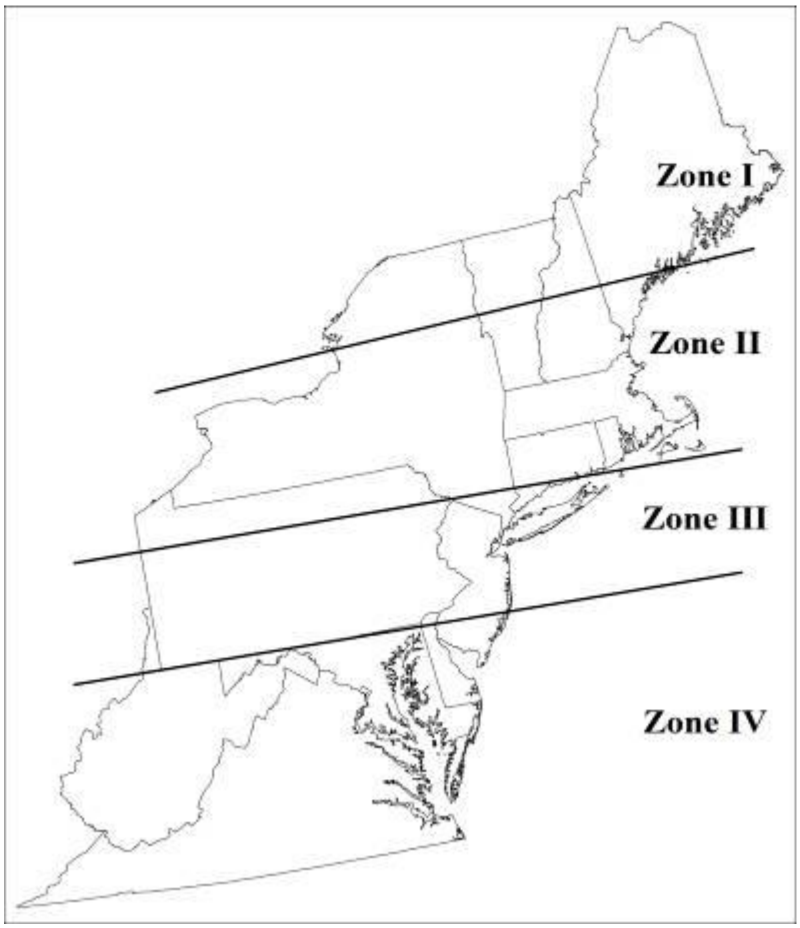

Figure 2. Latitudinal zones used in model application.

These zones correspond approximately to the major bioclimatic zones of the region. These are determined by systematic latitudinal variation in temperature, growing season length, plant hardiness, snow cover, etc. The zones shown in Figure 2 cannot correspond exactly to these climatic and ecological patterns because they are highly complex, due to the complication of topography, elevation, distance to the sea, etc. Nevertheless, they are a reasonable approximation.

Another objective of the modeling exercise was to provide individual states with approximations of the vulnerabilities of “their” habitats. It was not practical for us to run the model state-by-state, but we believe that the zones into which the region was divided are confined enough that states may use the results to extrapolate state vulnerabilities.

For each habitat that was investigated, the model was applied separately in each of the zones in which it occurred. For habitats that were ubiquitous throughout the region (e.g., northern hardwood forest), the result was four sets of vulnerability results, allowing us to compare variation in vulnerability north-south across the entire region. Some habitats were much more restricted in their distribution (e.g., alpine tundra), so fewer than four sets of vulnerability results were produced.

Model Application - peer review process

The NEAFWA Habitat Vulnerability Model was initially applied by Manomet to the 13 habitats identified in Chapter 4[8]. Once draft analyses of the model results were ready they were submitted for review to members of the expert panel who provided Manomet with reviews of the results. The participants in this process were:

Maine	Phillip deMaynadier	Inland Fisheries and Wildlife
	Andrew Cutko	Natural Areas Program
New Hampshire	Matt Carpenter	NH Fish and Game
Vermont	Eric Sorenson	VT Fish and Wildlife
Massachusetts	Caleb Slater	MA Fisheries and Wildlife
Connecticut	Min Huang	CT DEP
New York	Zoe Smith	Wild. Cons. Soc.
	Michale Glennon	Wild. Cons. Soc.
	Jerry Jenkins	Wild. Cons. Soc.
	Tracey Tomajer	NY DEC
New Jersey	Kris Schantz	NJ DFW
Pennsylvania	David Day	PA FBC
	Mary Anne Furedi	PAConserve
Virginia	David Norris	DGIF
	Chris Burkett	DGIF
West Virginia	Elizabeth Byers	WV DNR
	Kerry Bledsoe	WV DNR
	Paul Johansen	WV DNR
Maryland	Dana Limpert	MD DNR
Delaware	Robert Hossler	DE DFW
	Karen Bennett	DE DFW

[8] Three intertidal habitats and cold water fish habitat are being evaluated using a somewhat different approach and the results are being presented in separate reports to NEAFWA and the North Atlantic LCC.

Model Application – Land Cover

Table 2. Extent (in thousands of acres) of each habitat evaluated using the NEAFWA Habitat Vulnerability Model. Data from TNC/NEAFWA (2011) maps and database.

Habitat	ME	NH	VT	MA	NY	CT	RI	NJ	PA	MD	DE	VA	WV	DC
Alpine Tundra	3.6	4.2	0.11		0.28									
Spruce-Fir Forest	417.3	351.3	101.7	0.6	213.4									
N. Hardwood Forest	8,396	3,307	3,887	1,617	13,208	589.5	11.9	127.5	8,331	283.7	3.6	157	1,130	1.3
Oak-Hickory Forest	4.8	15.1	25.0	291.1	2,128	993.4	180.4	583.0	7,761	819.3	8.4	5,037	5,948	1.5
Southern Spruce-Fir Forest												6.4	59.0	
Pine Barrens	9.1	5.7	0.5	103.3	82.9	0.15	6.0	326.5						
White Cedar Swamp	0.65	1.1		11.8	0.09	2.5	1.7	35.7		1.0	4.9			
Boreal Bog/Fen/Peatland	355.7	10.2	9.05	4.9	119.4	0.6	0.3	0.1	30.1					
Shrub Swamp	354.0	63.5	53.4	79.1	319.9	24.1	5.2	69.9	46.9	32.5	11.6	44.4	10.4	0.01
Freshwater Marsh	257.8	50.7	52.0	62.8	257.9	19.3	6.2	112.5	64.3	81.5	25.1	101.5	16.8	0.19
All	9,798	3,808	4,128	2,171	16,329	1,629	212	1,255	16,233	1,218	53.6	5,346	7,164	3.0

A total of 69,347,600 acres of wetland and upland habitat was evaluated using the NEAFWA Habitat Vulnerability Model (Table 2). This comprises approximately 60% of the total wildlife habitat (excluding developed areas and agricultural land) in the NEAFWA Region (data from TNC/NEAFWA (2011) database).

Model Results

The results of the model runs on the 13 habitats are presented in Attachments 3-12 of this report. They are summarized, however, in Tables 3 through 5 and Figure 3 below.

Table 3. Vulnerabilities to Climate Change of Northeastern Habitats.

	Zone I	**Zone II**	**Zone III**	**Zone IV**
A-A Alpine Tundra	Highly Vulnerable			
A-A Montane Spruce-Fir Forest	Vulnerable	Highly Vulnerable		
L-A Northern Hardwood Forest	Less Vulnerable	Vulnerable	Vulnerable	Highly Vulnerable
App. Northern Hardwood Forest			Vulnerable	Highly Vulnerable
Central Oak-Pine Forest	Least Vulnerable	Least Vulnerable	Least Vulnerable	Vulnerable
Pine Barrens		Least Vulnerable	Least Vulnerable	Least Vulnerable
C-S App. Spruce-Fir Forest				Critically Vulnerable
North. Atlantic Coastal Plain Basin Peat Swamp		Less Vulnerable	Less Vulnerable	Less Vulnerable
B-L Bog	Highly Vulnerable	Highly Vulnerable		
B-L Acidic Fen	Highly Vulnerable	Highly Vulnerable		
N-C-I Acidic Peatland	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	
L-A Marsh	Less Vulnerable	Less Vulnerable	Less Vulnerable	Less Vulnerable
L-A Shrub Swamp	Less Vulnerable	Less Vulnerable	Less Vulnerable	Less Vulnerable

Are Northeastern Fish and Wildlife Habitats Vulnerable to Climate Change?

Most of the habitats that were evaluated in this study are likely to suffer range contractions under the changing climate (Table 3 and Figure 3). Eight of the 13 habitats are at significant risk of being eliminated entirely from the Northeast (Appalachian Spruce-Fir Forest), or of having their current distributions reduced by at least 50% in at least one zone (Alpine Tundra, Montane Spruce-Fir Forest, Northern Hardwood Forest, Appalachian Northern Hardwood Forest, Appalachian Spruce-Fir Forest, Boreal-Laurentian Bog and Acidic Fen, and Acidic Peatland). These are all habitats that are either northern or boreal in their distributions, confined to high elevations or mountain summits, or reach their southernmost extents within the region.

The most vulnerable habitat to climate change (Appalachian Spruce-Fir Forest) is one that is confined to areas with low temperatures and short growing seasons on the tops of the highest mountains in Zone IV, the southernmost zone. It is highly fragmented in its distribution. As temperatures increase, the "climatic envelope" of this habitat can be expected to rise above the tops of the highest mountains where it currently occurs – the habitat will be "stranded" and eradicated by climate change. The next most vulnerable habitat within the region, Alpine Tundra, is again confined to the highest elevations of only one zone, is highly fragmented in its distribution, and can persist only where temperatures are low, the weather conditions are extreme, and the growing season is short. These combinations of characteristics render both habitats extremely sensitive to climate change.

Montane Spruce-Fir and Northern Hardwood forests are more widespread in the Northeast than either tundra or Appalachian Spruce-Fir Forest, and less restricted in their latitudinal and altitudinal distributions. However, they are similar in that they are also limited, though less strictly, to areas that have lower temperature regimes and shorter growing seasons and are, therefore, vulnerable to warming.

In summary, habitats in the Northeast are indeed vulnerable to the changing climate, many of them likely to suffer major distributional contractions as the region warms. The habitats that are most vulnerable are those that are adapted to more northern or higher elevation areas where temperatures are typically low, the climatic conditions may be extreme, and growing seasons are short. These most vulnerable habitats are (in approximate decreasing order of vulnerability):

- Appalachian Spruce-Fir Forest
- Alpine Tundra
- Montane Spruce-Fir Forest
- Boreal Peatlands (bogs and fens)
- Northern Hardwood Forest

As the climate continues to warm, all of these habitats can be expected to greatly contract their distributions northward or upward in elevation, where this is possible. Where such geographic shifts are not possible, they may be replaced eventually by species and communities that are more tolerant of the changing climate. For most of these habitats (except Appalachian Spruce-Fir Forest) the northernmost zones and the highest elevations may well comprise refugia, assuming a doubling of $CO_{2.}$ If future emissions result in greater atmospheric concentrations of greenhouse gases, even these refugia can be expected to diminish further.

Do Habitat Vulnerabilities Vary Across the Region?

For many of the habitats that are vulnerable to climate change and that occur in two or more zones (Montane Spruce-Fir Forest, Northern Hardwood Forest, Appalachian Northern Hardwood Forest, Central Oak-Pine Forest) their vulnerabilities increase from north to south, as their bioclimatic range limit is approached. Thus, their vulnerabilities are generally lowest in the most northern parts of the region. For example, Laurentian-Acadian Northern Hardwood Forest is at its most vulnerable at the southern edge of its distribution (Zone IV), but its vulnerability decreases to the north until in Zone I it may be relatively less affected by the changing climate. Central Oak-Pine Forest is least vulnerable in the 3 most northern zones, where it may be able to benefit from a warming regime and expand into areas from which it is currently excluded by lower temperatures, shorter growing seasons, and competition from northern hardwood species. However in Zone IV, where Central Oak-Pine Forest approaches its southern range limit it is more vulnerable as it faces competition from southern conifer forests that may be expanding northward.

Thus, the vulnerabilities of many habitats in the Northeast to climate change are not uniform across the region, but show significant latitudinal changes. If asking the question – is a particular northeastern habitat vulnerable to climate change – the geographical context in which the question is asked must be made explicit. If it is not, the answer to the question may be misleading.

Are All Habitats Vulnerable to Climatic Change?

Table 3 shows that not all habitats are equally vulnerable to climate change. In fact, while some seem to be highly vulnerable, others (Atlantic White Cedar Swamps, Pine Barrens, Emergent Marshes and Shrub Swamps) are much less so. So, climatic change is not likely to adversely affect all habitats and the habitats already named may show little impact. This is because these habitats are not northern in their distributions. In fact, they extend far to the south of the Northeast Region and into areas where the climatic conditions are already similar to those that are projected for the region in the future. Also, many of them are not particularly sensitive to the types of ecological disruptions that can be expected to occur under the changing climate. For example, drought and more frequent and intense wildfires are projected for the future climate in the Northeast. However, Pine Barrens is a habitat type that is dependent on this for its continued existence in an area, and recovers quickly from burning. Also, oak-pine forest, which is projected to extend its range throughout the Northeast at the expense of northern hardwoods, is less sensitive to wildfires that the habitat that it is likely to replace.

May Some Habitats Benefit From Climate Change?

As vulnerable habitats contract their ranges under the changing climate, they will not leave behind habitat-free areas. Other, better-adapted species and habitats will expand their distributions into these areas from which they may have previously been excluded by competition. So, climate change ecological responses involve both losers and winners.

The most obvious example in Table 3 is Central Oak-Pine Forest which is likely to expand its range into areas that are currently dominated by northern hardwood plant species. At present, oak-pine forest is a low-middle elevation community in the central and southern states of the Northeast, and reaches its northernmost outpost in low-lying areas in central New England. At higher elevations and more northern areas it transitions into northern hardwood forests. In the future, we might expect to see the foundational species of oak-pine forest (various oak and hickory species, for example) shifting northward in New England and upwards in elevation throughout the region. In consequence, the plant and animal species that are characteristic of this habitat type may also benefit from these shifts and also extend their ranges.

Is Climate Change Likely to be the Major Stressor in the Future?

Table 4 shows that non-climate stressors that already impact many habitats will continue to be important stressors in the future. For example, invertebrate pests already adversely impact some forest types, such as hemlock stands or Central-Southern Appalachian Spruce-Fir Forests. Indeed, in some areas these pests are a major determinant of the condition and distribution of these habitats. The same applies to over-abundance of white-tailed deer in northeastern forests and their effects on the habitat through grazing and browsing, or the invasion of native plant communities by exotic species. While climate change may increasingly exert adverse effects on these habitats, the current stressors will also likely continue to be important, conceivably more important.

Paradoxically, this offers some hope for being able to mitigate the effects of the changing climate. While it may be difficult to prevent climate change, by lessening the impacts of non-climate stressors on species and habitats we may be able to increase their overall resilience and adaptive capacities to the changing climate.

Will Climate Change and Non-Climate Stressors Interact to Affect Habitats?

Projecting changing interactions between species due to a changing climate is fraught with uncertainties because many such changes are likely to become obvious only as they actually occur, and many of them may be non-linear in nature. However, the analyses reported in Attachments 3-12 in this report identify many instances where such interactions may occur. Also, these interactions may exacerbate the impacts of the changing climate. The most obvious examples concern the “beneficial” effects that climate change may have on the life cycles of pest species. There is already evidence that some forest pests are benefiting from the changed climatic conditions. Hemlock wooly adelgid, for example, is shifting its range northwards and impacting hemlock stands that were previously not vulnerable to it. This is due to the warming winter temperatures allowing the pest (which is temperature-limited) to colonize new areas. The same may also be happening at higher elevations, though this has not yet been demonstrated.

The spread and impacts of other stressors, such as white-tailed deer, emerald ash borer and balsam wooly adelgid, are limited by climate. Climate change introduces the potential of their impacts being increased and extended in the region.

How Important Will Societal Responses to Climate Change Be?

The analyses carried out in this study indicate that in at least some instances the responses of human communities to the changing climate may be as important as climate change itself for the conditions of habitats and their associated species. How will societies react to the increasing frequencies and intensities of wildfires in forest habitats that are already settled by communities, or that are the target of future settlements? How will we view the potential need for more controlled burns in such areas? How will human communities respond to increasing algal blooms in lakes that are used for recreation (as well as providing habitat for sensitive aquatic species)? How will humans view the increased need for control of pest species, such as deer? The answers to these questions are more obscure than questions about how climate change may directly impact species and habitats and may only become obvious as the changes progress and the need for societal decisions become more urgent.

Table 4. Future Vulnerabilities of Northeastern Habitats to Non-Climate Stressors.

	Zone I	**Zone II**	**Zone III**	**Zone IV**
A-A Alpine Tundra	Vulnerable			
A-A Montane Spruce-Fir Forest	Vulnerable	Highly Vulnerable		
L-A Northern Hardwood Forest	Vulnerable	Vulnerable	Vulnerable	Vulnerable
App. Northern Hardwood Forest			Vulnerable	Vulnerable
Central Oak-Pine Forest	Less Vulnerable	Less Vulnerable	Vulnerable	Vulnerable
Pine Barrens		Least Vulnerable	Least Vulnerable	Least Vulnerable
C-S App. Spruce-Fir Forest				Critically Vulnerable
North. Atlantic Coastal Plain Basin Peat Swamp		Less Vulnerable	Less Vulnerable	Less Vulnerable
B-L Bog	Less Vulnerable	Less Vulnerable		
B-L Acidic Fen	Less Vulnerable	Less Vulnerable		
N-C-I Acidic Peatland	Less Vulnerable	Less Vulnerable		
L-A Marsh	Vulnerable	Vulnerable	Vulnerable	Vulnerable
L-A Shrub Swamp	Vulnerable	Vulnerable	Vulnerable	Vulnerable

Table 5. Overall Future Vulnerabilities of Northeastern Habitats.				
	Zone I	**Zone II**	**Zone III**	**Zone IV**
A-A Alpine Tundra	Highly Vulnerable			
A-A Montane Spruce-Fir Forest	Vulnerable	Critically Vulnerable		
L-A Northern Hardwood Forest	Vulnerable	Vulnerable	Vulnerable	Highly Vulnerable
App. Northern Hardwood Forest			Vulnerable	Highly Vulnerable
Central Oak-Pine Forest	Least Vulnerable	Least Vulnerable	Less Vulnerable	Vulnerable
Pine Barrens		Less Vulnerable	Less Vulnerable	Less Vulnerable
C-S App. Spruce-Fir Forest				Critically Vulnerable
North. Atlantic Coastal Plain Basin Peat Swamp		Less Vulnerable	Less Vulnerable	Less Vulnerable
B-L Bog	Highly Vulnerable	Highly Vulnerable		
B-L Acidic Fen	Highly Vulnerable	Highly Vulnerable		
N-C-I Acidic Peatland	Highly Vulnerable	Highly Vulnerable		
L-A Marsh	Vulnerable	Vulnerable	Vulnerable	Vulnerable
L-A Shrub Swamp	Vulnerable	Vulnerable	Vulnerable	Vulnerable

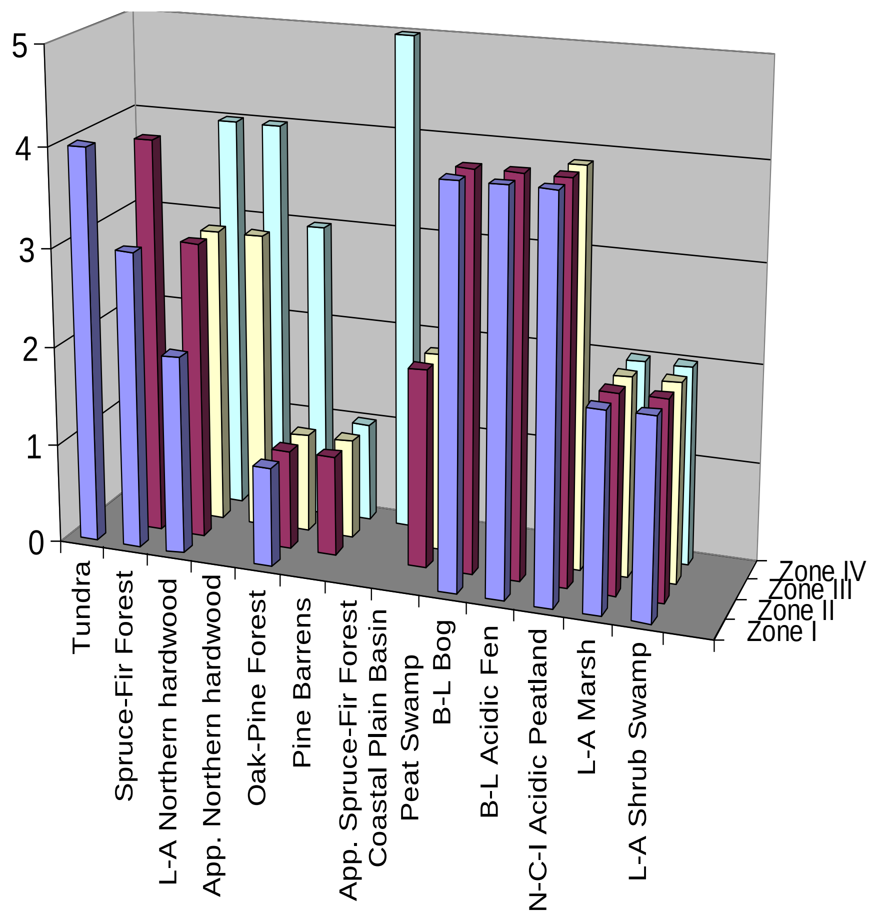

Figure 3. Vulnerabilities of Northeastern habitats to climate change. On y-axis, 5 represents Critically Vulnerable, 4 represents Highly Vulnerable, 3 represents Vulnerable, and 2 and 1 represent Less and Least Vulnerable respectively.

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Attachment 1. Climate Change in the Northeast

Introduction

Climate modeling analyses for the Northeast Region of the United States have projected major changes over the rest of this century (e.g., Hayhoe *et al*., 2006). They also indicate that the magnitudes of these changes are likely to vary spatially across the region (e.g., Hayhoe *et al*., 2006; IPCC, 2007; Hayhoe *et al*., 2007; Karl *et al.*, 2009; Sallenger *et al*., 2012). Exposures[9] of systems or species will, therefore, also vary temporally and geographically. Therefore, if the vulnerabilities of ecological resources to climate change are to be understood, the magnitudes and geographical variations in future exposure must be taken into account (Parmesan and Galbraith, 2004; Glick *et al*., 2011). This attachment presents information from the literature (and some new analyses) describing how the exposures of northeastern species and systems may change and vary geographically over this century. This is not intended to be an exhaustive analysis of future climate change. Rather, it uses mostly existing data, and was intended to provide project expert panel and habitat workgroup members who were assessing vulnerabilities with background information describing likely climate futures. As they evaluated vulnerability assessments for selected habitats across the region, workgroup members were able to use the figures and tables presented in this report to asses how climatic changes and exposures may vary across the region. The data were gathered from two sources – the Northeast Climate Impacts Assessment (NECIA), and the web-based tool, ClimateWizard. NECIA (2006)

was a major effort to describe plausible climate futures in the Northeast by statistically downscaling 3 Global Circulation Models (GCMs) to a 1/8 ^{o} scale. The results were presented in a project report (NECIA, 2006), several scientific papers (e.g., Hayhoe *et al.*, 2006 and Hayhoe *et al.*, 2007), and in an interactive website (http://www.northeastclimatedata.org/). ClimateWizard is a web-based interactive tool (http://www.climatewizard.org/) developed by The Nature Conservancy and the Universities of Washington and Southern Mississippi. It uses various combinations of the output of 16 GCMs to statistically downscale information to a 12 km grid scale. Both sources provide the most recent and thorough downscaled analyses of how the climate may change in the Northeast Region over the remainder of this century.

The southern boundary of the NECIA (2006) study area included the southern states of the NEAFWA area. However, for some variables (temperature, precipitation, evapotranspiration, soil moisture, snow cover days, drought, runoff, and stream flow) it excluded the southern portions of Virginia and West Virginia. ClimateWizard was used to fill this gap in coverage for the first two variables.

Also, the temperature and precipitation metrics that can be addressed using ClimateWizard do not exactly match those that can be derived from the NECIA data-set. For example, the NECIA upper emissions estimates (Nakienovi *et al*. 2000) are based on

[9] The exposure of an ecological resource (i.e., plant, animal, or community) to climate change refers to the direction and magnitude of change that the resource will experience (Glick *et al.*, 2010)

the A1Fi emissions scenario, while ClimateWizard generally uses the A2 scenario. However, they are close enough for an acceptable match for the purposes of vulnerability assessment. Furthermore, the NECIA analyses cover a wider range of variables (temperature, precipitation, growing seasons, stream flow, snow cover, etc.) than are available in ClimateWizard, which is restricted to temperature and precipitation. We used both analytical tools to develop a comprehensive appraisal of how northeastern climate and climate-related parameters will likely change over this century.

Exposure Information

The results of both downscaling analyses for the northeastern region are shown in Table 1 and in Figures 1 through 23. Table 1 presents the key, biologically relevant findings of the NECIA study for the region. Figures 1 through 5 describe how temperature and precipitation regimes are expected to alter over the next decades assuming low and a high (or medium-high) emissions scenarios. Figures 6 and 7 present NECIA results on how growing season and plant hardiness zones may alter. Figures 8 and 9 describe anticipated changes in evapotranspiration and soil moisture content. Figure 10 shows projected changes in the characteristics of future snow cover in the region and Figure 11 projects future drought frequencies. Figures 12 through 17 project future changes in stream flow, runoff and low flow periods over the remainder of the century, while Figures 18 through 22 use ClimateWizard analyses to project temperature and precipitation changes for the states of Virginia and West Virginia. Figure 23 and Table 2 show projections of future sea level rise for each state based on current rates of change from tide gauge stations in the northeastern states plus two assumptions about future extent of sea level rise due to climate change: one meter and two meters.

Table 1. Projected changes in key climate indicators for the periods 2035-2064 and 2070-2099 (from NECIA, 2006).

		1961-1990	2035-2064			2070-2099		
	UNITS	20C3M	B1	A2	A1FI	B1	A2	A1FI
Temperature								
Annual	°C	7.8	+2.1	+2.5	+2.9	+2.9	+4.5	+5.3
Winter (DJF)	°C	-4.8	+1.1	+1.7	+3.1	+1.7	+3.7	+5.4
Summer (JJA)	°C	20.0	+1.6	+2.2	+3.1	+2.4	+4.3	+5.9
Precipitation								
Annual	cm (%)	102.9	+5%	+6%	+8%	+7%	+9%	+14%
Winter (DJF)	cm (%)	20.95	+6%	+8%	+16%	+12%	+14%	+30%
Summer (JJA)	cm (%)	28.03	-1%	-1%	+3%	-1%	-2%	0%
Sea Surface Temperatures[1]								
Gulf of Maine	°C	11.6[1]	+1.3[1]	+1.5[2]	–	+1.9[1]	+3.3[2]	–
Gulf Stream	°C	23.4[1]	+0.9[1]	+1.3[2]	–	+1.2[1]	+2.3[2]	–
Terrestrial Hydrology								
Evaporation	mm/day	1.80	+0.10	–	+0.16	+0.16	–	+0.20
Runoff	mm/day	1.14	+0.12	–	+0.09	+0.21	–	+0.18
Soil Moisture	% sat	55.0	+0.4	–	+0.02	+1.0	–	-0.07
Streamflow								
Timing of spring peak flow centroid	days	84.5	-5	–	-8	-11	–	-13
Low flow days (Q<0.0367 m3/s/km2)	days	65.5	-14	–	-1.5	-26	–	+22
7-Day low flow amount	%	100%	-4	–	-1	-4	–	-11
Drought Frequency								
Short	no. of droughts per 30 years	12.61	+5.12	–	+7.19	+3.06	–	+9.99
Med	no. of droughts per 30 years	0.57	+0.03	–	+0.51	+0.39	–	+2.21
Long	no. of droughts per 30 years	0.03	+0.03	–	+0.11	+0.04	–	+0.39
Snow								
Total SWE	mm	11.0	-4.4	–	-5.5	-5.9	–	-9.3
Number of snow days	days/mnth	5.2	-1.7	–	-2.2	-2.4	–	-3.8
Growing Season[2]								
First frost (autumn)	day	295	+1	+16	–	+6	+20	–
Last frost (spring)	day	111	-8	-14	–	-16	-23	–
Length of growing season	days	184	+12	+27	–	+29	+43	–
Spring Indices[2]								
First leaf	day	98.8	-3.0	-5.2	-3.9	-6.7	-15	-15
First bloom	day	128.8	-3.7	-6.0	-5.6	-6.3	-15	-16

[1] Based on SST output ("tos") from HadCM3, MIROC, CGCM CCSM, and PCM only

[2] Time periods restricted by output availability to 2047-2065 and 2082-2099.

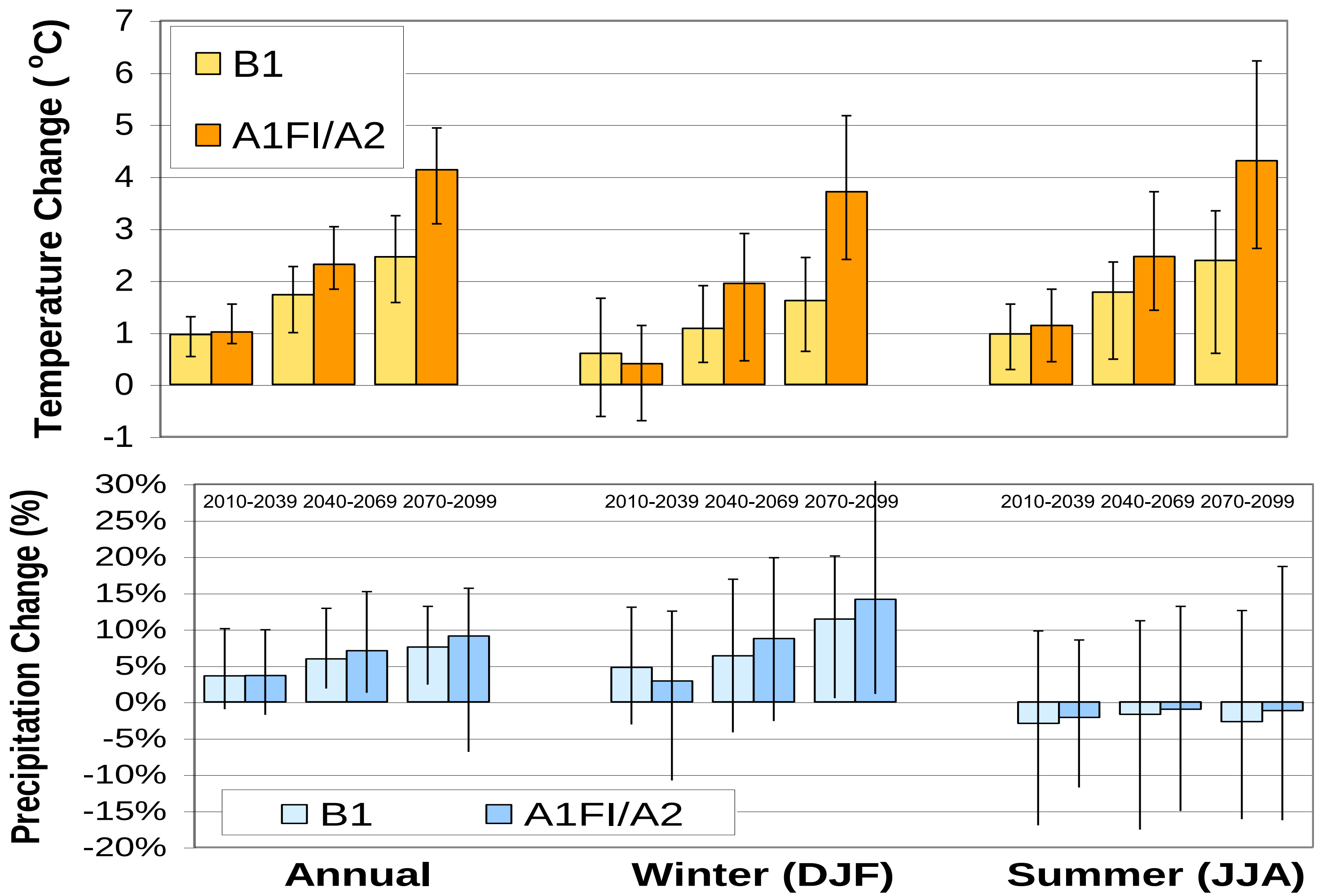


Figure 1. Projected mean annual temperature and precipitation change across entire Northeast Region under two emissions scenarios and in three time periods. From NECIA, 2006.

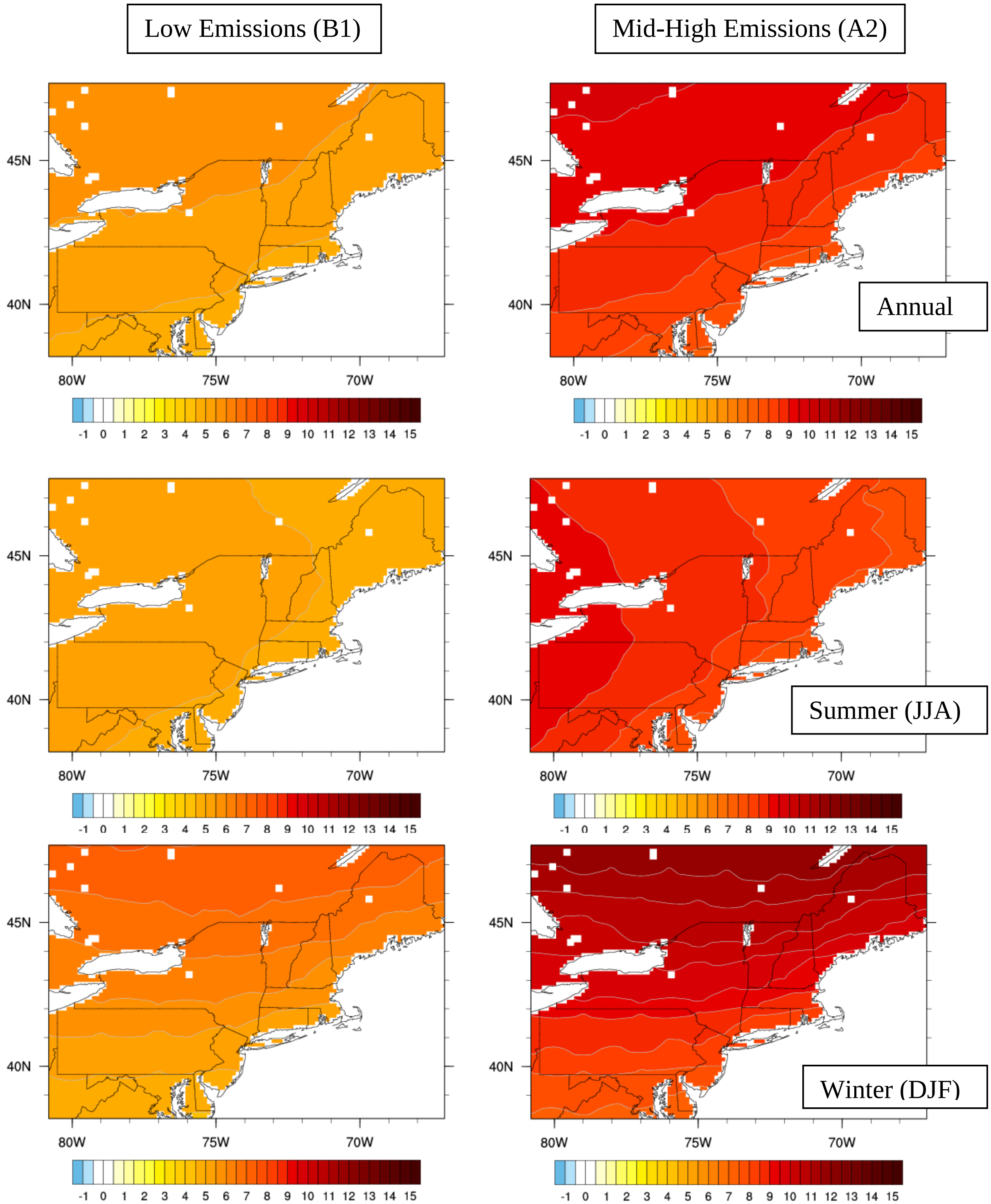


Figure 2. Projected mean temperature change (°F) by 2080-2099 relative to 1971-2000. From NECIA, 2006.

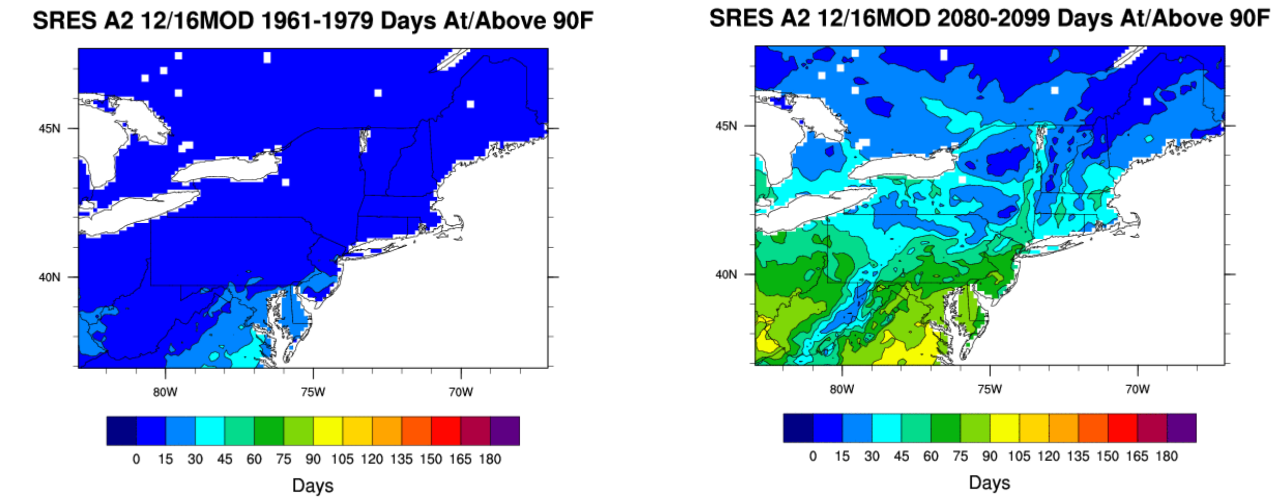


Figure 3. Extreme heat days (>90 °F) Historic and Mid-High Emissions (A2). From NECIA, 2006.

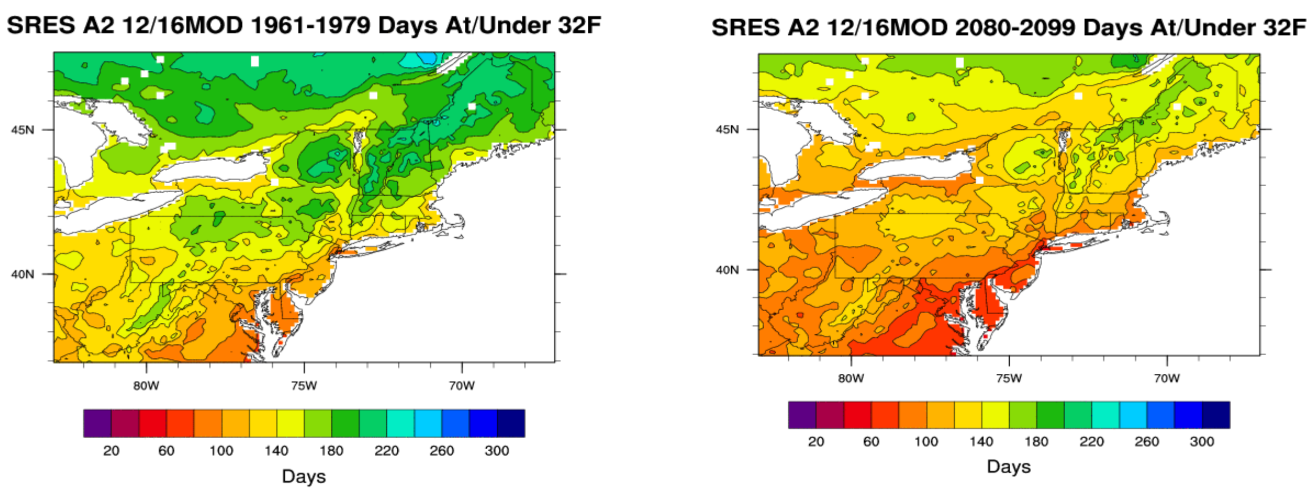


Figure 4. Freeze days (minimum temperature <32 °F). Historic and Mid-High Emissions. From NECIA, 2006.

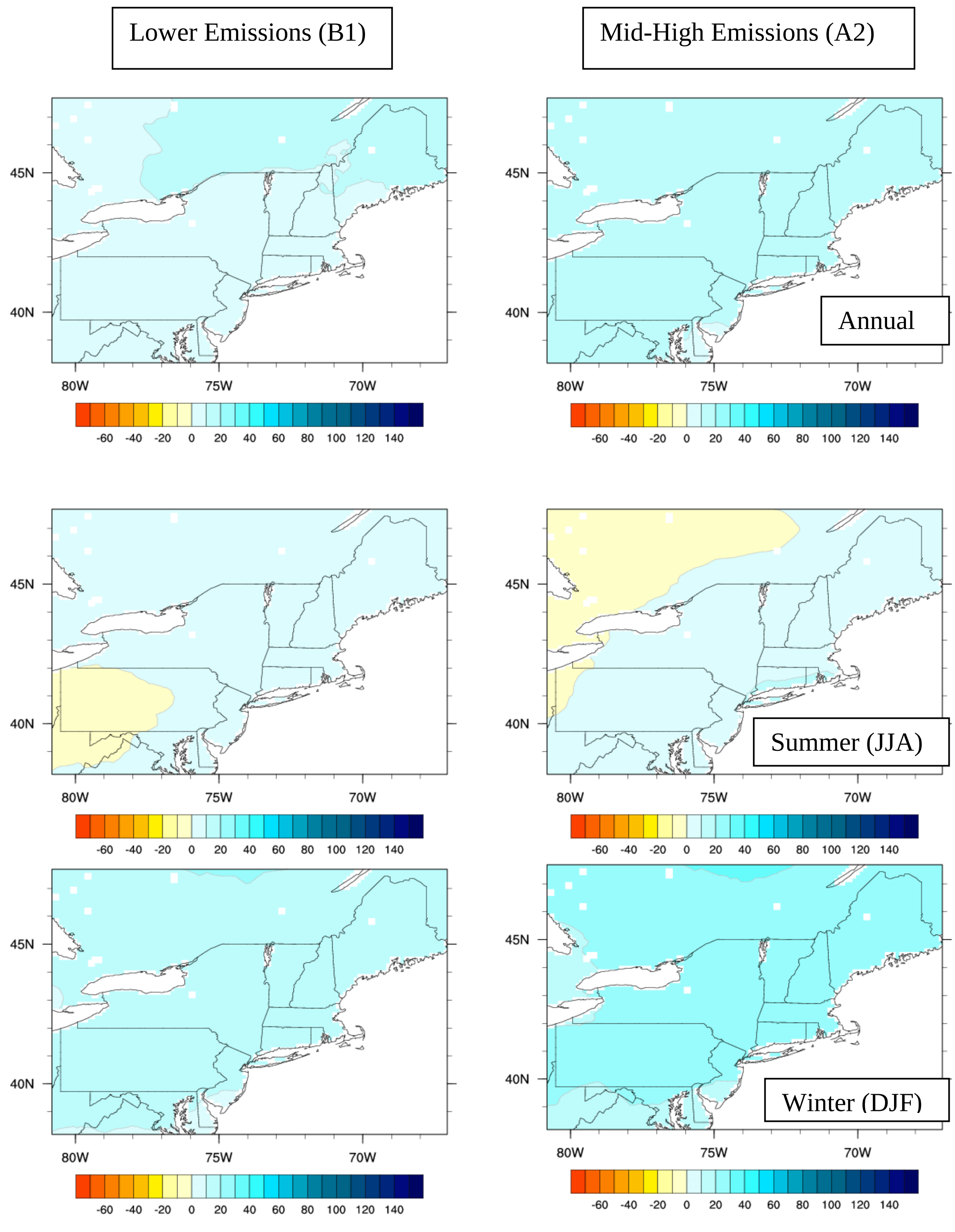


Figure 5. Projected mean precipitation % change relative to 1971-2000 by 2080-2099. From NECIA, 2006.

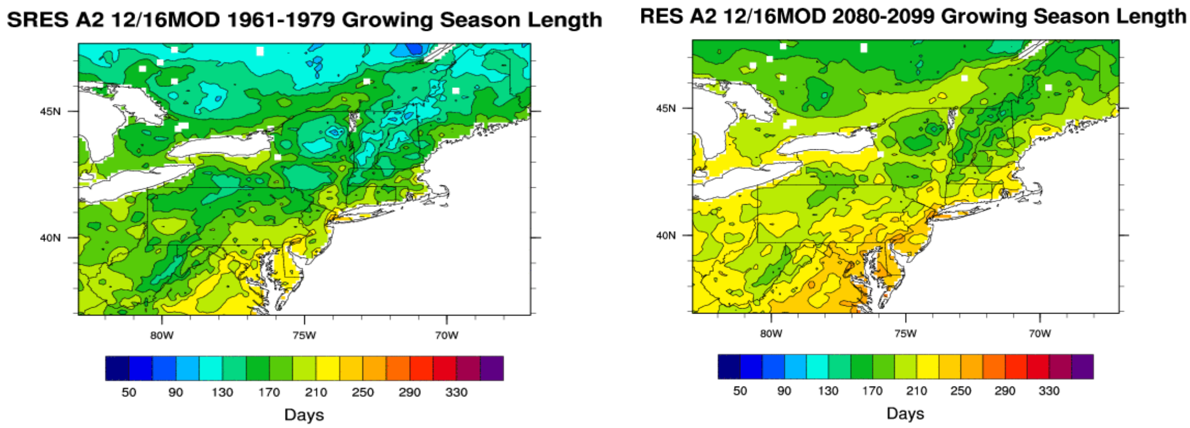


Figure 6. Modeled growing season length (days) in 1961-1979 and 2080-2099. Mid-High Emissions (A2). From NECIA, 2006.

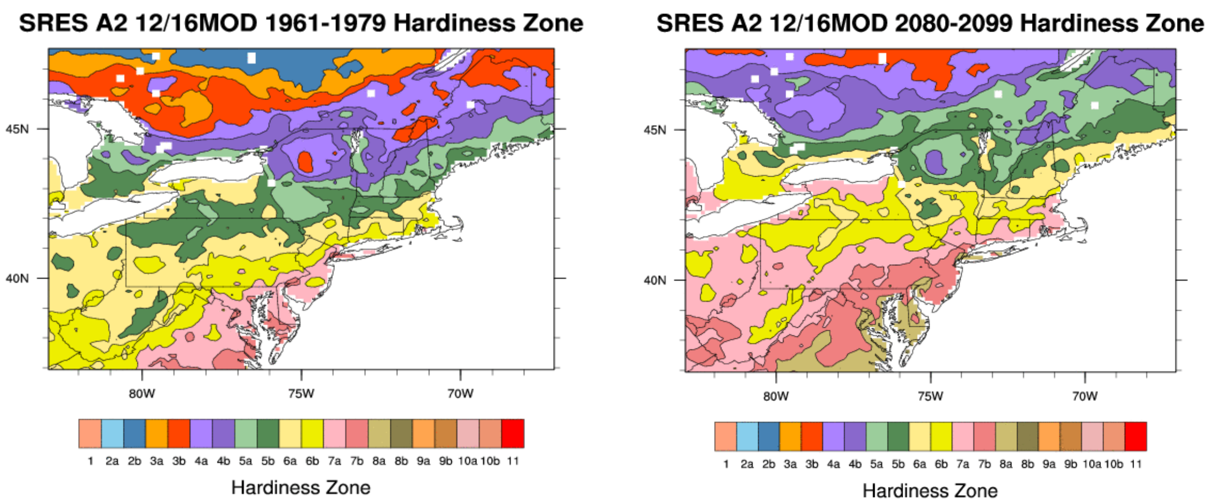


Figure 7. Modeled plant hardiness zones in 1961-1979 and 2080-2099. Mid-High Emissions (A2). From NECIA, 2006.

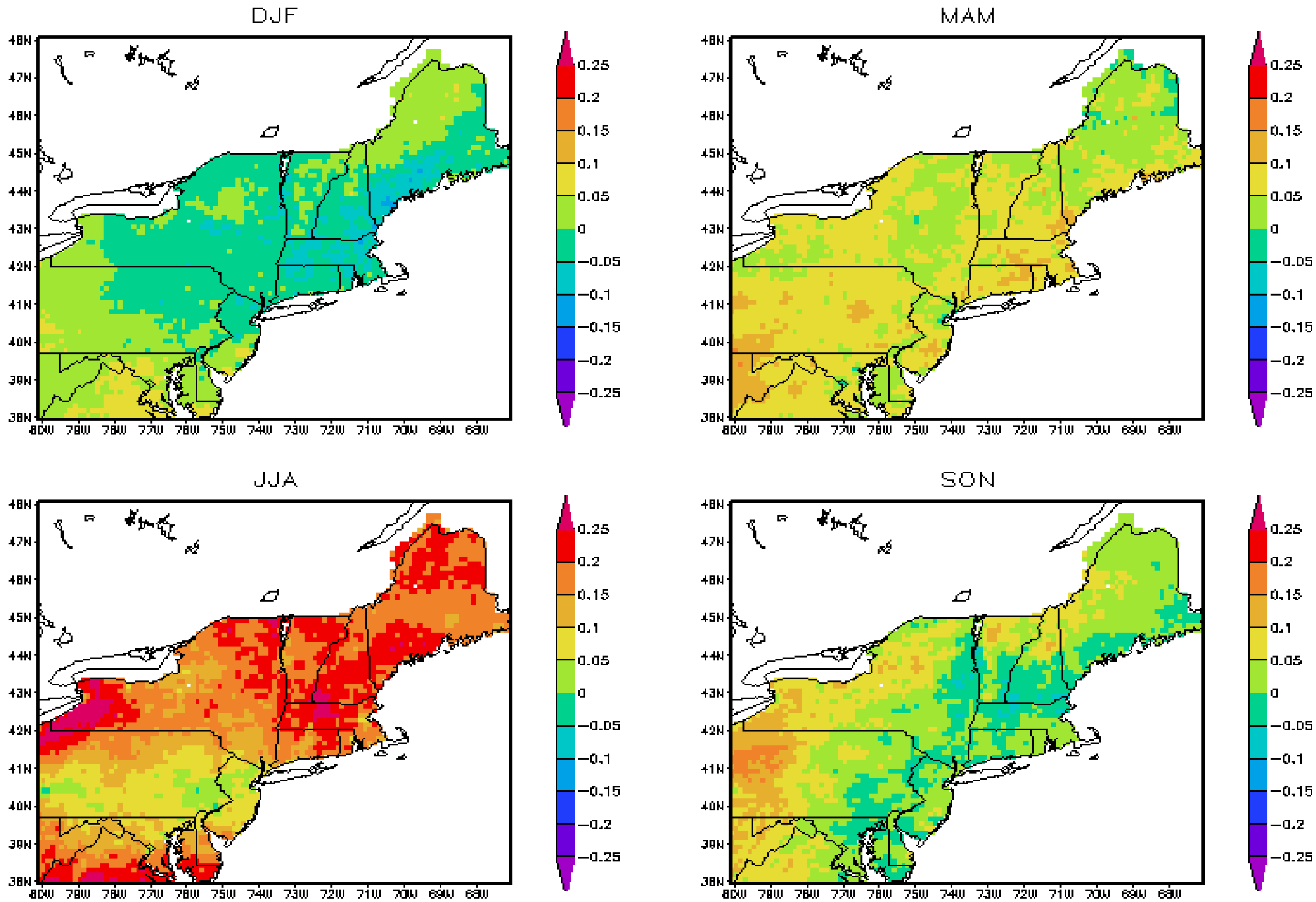


Figure 8. Projected percent seasonal changes in evapotranspiration. 2030-2060 relative to 1970-1999. B1 emissions scenario. From NECIA, 2006.

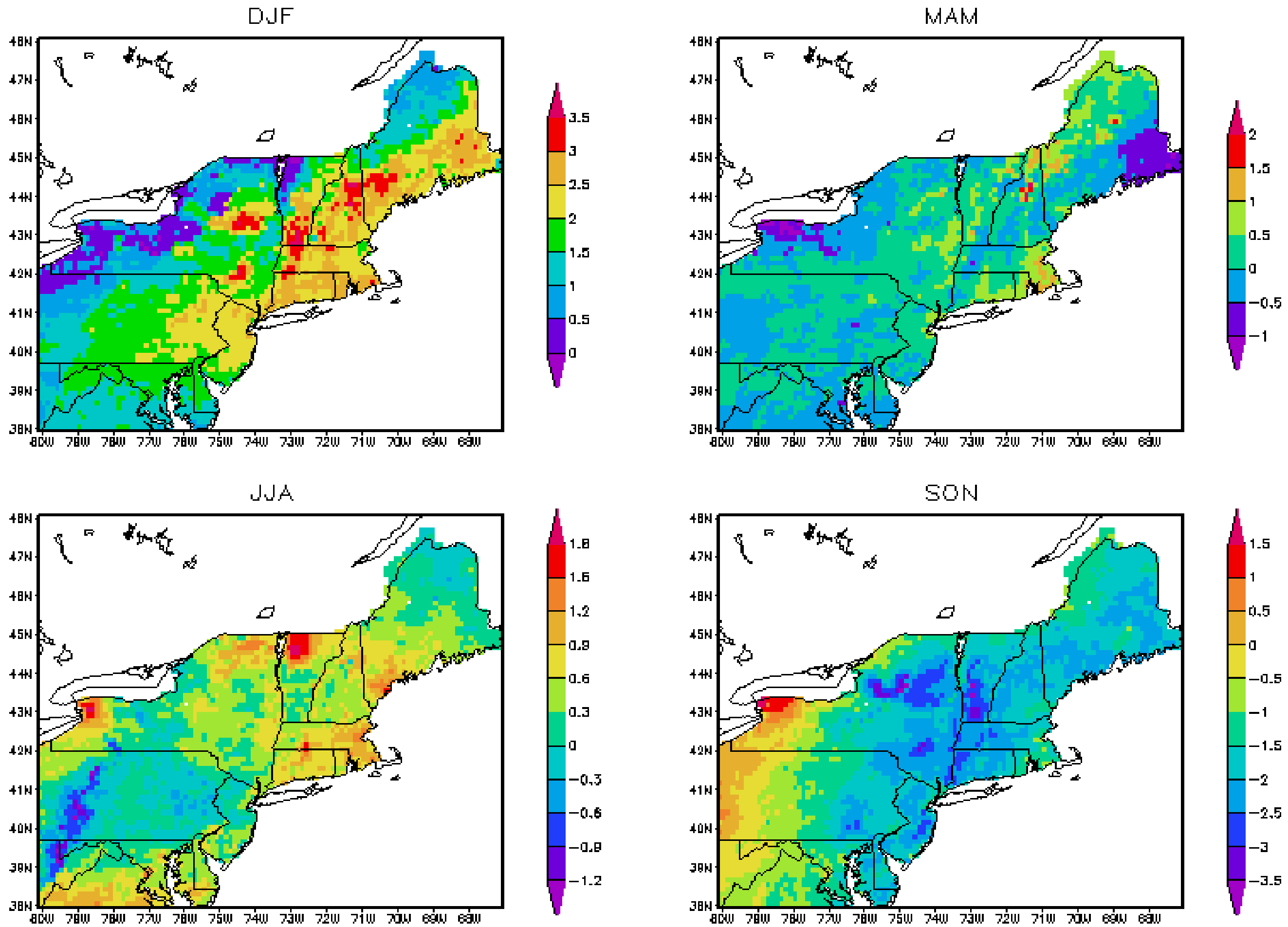


Figure 9. Projected percent seasonal changes in soil moisture. 2030-2060 relative to 1979-1999 (A1Fi emissions scenario). From NECIA, 2006.

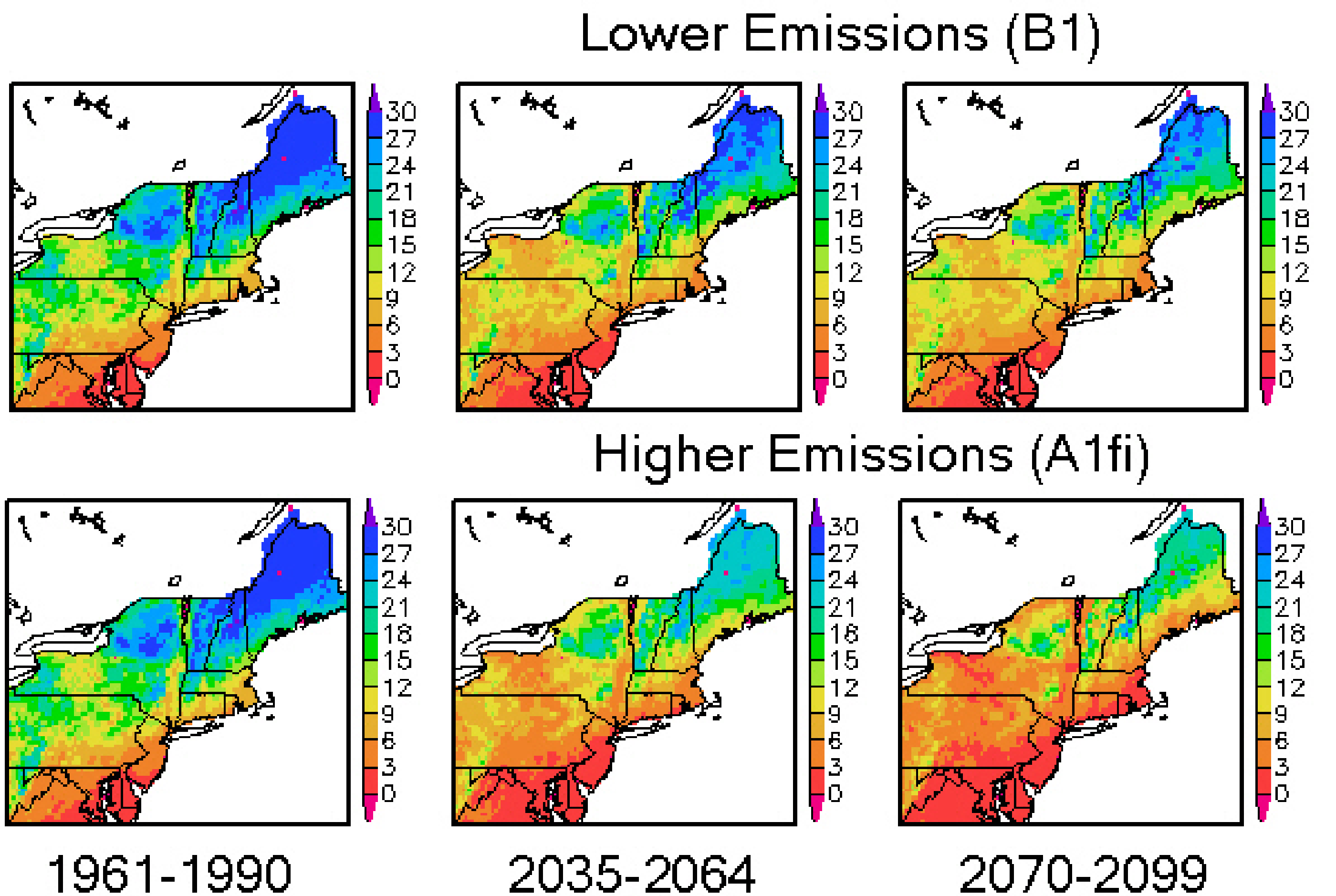


Figure 10. Number of Snow-covered days/month (Dec-Feb). From NECIA, 2006.

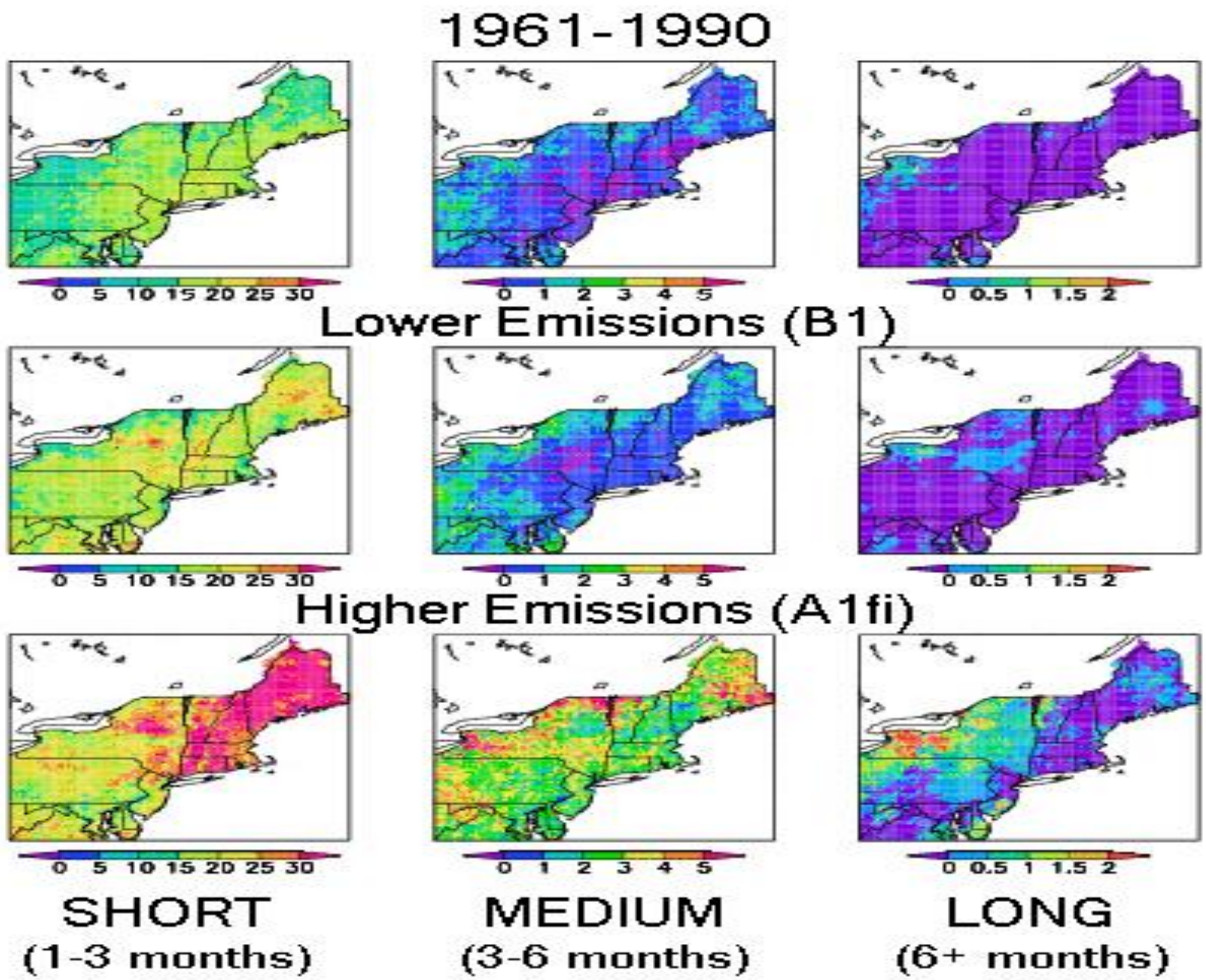
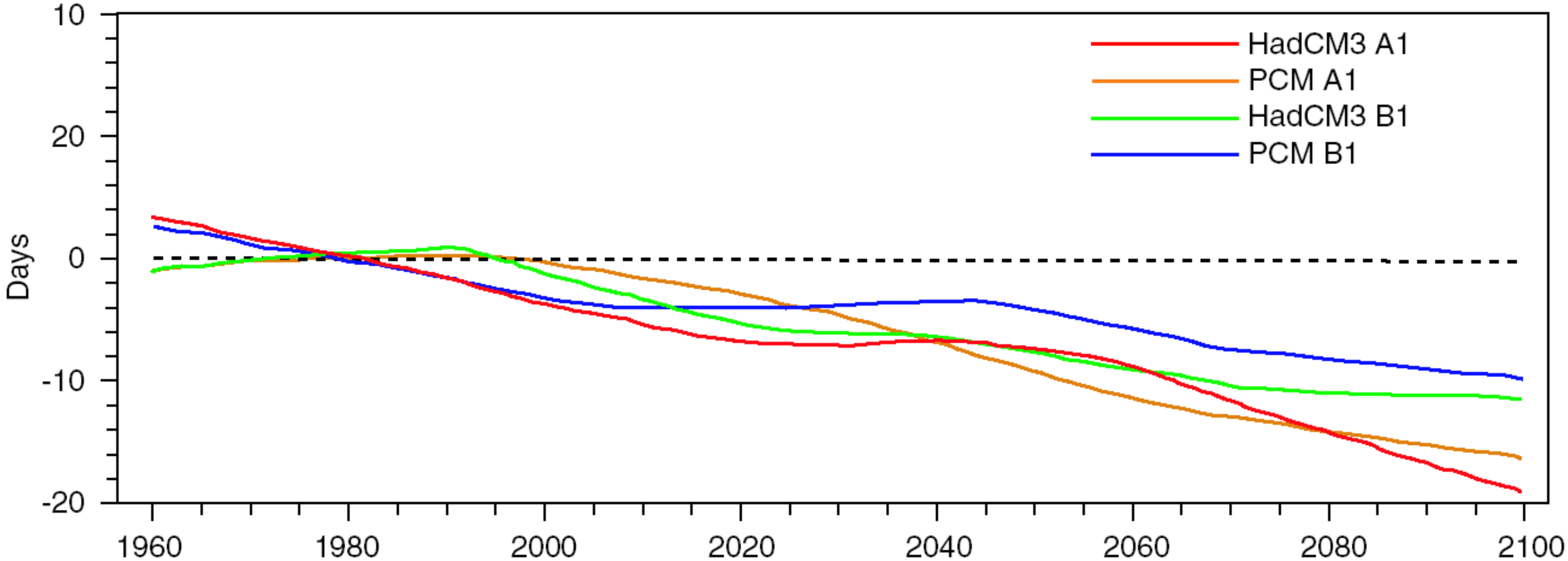


Figure 11. Frequencies of Short-, Medium-, and long-term droughts during 1961-1990 and projected for the 30 year period 2070-2099. Values are the average of the HadCM3 and PCM models. From NECIA, 2006.



~ 1.5 to 2 weeks earlier (lower emissions, B1)
~ 2 to 2.5 weeks earlier (higher emissions, A1Fi) by 2100

Figure 12. Projected Advance in Peak Spring Flow. From NECIA, 2006.

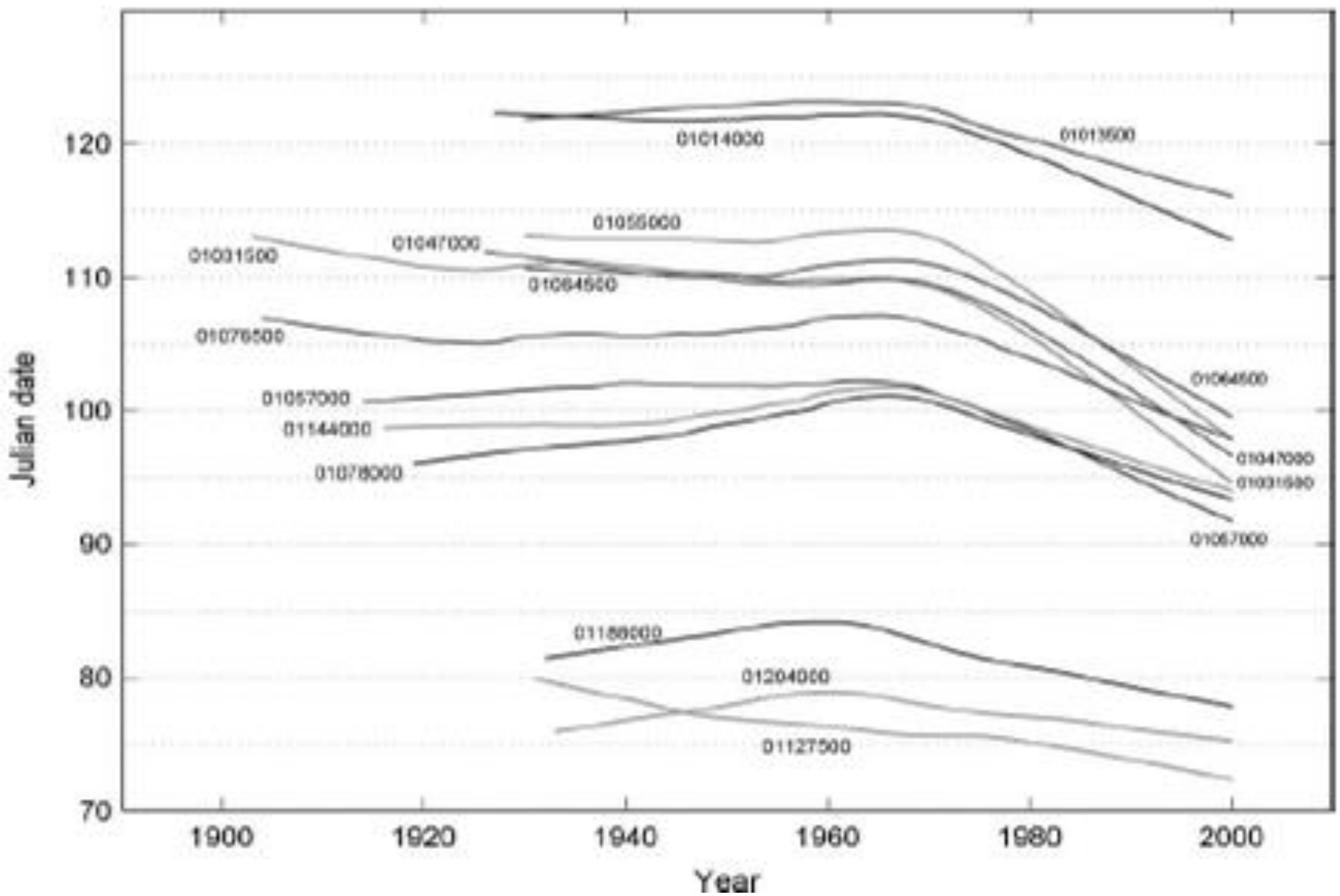


Figure 13. Earlier spring peak flow: observed. From NECIA (2006).

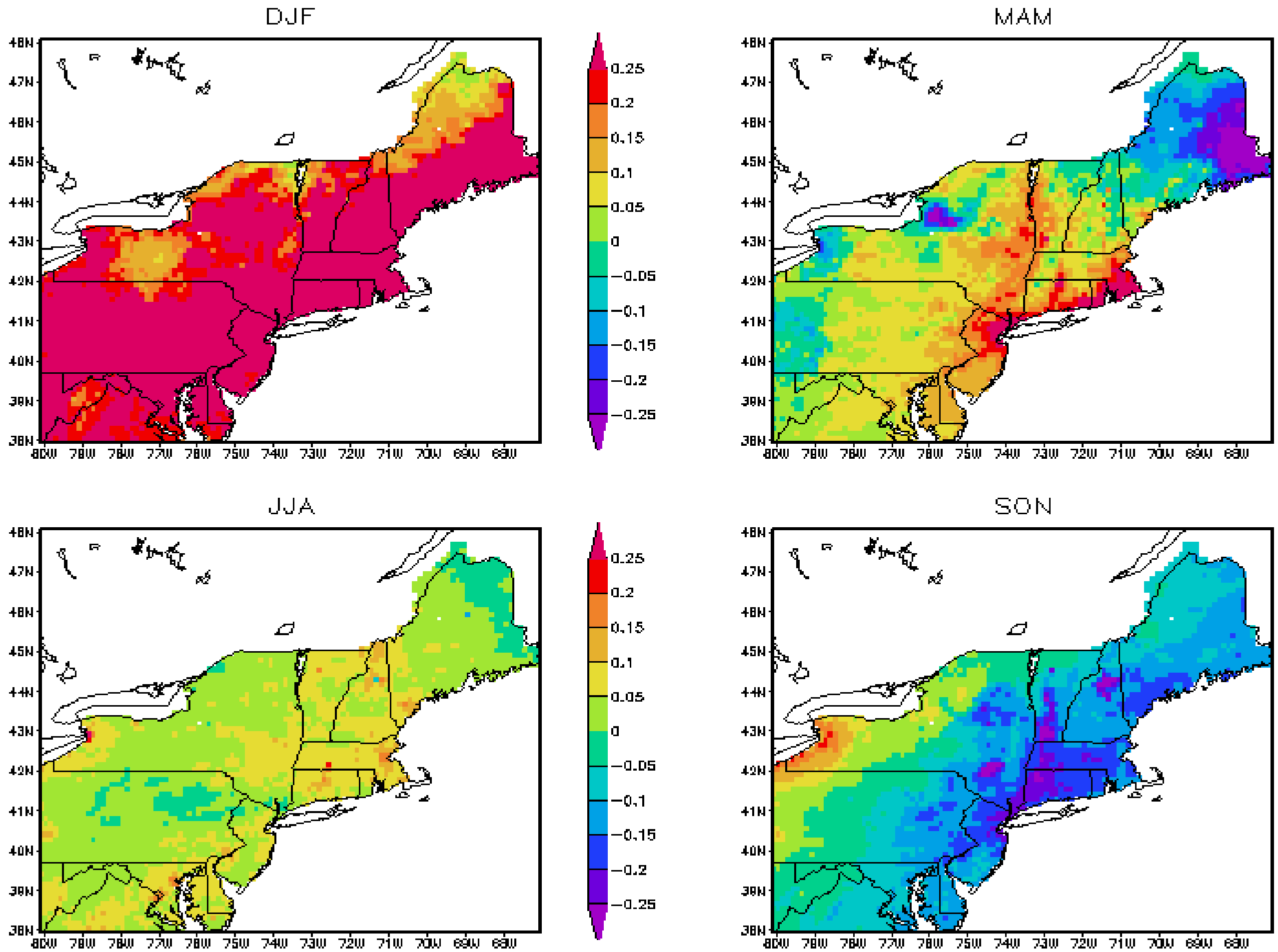


Figure 14. Projected average seasonal change in runoff (mm/day), 2030-2060 relative to 1970-1999. A1Fi emissions scenario. From NECIA, 2006.

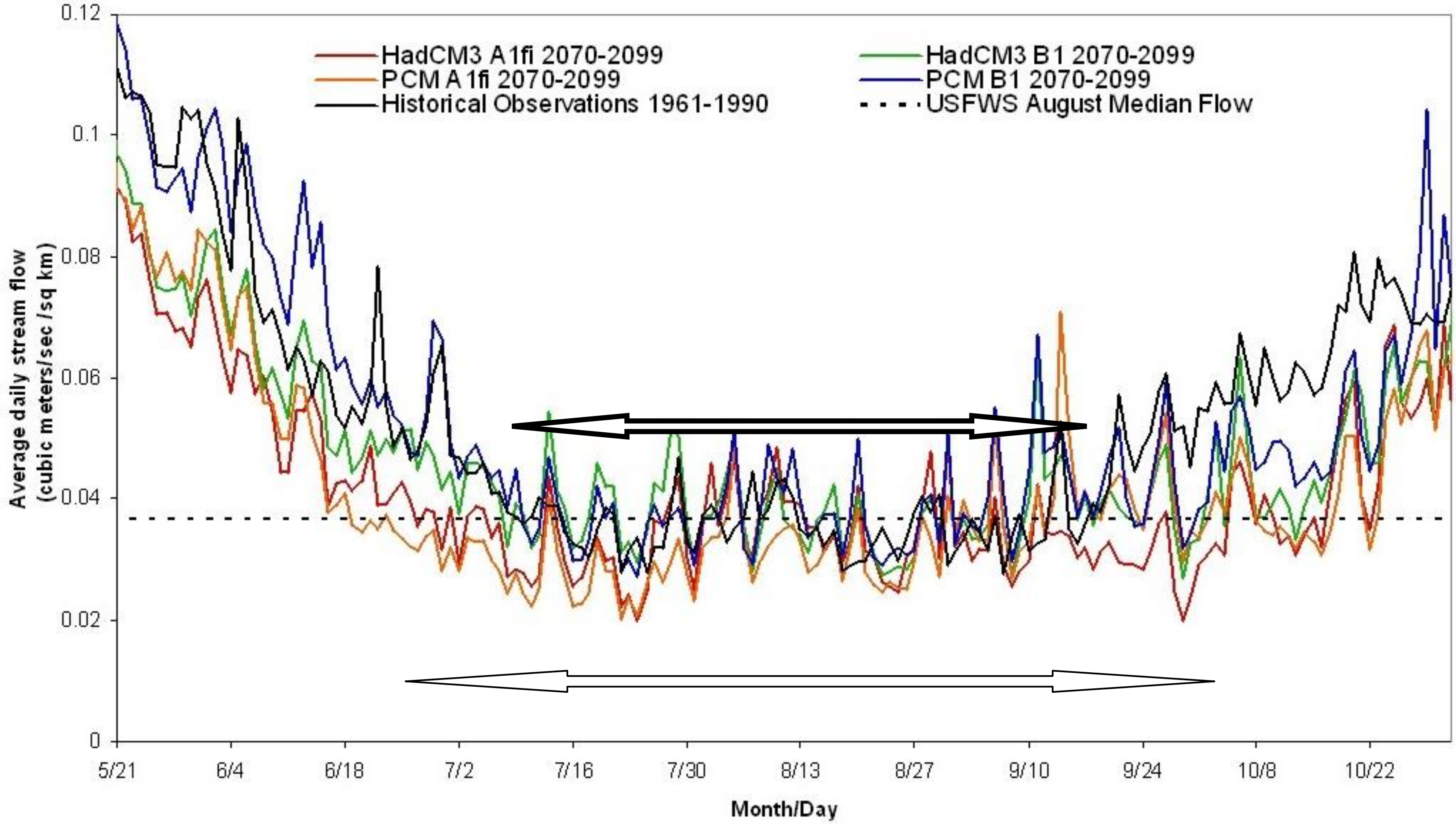


Figure 15. Increase in duration of summer low flow periods. From NECIA, 2006.

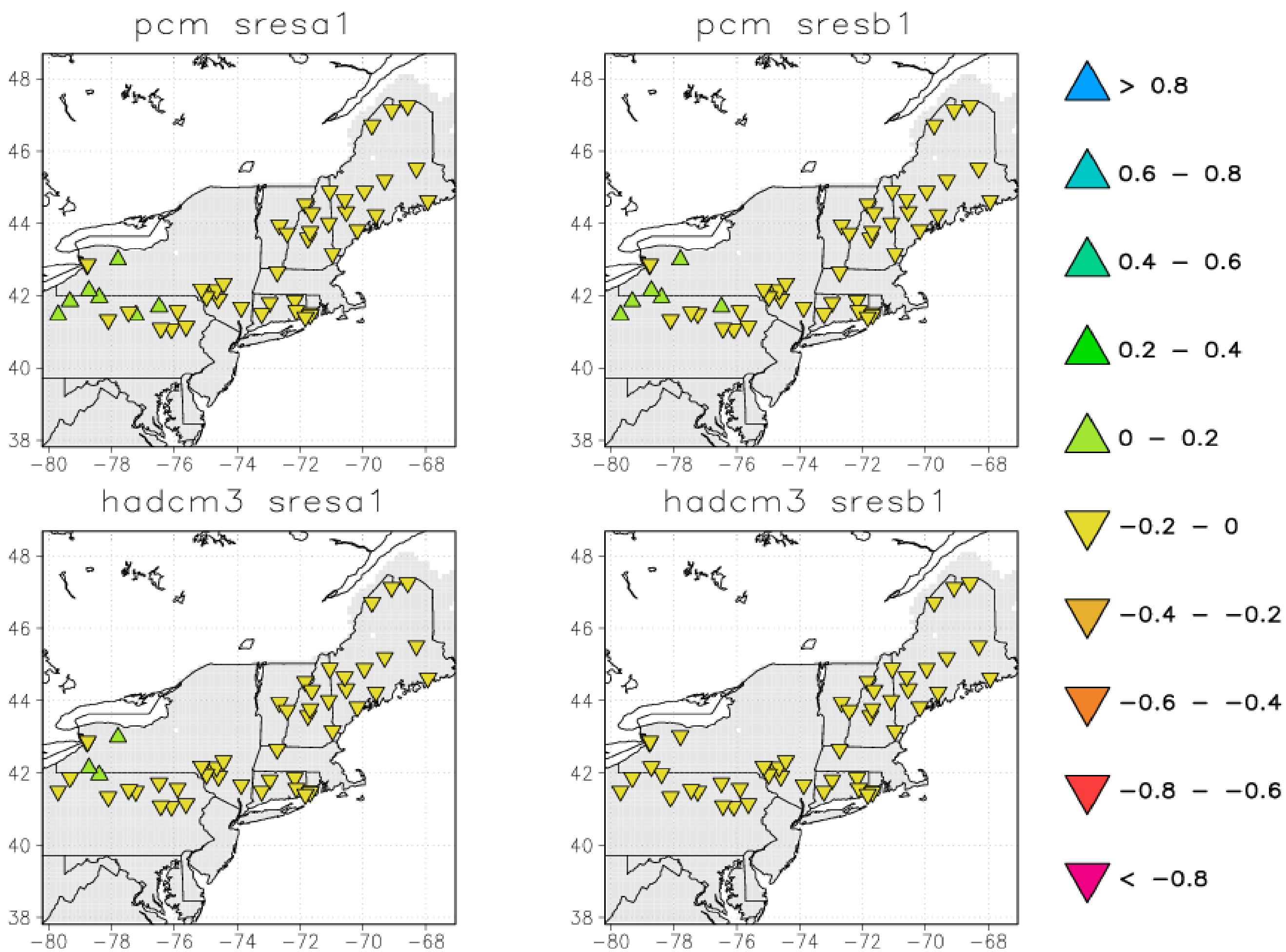


Figure 16**.** Projected change in the probability of low (10%) flows from the historic (1961-1990) to the future (2070-2099) periods for winter (DJF) for selected basins. Indicates a decreased probability of low flow events across much of the northern part of the NE under the A1FI scenario as compared with B1. From NECIA, 2006.

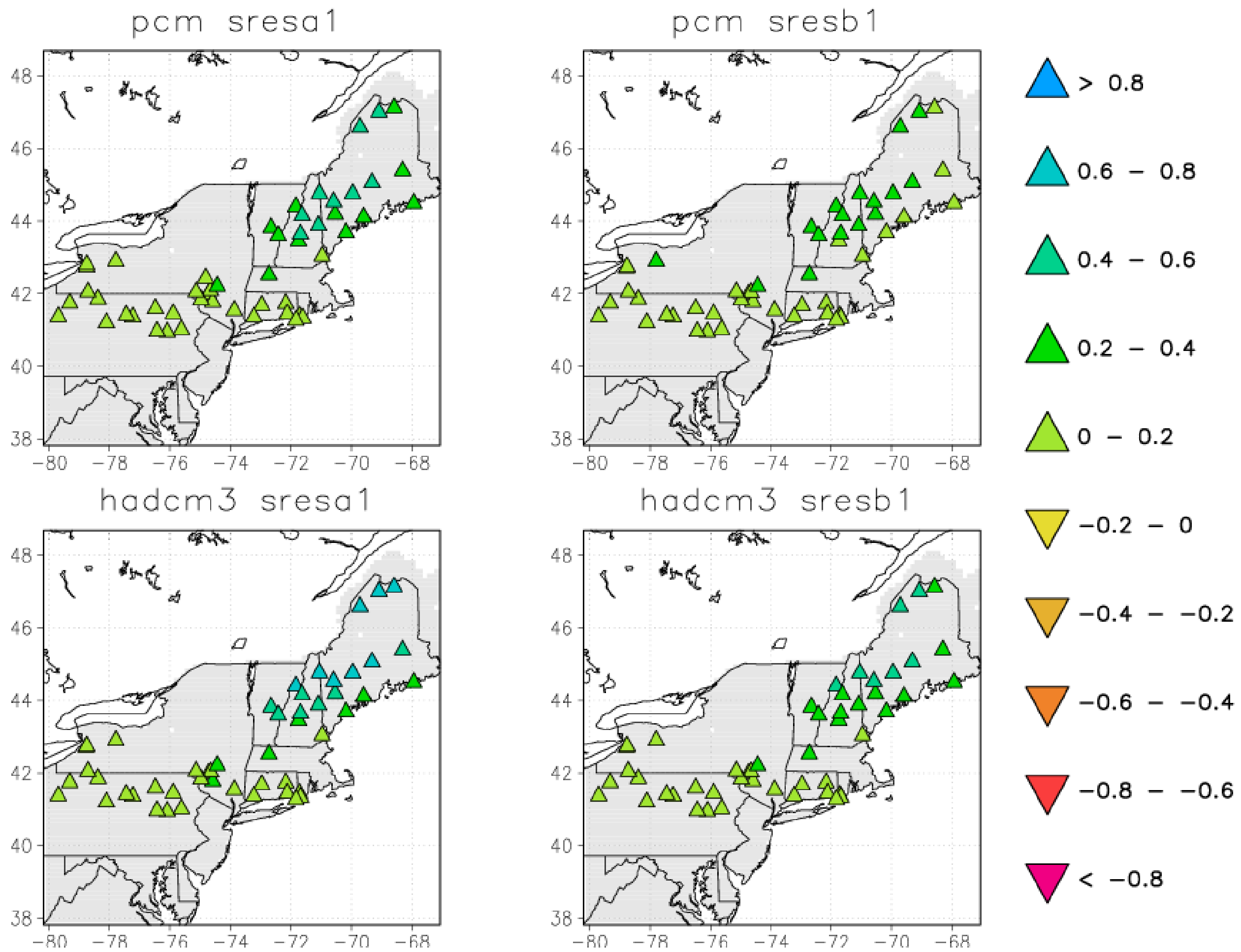


Figure 17. Projected change in the probability of high (90%) flows from the historic (1961-1990) to the future (2070-2099) periods for winter (DJF) for selected basins. Simulations indicate an increased probability of high flow events across much of the northern part of the NE under the A1FI scenario as compared with B1. From NECIA, 2006.

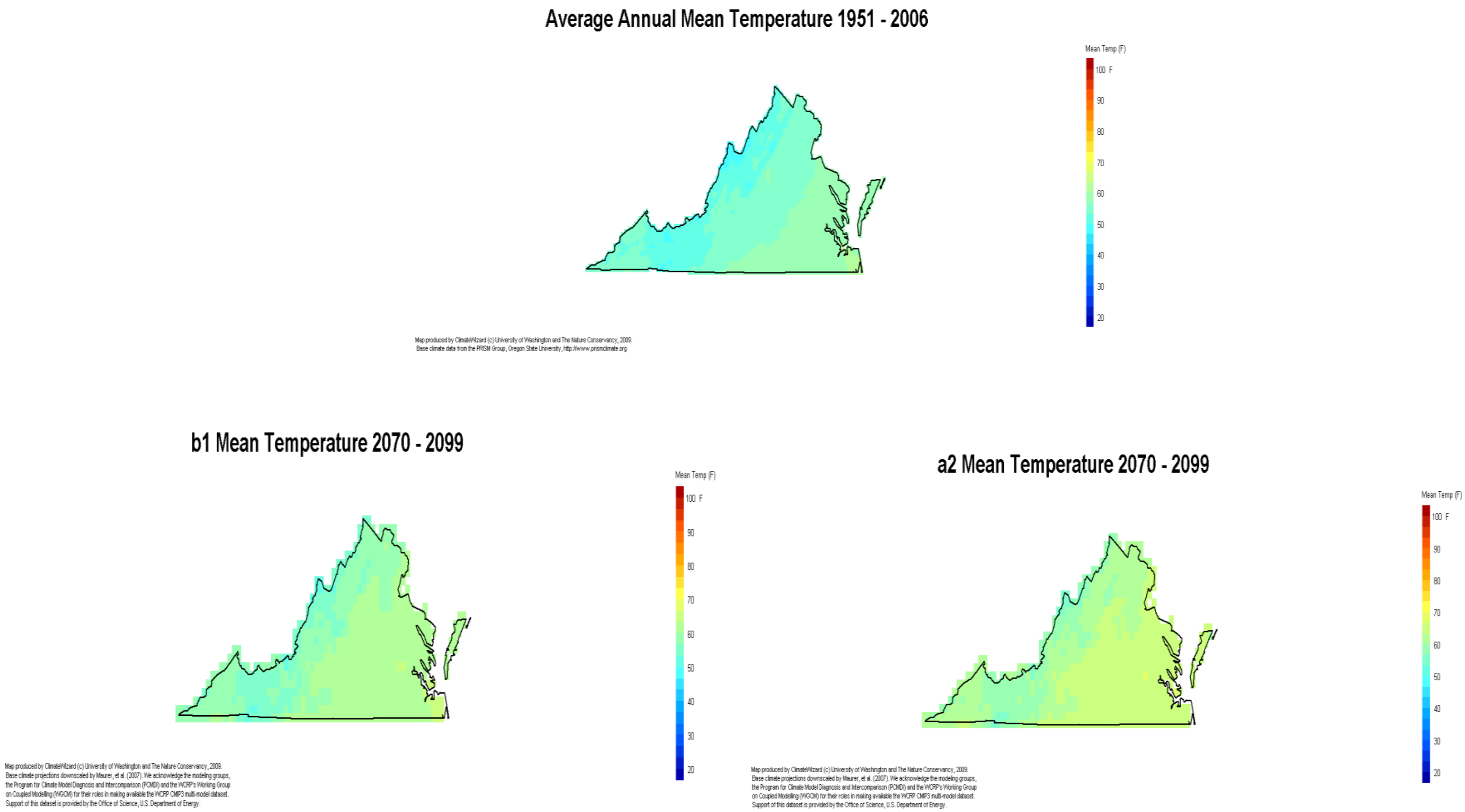


Figure 18. Current and projected annual mean temperatures in Virginia under the B1 and A2 emissions scenarios. Data are means of 16 GCM predictions (analyses from ClimateWizard).

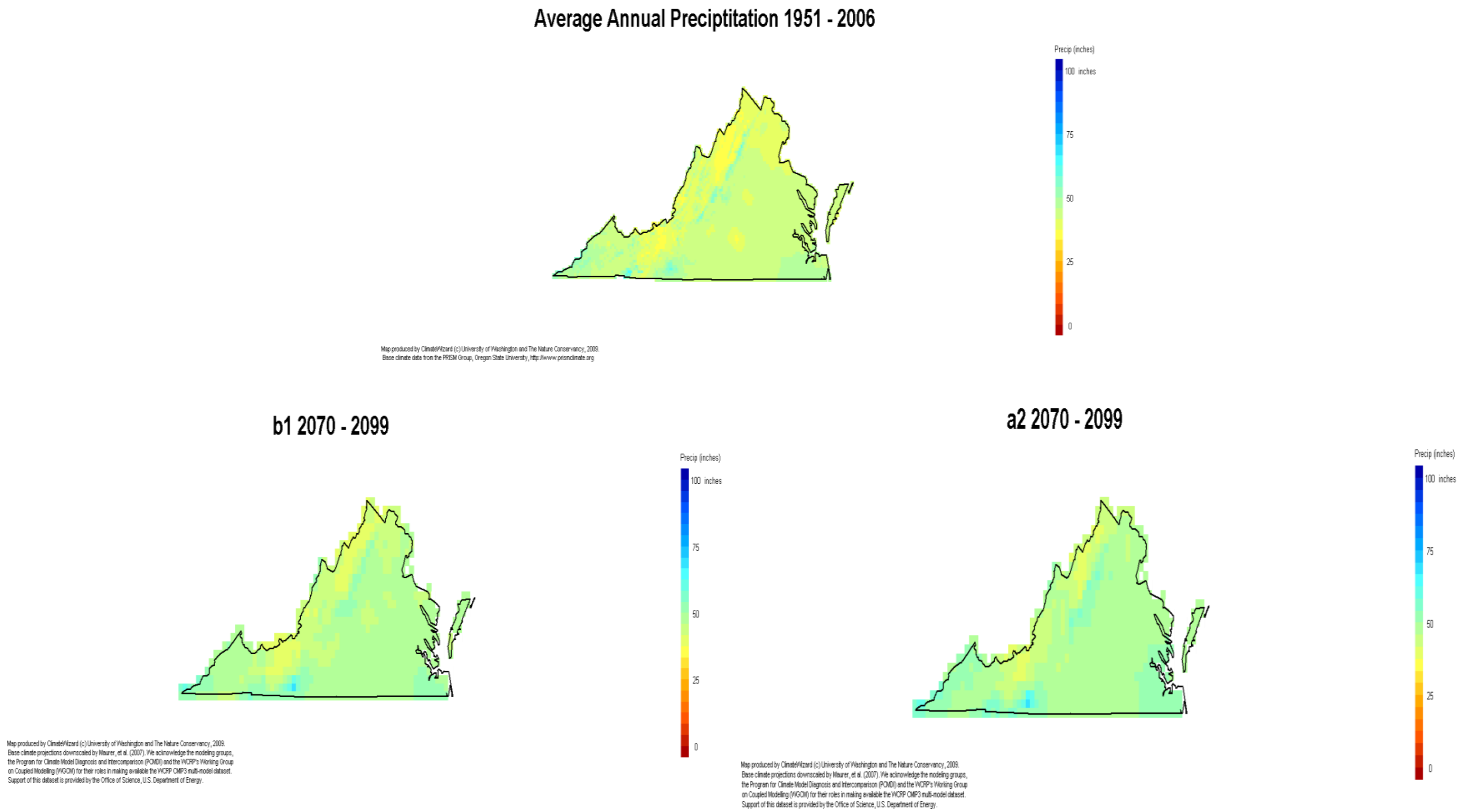


Figure 19. Current and projected annual mean precipitation in Virginia under the B1 and A2 emissions scenarios. Data are means of 16 GCM predictions. Analyses from ClimateWizard.

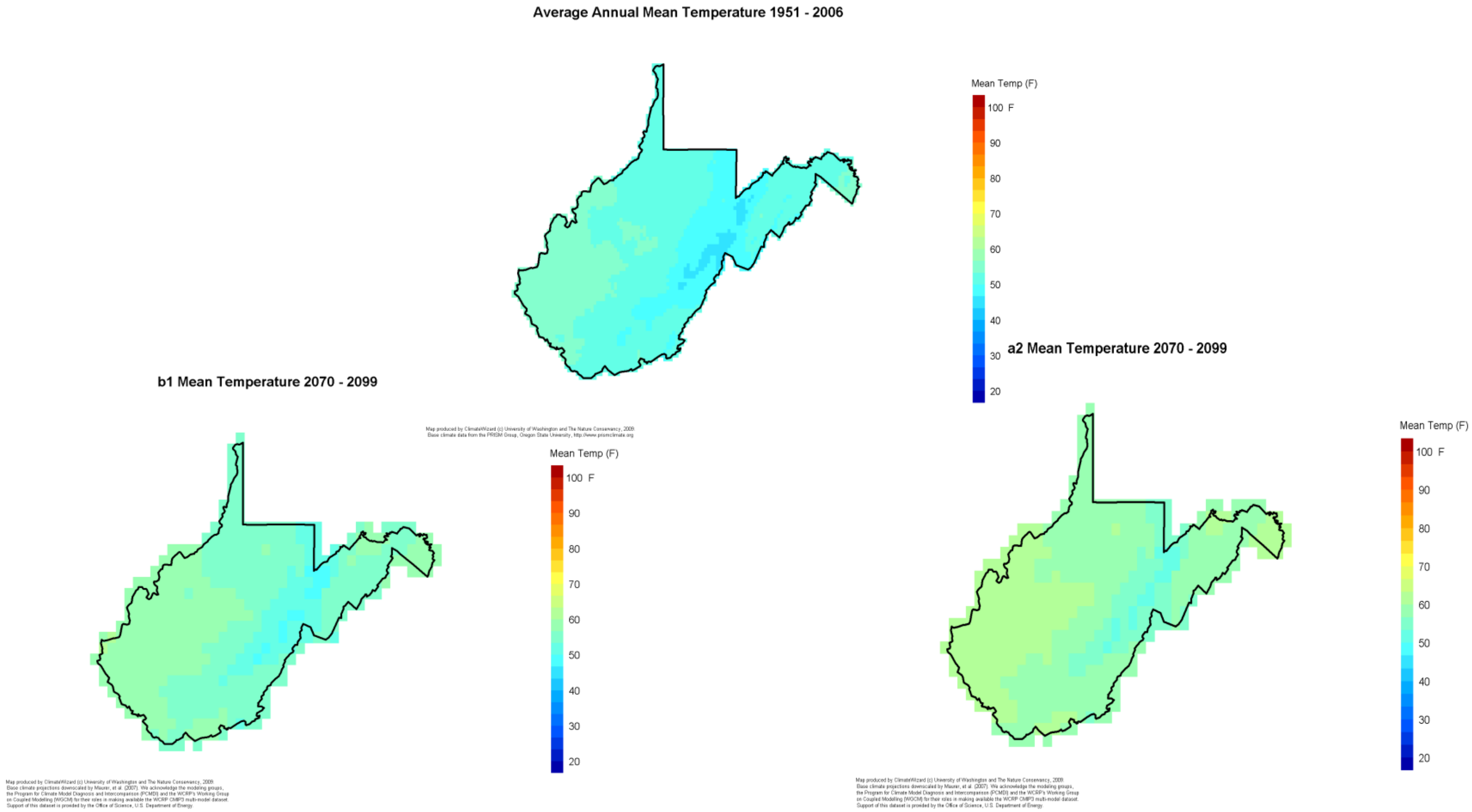


Figure 20. Current and projected annual mean temperatures in West Virginia under the B1 and A2 emissions scenarios. Data are means of 16 GCM predictions. Analyses from Climate Wizard.

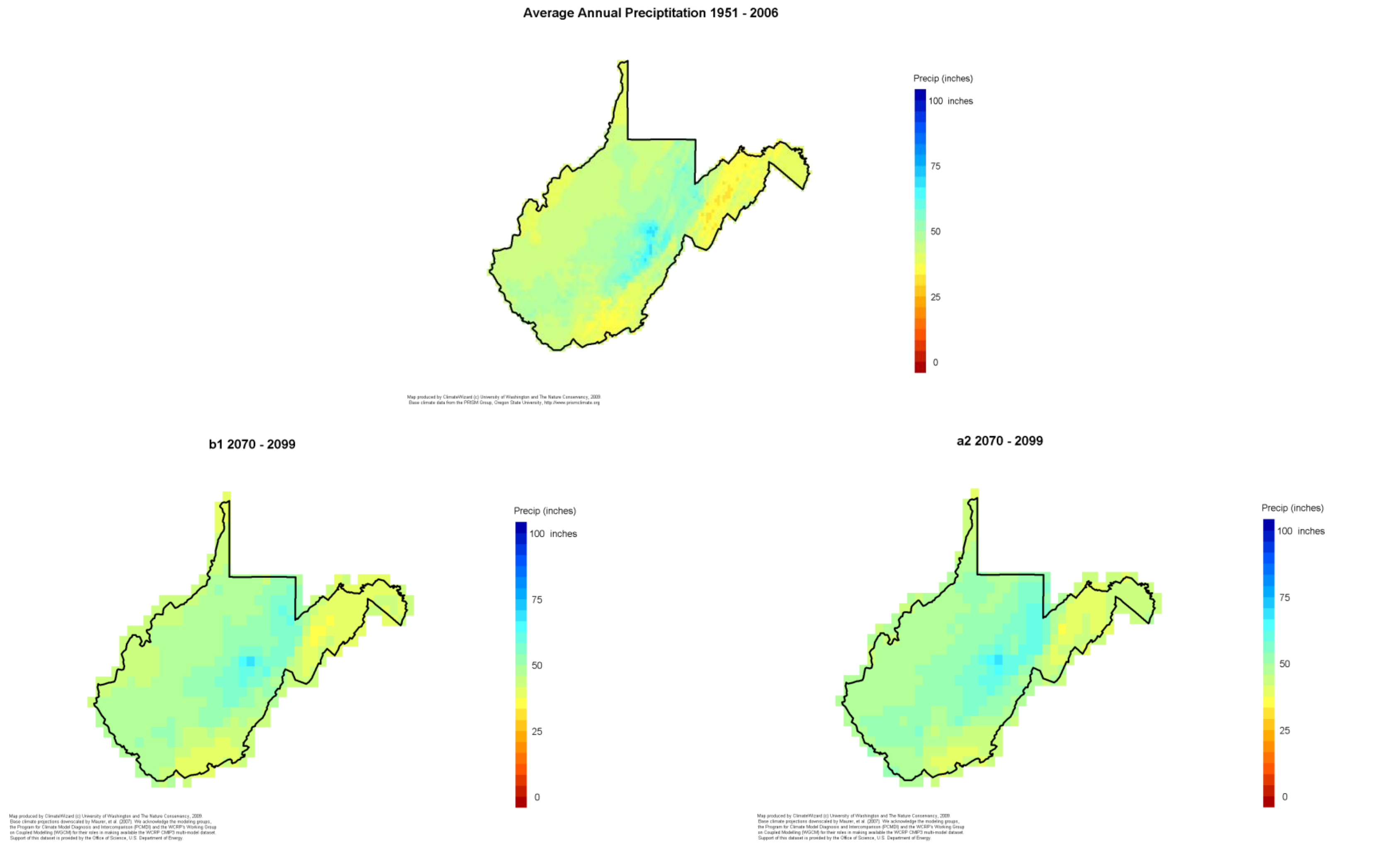


Figure 21. Current and projected annual mean precipitation in West Virginia under the B1 and A2 emissions scenarios. Data are means of 16 GCM predictions. Analyses from ClimateWizard.

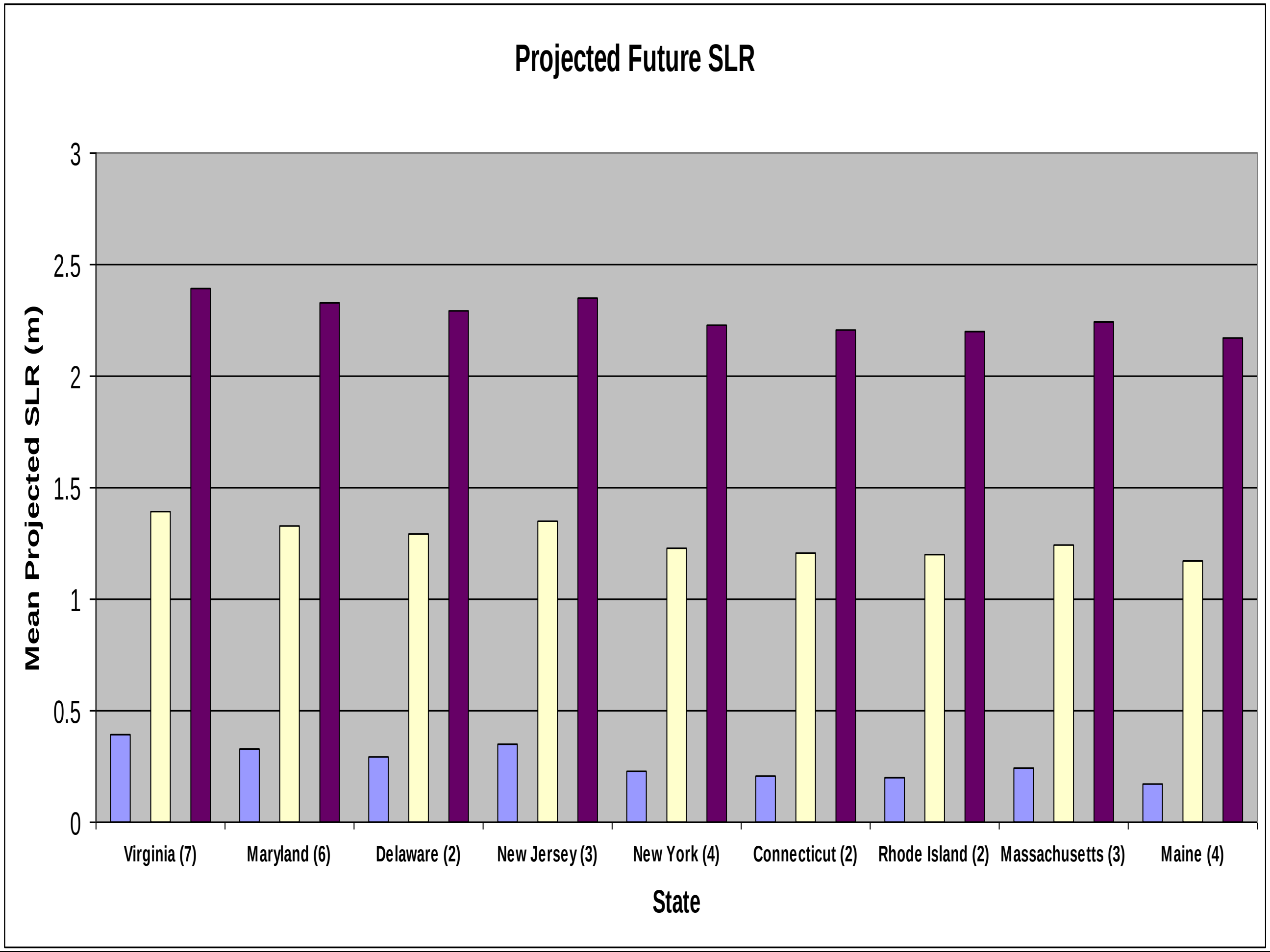


Figure 23. Projected Sea Level Rise in northeastern states by 2100. Blue is historic rate of SLR only; yellow is historic plus 1 meter; red is historic plus 2 meters. Historic data are means from sampling stations (data from http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). Numbers in parentheses are numbers of sampling stations.

Table 2. Historic and future rates (mm/yr) and extents of sea level rise in Northeast States. Data from noaa.gov/sltrends/sltrends_states.shtml?region.				
Tide Gauge Station	**Historic rate of rise**	**2100 at historic rate**	**2100 at historic rate + 1 meter**	**2100 at historic rate + 2 meters**
Virginia:				
Kiptopeke	3.48	309.72	1.310	2.310
Colonial Beach	4.78	425.42	1.425	2.425
Lewisetta	4.97	442.3	1.442	2.442
Gloucester Point	3.81	339.09	1.339	2.339
Sewell's Point	4.44	395.16	1.395	2.395
Portsmouth	3.76	334.64	1.334	2.334
Chesapeake Bay	6.05	538.4	1.538	2.538
Pennsylvania:				
Philadelphia	2.79	248.31	1.248	2.248
Maryland:				
Ocean City	5.48	487.72	1.488	2.488
Cambridge	3.48	309.72	1.310	2.310
Chesapeake City	3.78	336.42	1.336	2.336
Baltimore	3.08	274.12	1.274	2.274
Annapolis	3.44	306.16	1.306	2.306
Solomon's island	3.41	303.49	1.303	2.303
Delaware:				
Reedy Point	3.46	307.94	1.307	2.307
Lewes	3.20	284.8	1.284	2.284
New Jersey:				
Sandy Hook	3.90	347.1	1.347	2.347
Atlantic City	3.99	355.1	1.355	2.355
Cape May	4.06	361.34	1.361	2.361
Washington, DC	3.16	281.24	1.281	2.281
New York:				
Montauk	2.78	247.42	1.247	2.247
Port Jefferson	2.44	217.6	1.217	2.217
Kings Point	2.35	209.15	1.209	2.209
The Battery	2.77	246.53	1.246	2.246
Connecticut:				
New London	2.25	200.25	1.200	2.200
Bridgeport	2.56	227.84	1.228	2.228
Rhode Island:				
Newport	2.58	229.62	1.229	2.229
Providence	1.95	173.55	1.173	2.173
Massachusetts:				
Boston	2.63	234.07	1.234	2.234
Woods Hole	2.61	232.29	1.232	2.232
Nantucket Island	2.95	262.55	1.262	2.262
Maine:				
Eastport	2.00	178	1.178	2.178
Bar Harbor	2.04	181.56	1.181	2.181
Portland	1.82	161.98	1.161	2.161
Seavey Island	1.76	156.64	1.156	2.156

Summary of Projected Changes in Climate in the Northeast

Based on the NECIA (2007) analysis and our analyses using ClimateWizard, we project the following climatic changes across the Northeast Region by 2100:

- The annual average temperature across the region will increase by 2-5^{o}C (3.6-9.0^{o}F) depending on the emissions scenario.

- The annual average temperature increase will have seasonal and geographical components, being greatest in the winter months and at higher latitudes.

- The annual average precipitation across the region will increase by about 7-15%, depending on the emissions scenario.

- The number of extreme heat days per year (>50^{o}C, 90^{o}F) will increase from the current 10 to 20-40 days depending on the emissions scenario.

- The annual number of freeze days (days when temperature <^{o}C, 32^{o}F) will decrease across region by about 20-30%.

- The length of the plant growing season (days between last and first killing frosts) will extend by 30-50 days, depending on the emissions scenario, and the plant hardiness zones will advance north.

- The area of the region that is typically snow covered in winter will contract north to the northernmost parts of Vermont, New Hampshire and Maine.

- Soil moisture content (percent saturation) will decrease, particularly during the summer months (by about 1-2%).

- Evapotranspiration rates in the region will increase in the spring and summer by 1-2% depending on the emissions scenario.

- Under the A1FI emissions scenario, the frequency of short-term droughts (1-3 months in duration) will increase from the current 13 per 30 yr period to about 22 per 30 yr period. The frequencies of medium term droughts (3-6 months duration) will increase from the current 0.6 per 30 yr period to 2.2 per 30 yr period. Long-term droughts (>6 months duration) will increase from 0.3 per 30 yr period to about 0.4. Much smaller changes are projected under the B1 scenario.

- Sea levels in much of the Northern Hemisphere have been rising over the last century. The observed rate at any point on the coast is a function of the current rate of sea level rise (SLR) and crustal processes, particularly coastal subsidence or elevation. The future rate of SLR is expected to accelerate due mainly to the steric expansion of the sea water (under increasing air temperatures) and to an acceleration in the melt rates of ice caps and glaciers. Our best estimate of the future degree of SLR due to the changing climate is that global sea levels will rise by the end of this century by between 1 and 2 meters (Pfeffer et al., 2008; Rahmstorf, 2007). The likely extent of SLR can be estimated at any point on the coast by adding these future estimates to the current observed rate of SLR. Table 2 and Figure 23 show current rates of SLR in the Northeast Region. Rates of SLR decrease from south to north and between about 2 and 5 mm/yr. This translates over the next 88 years (by 2100) into a total rise of 231 to 258 mm, with a midpoint of 242mm. Assuming a global SLR due to climate change of 1 or 2 meters this becomes 1.24 to 2.5 meters, or 2.2 to 2.5 meters, respectively. The highest projections are for the southernmost states.

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Attachment 2. Model Structure and Variables

Table 1. Definitions for Module 1: Vulnerability of Non-tidal Habitats to Current and Future Climate Change, for the NEAFWA Habitat Vulnerability Model. Each component of the model is assigned a vulnerability score. Additionally, the degree of certainty is expressed for each vulnerability score according to the following scale: High = 3, Medium = 2, and Low = 1. More details and discussion of each of the variable descriptions can be found in Chapter 3 or by opening the associated model Excel files and viewing the comments (alt-text).

Model Variable	Model Variable Description	Vulnerability Score
1. Location in geographical range of habitat	Close to (<200 km) southern limit of habitat distribution	5
	More distant from southern limit of habitat distribution	1
2. Degree of cold-adaptation	Important constituent species limited to cold-temperature areas	5
	Important constituent species limited to cool temperature areas	3
	Important constituent species tolerant of warmer temperatures	1
3. Sensitivity to extreme climatic events	Highly vulnerable to extreme climatic events	5
	Less vulnerable to extreme climatic events	3
	Not vulnerable to extreme climatic events	1
4. Vulnerability to maladaptive human responses	Highly vulnerable to maladaptive human responses	5
	Less vulnerable to maladaptive human responses	3
	Not vulnerable to maladaptive human responses	1
5. Location relative to highest elevation	Mountain summit habitat confined to within 1,000 feet of the highest elevations	5
	High elevation habitat mainly occurring between 1,000 and 2,000 feet below the highest mountain tops	3
	Lower elevation habitat that should be able to move upslope	1

Table 1, continued. Definitions for Module 1: Vulnerability of Non-tidal Habitats to Current and Future Climate Change, for the NEAFWA Habitat Vulnerability Model.

Model Variable	Model Variable Description	Vulnerability Score
6. Intrinsic adaptive capacity	Unlikely to be significant	5
	Likely to be significant	1
7. Dependence on specific hydrologic conditions	Habitats that are dependent on specific hydrologic conditions	5
	Habitats less dependent on specific hydrologic conditions	1
8. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. Likely to be particularly vulnerable to climate change	5
	Foundation/keystone spp. Unlikely to be vulnerable to climate change	1
9. Constraints on latitudinal range shifts	Highly constrained	5
	Somewhat constrained	3
	Low level of constraint	1
10. Likelihood of managing/alleviating climate change impacts	Feasible	5
	Not feasible	1
11. Potential for climate change to exacerbate impacts of non-climate stressors, or vice versa	Potential for large increase in stressor impacts	5
	Potential low	1

Table 2. Definitions for Module 2: Vulnerability of Non-tidal Habitats to Current and Future Non-Climate Stressors, for the NEAFWA Habitat Vulnerability Model. Each component of the model is assigned a vulnerability score. Additionally, the degree of certainty is expressed for each vulnerability score according to the following scale: High = 3, Medium = 2, and Low = 1. More details and discussion of each of the variable descriptions can be found in Chapter 3 or by opening the associated model Excel files and viewing the comments (alt-text).

Model Variable	Model Variable Description	Vulnerability Score
1. Current extent of habitat	Highly limited in distribution and highly fragmented	5
	Less limited in distribution and somewhat fragmented	3
	Widespread and contiguous	1
2. Current extent trend	Rapidly diminishing	5
	More limited losses	3
	Stable or increasing	1
3. Likely future extent trend	Major losses	5
	Some losses	3
	Stable or increasing	1
4. Current impacts of non-climate change stressors	Highly affected by non-climate change stressors	5
	Less affected by non-climate change stressors	3
	Least affected by non-climate change stressors	1
5. Likely future stressor trends	Large increase	5
	Some increase	3
	Little or no increase or lessening	1

Table 3. Metric for assigning vulnerability level for overall modules.

Vulnerability category	**Module 1 Score Range**	**Module 2 Score Range**
Least Vulnerable (Vc1)	11-20	5-8
Less Vulnerable (Vc2)	21-29	9-12
Vulnerable (Vc3)	30-38	13-16
Highly Vulnerable (Vc4)	39-47	17-20
Critically Vulnerable (Vc5)	> 47	> 20

Table 4. Matrix for assigning overall vulnerability level inclusive of modules 1 and 2.

		Non-climate Stressor Vulnerability Score (Module 2)				
		Vb5	**Vb4**	**Vb3**	**Vb2**	**Vb1**
Climate Change Vulnerability Score (Module 1)	**Vc5**	Vo5	Vo5	Vo5	Vo4	Vo4
	Vc4	Vo5	Vo5	Vo4	Vo4	Vo3
	Vc3	Vo5	Vo4	Vo3	Vo3	Vo2
	Vc2	Vo5	Vo4	Vo3	Vo2	Vo1
	Vc1	Vo4	Vo3	Vo2	Vo1	Vo1

Attachment 3. Habitat Vulnerability Evaluation: Acadian-Appalachian Alpine Tundra

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

Summary of Results

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 four northernmost states of the Northeast Region: The Katahdin Range in Maine, The White Mountains of New Hampshire and Maine, the northern Green Mountains in Vermont, and New York's Adirondack Mountains. Its greatest extents are in Maine and New Hampshire, which together support more than 95% of this habitat type (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 at the highest 600 feet in elevation in Vermont, the highest 1,700 feet in New York and Maine, and the highest 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.

Table 1. Extent of Acadian-Appalachian Alpine Tundra in Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

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
Total acres	8,184	

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, approximately two months shorter than growing seasons closer to sea level. 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).

Figure 2. Distribution of Acadian-Appalachian Alpine tundra in the Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project

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.

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	Medium

These results indicate that alpine tundra is a particularly vulnerable habitat in the Northeast Region. Its vulnerability is due to several factors: (1) its limited extent in the region; (2) its ability to persist only in high elevation areas where harsh climatic conditions prevent colonization by forest; (3) 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 could contract this bioclimatic range further north and out of the Region; (4) 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; and (5) 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 level for these predictions is only Medium (while we generally know much about the distribution of this habitat type and its climatic-ecological relationships, recent work, see below, raises the possibility that this habitat type may be more resistant to the effects of climate change than previously thought).

Recent work by Siedel *et al*. (2009) on Mount Washington, New Hampshire suggests that the tundra there may be more resistant to the effects of climate change than previously assumed. They have shown that the climate on the mountain's summit has changed little over the last 70+ years (possibly because of the mitigating effects of thermal inversions and frequent cloud fog). Also, Spear (1989) has shown over the last 5,000 years that the distribution of Mount Washington tundra has demonstrated minimal geographical shifts. Whether this also applies to lower mountain ranges in New England outside of New Hampshire is not known. It is possible that the Zone I vulnerability results shown in Table 3 should actually vary across the zone, with lower scores on the highest elevation areas of Mount Washington.

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 eliminated 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 ^{o}F for every 330 feet vertical gain

(Richardson *et al*., 2004). Consequently, a rise in mean annual temperature of 1 ^{o}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 ^{o}F increase would eliminate it in New York and Maine, and a 6 ^{o}F increase would eliminate it in New Hampshire (Table 4). The most recent and detailed climate 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 ^{o}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 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.

However, recent work by Siedel et al (2009) suggests that tundra may be more resistant to the effects of climate change than we previously assumed. We do not know, however, if this result applies to all tundra in the northeast or only to their Mount Washington study site (see above).

Table 4. Fate of alpine tundra in Northeast region under future degree warming scenarios.

	Number of patches	**Mean Patch Size (ac)**	**Area in Region (ac)**
Current	138	59	8,185
+1^{o}F	30	230	6,891
+2^{o}F	19	221	4,202
+3^{o}F	9	164	1,476
+4^{o}F	4	77	308
+5^{o}F	2	25	49
+6^{o}F	0	0	0

In addition to eliminating tundra habitat, the earlier stages of warming will likely result in the fragmentation of the habitat that is able to persist. On Mount Washington, New Hampshire, projected climate change warming could result in the fragmentation of the habitat (Figure 3). This could have important adverse consequences for organisms that may depend on habitat contiguity (because, for example, they are dependent on recolonization potential after local extinctions or population reductions). In such cases we may expect species extinctions before the habitat is lost entirely.

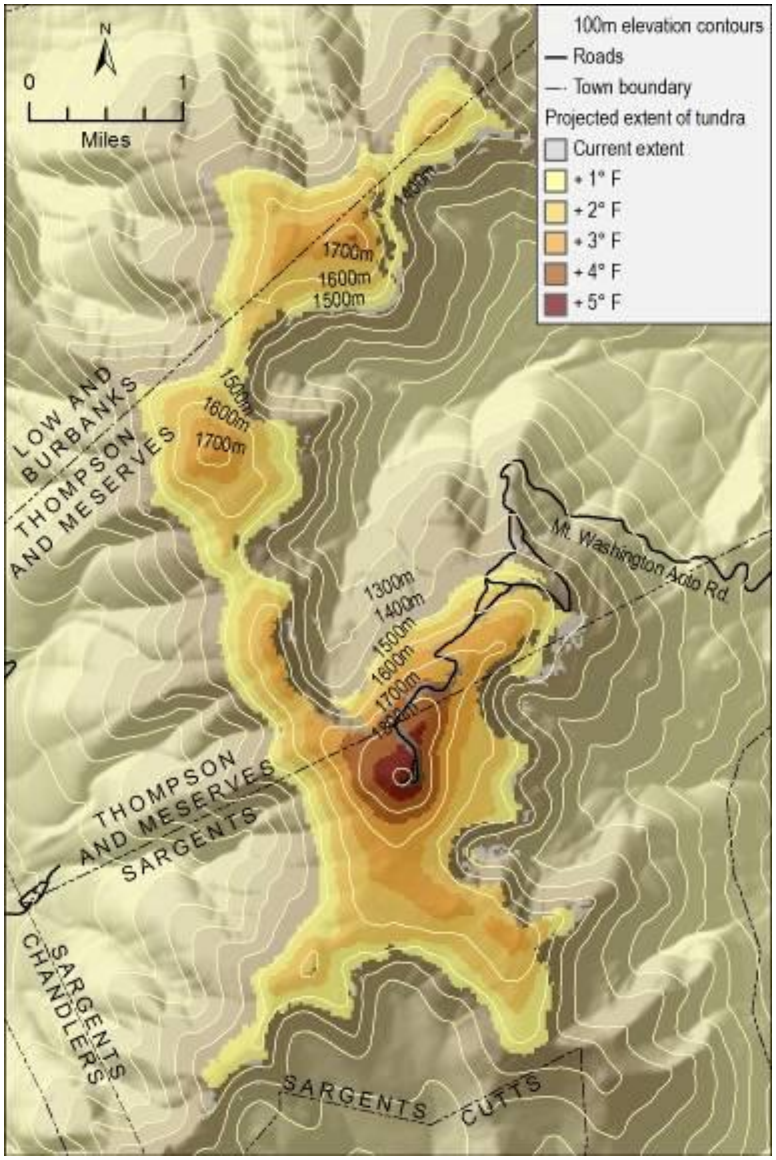

Figure 3. Projected fragmentation of alpine tundra habitat on Mount Washington, New Hampshire under degree warming scenarios. Data from TNC/NEAFWA (2011) and an assumed adiabatic lapse rate of 1°F for 330 feet vertical gain.

These results indicate that it is possible that all or much of the northeastern tundra could be eliminated 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 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 100 m over the 40-year period beginning in 1964, and during which annual average temperatures have risen by about 1.7 ^{o}F. This could signal the encroachment of forested habitat into the high elevation alpine tundra zone.

Uncertainty Analysis

The certainty levels for the projections in this analysis are Medium. Although we generally know much about the distribution of this habitat type and its climatic-ecological relationships, there is some uncertainty surrounding its ability to resist or adapt to the impacts of a changing climate. The research that has uncovered these questions has been confined thus far to Mount Washington in New Hampshire (see above), and we do not know whether the apparent adaptive capacity of tundra habitat there applies to other, lower montane areas. If it does, the vulnerability of tundra in New England and New York may not be as severe as we project in this analysis. In the absence of real evidence, however, it seems most prudent to give credence to the vulnerability scores developed above.

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 200 km, most within 100 km, 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 and elsewhere. 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, which may be exacerbated under a warming climate. 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 is affected by anthropogenic stressors. 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) and because of the uncertainties raised by Siedel *et al*. (2009) on Mount Washington.

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 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 relationships 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 across 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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Attachment 4. Habitat Vulnerability Evaluation: Acadian-Appalachian Montane Spruce-Fir Forest

Figure 1. Acadian-Appalachian 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 band of 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.

Summary of Results

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 and New Hampshire, which together support 70% of this habitat type (Table 1). Its southernmost fragments occur in the Catskill Mountains of New York and the Berkshires in Massachusetts (Figure 2). Further south it is replaced by Central and Southern Appalachian Spruce-Fir Forest (NEHCMP, 2008). It is generally limited to elevations above 2,500-3,000 feet (Table 2). At lower elevations, it transitions into northern hardwood forest, while at higher elevations (approximately above 4,000 feet) it may transition through a Krummholz zone into alpine grass and forb meadows[10]. 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 and lichens. It provides breeding habitat for a number of vertebrate species that are very 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).

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

[10] This definition of montane spruce-fir forest focuses on higher elevation forests and excludes lower elevation spruce-fir forest (much of which is actively managed for timber) in many parts of Maine (Gawler and Cutko, 2010).

during the summer cooling of the Little Ice Age, then, more recently, contracted northward (Figure 3). Current and future warming may accelerate this northward shift.

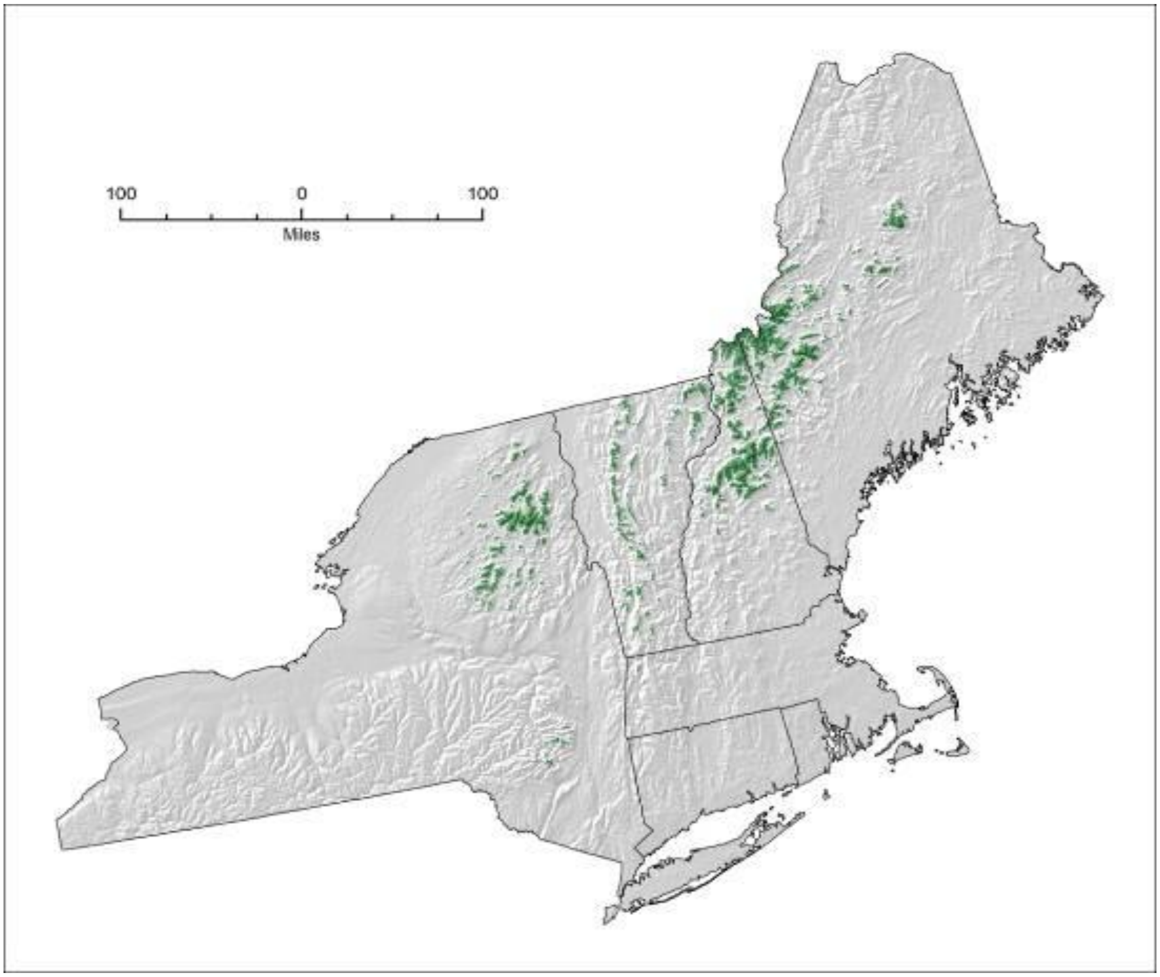

Figure 2. Distribution of Acadian-Appalachian Montane Spruce-Fir forest in Northeast Region. Data from Northeast Habitat Mapping Project (TNC/NEAFWA, 2011).

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 (from Jacobson *et al*. 2009).

Table 1. Extent of Acadian-Appalachian Montane Spruce-Fir forest in the Northeast (TNC/NEAFWA, 2011).		
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
Total acres	1,084,374	

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 (New York, northern Vermont, New Hampshire, and Maine) and II (central and southern Vermont and New Hampshire south to Massachusetts) are shown in Table 3.

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 limited by climate, rather than 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 significant 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.

Uncertainty Analysis

The certainty levels for the projections in Table 3 are High, since we generally know much about the distribution of this habitat type and its climatic-ecological relationships. However, as for alpine tundra, there is some uncertainty surrounding the abilities of high elevation habitats to resist or adapt to the impacts of a changing climate. The research that has uncovered these questions has been confined thus far to Mount Washington in New Hampshire, and we do not know whether the apparent adaptive capacity of tundra habitat there applies to other, lower montane areas or whether it extends from tundra into spruce-fir forests. If it does, the vulnerability of spruce-fir forests may be lower than we project in this analysis. In the absence of real evidence, however, it seems most prudent to give credence to the vulnerability scores developed above.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fate of the habitat type in both zones suggests that most, perhaps all, of the habitat type in Zone II, could be eliminated 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.

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 200 km of this range boundary. In contrast, all of this habitat in Zone I is at a greater distance than 200 km 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 1.0 ºF 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 4-5 ºF to entirely eliminate the climatic envelope in which most of this habitat exists in southern VT, NH, and Massachusetts. The most recent and detailed climate 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[11]. 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 exacerbated under a warming climate. 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 100 m 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. In most states in the region much of this habitat type currently exists in protected areas (e.g., Green Mountain National Forest, White Mountains National Forest, Baxter State Park, and 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.

[11] The forest transition is likely to lag behind the climatic change, although by how much is not known.

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 elevation. 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 southernmost patch of habitat in Massachusetts on 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 across 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 make them amenable to 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. Most of this habitat exists in protected areas where stressors such as habitat destruction and logging are minimal, and few other stressors are currently affecting it. However, 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 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. Also, emerging stressors may increase their effects in the future, timber harvesting for biofuels, for example. However, this is likely to be confined to lower elevation areas. For this reason, we score this variable as Some Increase. Our certainty score is only Low to reflect the high degree of uncertainty that surrounds this prediction.

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Attachment 5. Habitat Vulnerability Evaluation: Laurentian-Acadian and Appalachian Northern Hardwood Forests

Figure 1. Laurentian-Acadian 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.

Summary of Results

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

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.

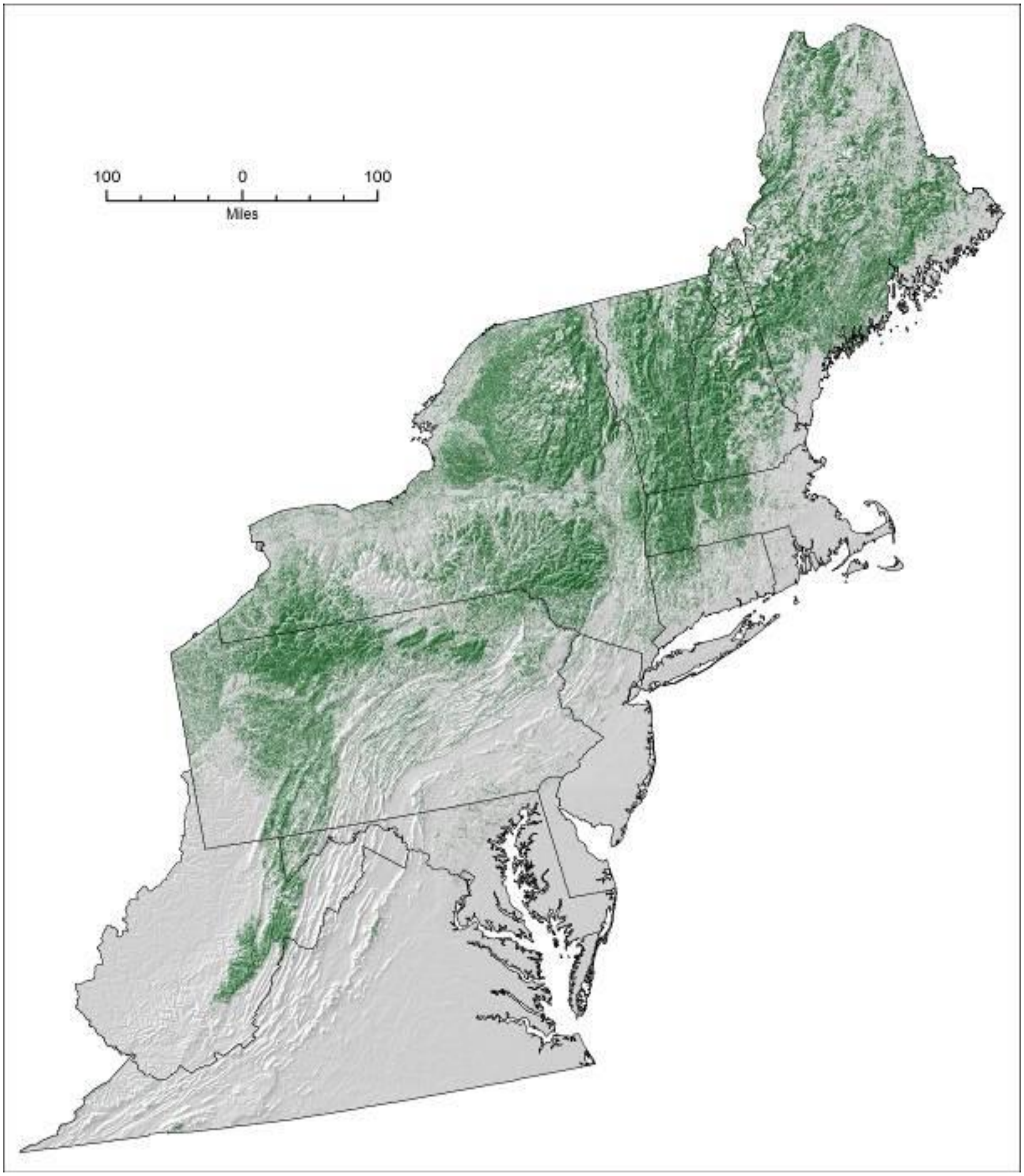

Figure 2. Current distribution of Northern Hardwood Forests in the Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011). The forests in West Virginia, Virginia, and Pennsylvania are largely Appalachian Northern Hardwoods, while those further north are Laurentian-Acadian Northern Hardwoods.

Table 1. Extent of Northern Hardwood Forest in Region (TNC/NEAFWA, 2011).		
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
Total acres	41,051,119	

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 sugar maple, 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). Laurentian-Acadian Northern Hardwood Forests 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 Appalachian Hardwood Forests occur 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.

In this analysis, the hardwood forests in Zones I and II correspond to Laurentian-Acadian Northern Hardwood Forest, while the forests in Zones III and IV are Appalachian Hardwood Forests.

The shrub layer of Northern Hardwood Forests 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 power line 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.

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	Vulnerable	Vulnerable	High
Zone II	Vulnerable	Vulnerable	Vulnerable	High
Zone III	Vulnerable	Vulnerable	Vulnerable	High
Zone IV	Highly Vulnerable	Vulnerable	Highly Vulnerable	High

These results indicate that the vulnerability of these habitat types vary geographically in the Northeast, with the highest risk from future climate change in the southernmost zone (Appalachian Hardwood Forests). This 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 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 types across all zones suggests that under a doubling of the atmospheric concentrations of greenhouse gases much of the Laurentian-Acadian Northern hardwood Forest in Zone I could survive, although the composition may change to include more oaks and white pine. 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 of Appalachian Hardwood Forest 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 these habitat types 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 in place (though still resembling Northern Hardwood Forest).

Uncertainty Analysis

Our certainty scores for this habitat type are generally High. However, there are significant uncertainties associated with human exploitation patterns in these forests. If extraction of timber for biofuels reaches the scales that the industry projects, we may see the impacts of the changing climate being exacerbated by this related stressor. Also, extraction of natural gas from the Marcellus Shales in Zones III and IV could result in significant impacts to this forest type. As yet, the potential scales of these impacts are not known.

Modeling Assumptions

Module 1. Location in geographical range of habitat. Given the high degree of precision and accuracy of the TNC/NEAFWA Northeast 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 complex of habitat types 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 200 km 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 these habitat types in the Northeast. Specifically, they typically occur 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 1.0 ºF for every 330 feet in the Northeast (Richardson *et al*., 2004), and the fact that all of Appalachian Northern Hardwood Forests in Zone IV occur 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 3-4 ºF 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 effect (though, the habitat is still relatively vulnerable).

It is possible that we may already be witnessing upward elevational shifts in more northern hardwood forest 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, these habitat types may be locally sensitive to extreme climatic events – such as damage due to ice storms or blowdown, which may be exacerbated under a warming climate. 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 these habitats depend. This could result in at least local habitat loss.

Based on these data and considerations, we have determined that these habitat types 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 they are 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 Appalachian Northern Hardwoods in 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 limits of these habitat types are determined by elevation. In Zones I and II where the elevation range exceeds 4,000 feet, there is potential for the Laurentian-Acadian Northern Hardwoods 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 for Appalachian Northern hardwoods 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 these habitat types decrease from north to south, from Zone I to Zone IV. We assume this because they becomes much less widespread, patchier, 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 Appalachian Northern Hardwood Forests in the two southernmost zones (III and IV), but as I (likely to be significant) for the Laurentian-Acadian Northern Hardwoods in 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 these are not wetland or aquatic habitats, they are not dependent on specific hydrologic conditions.

Module 1. Vulnerability of Foundation/Keystone species to climate change. Northern Hardwood Forests are relatively diverse communities, with the canopy dominated by a varied range of tree species depending on climate, land-use, elevation, aspect, etc. Unlike Montane Spruce-Fir Forest, the 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, Appalachian Northern Hardwood Forest exists as isolated patches at higher elevations, widely separated by intervening and extensive tracts of lower-lying ground. Further north, Laurentian-Acadian Northern Hardwoods patches 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 (Appalachian Northern Hardwood Forest), 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 distributions of these habitat types, 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 (although in Maine this trend may have ended and is reversing – A. Cutko, Maine DEC, 2012 *pers. comm.*). Accordingly, we have assigned to this variable a score of 3 (Limited Losses) for all 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 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 all Zones.

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. Also, emerging stressors may increase their effects in the future, timber harvesting for biofuels, for example. 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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Attachment 6. Habitat Vulnerability Evaluation: Central Mixed Oak-Pine Forests

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.

Summary of Results

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 either by 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[12], 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 up to 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.

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, which together support almost 80% of this habitat type (Table 1). Prasad *et al*. (2007-ongoing)

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[12] Ash trees are currently being adversely impacted by emerald ash borer in PA and other southern states. This could eventually lead to the elimination of this tree species from much of its range (Greg Podniesinski, PA DECNR*, pers. comm*.)

map the distribution of this habitat type as extending south from Pennsylvania to Georgia, and west to the Ozark Mountains of Missouri and Kansas (Figure 2 and Table 1). However, this pattern does not accurately portray the northern distribution of this habitat type, as variants of oak-hickory and oak-pine forests extend north to northern New York State, southern Vermont, New Hampshire, and Maine (Edinger *et al*., 2002; Thompson and Sorenson, 2000; Sperduto and Nichols; Gawler and Cutko, 2010).

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^{o}C, and mean January temperatures of about 0^{o}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^{o}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).

Table 1. Extent of Central Mixed Oak-Pine Forest in Region (TNC/NEAFWA, 2011).

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
Total acres	23,796,554	

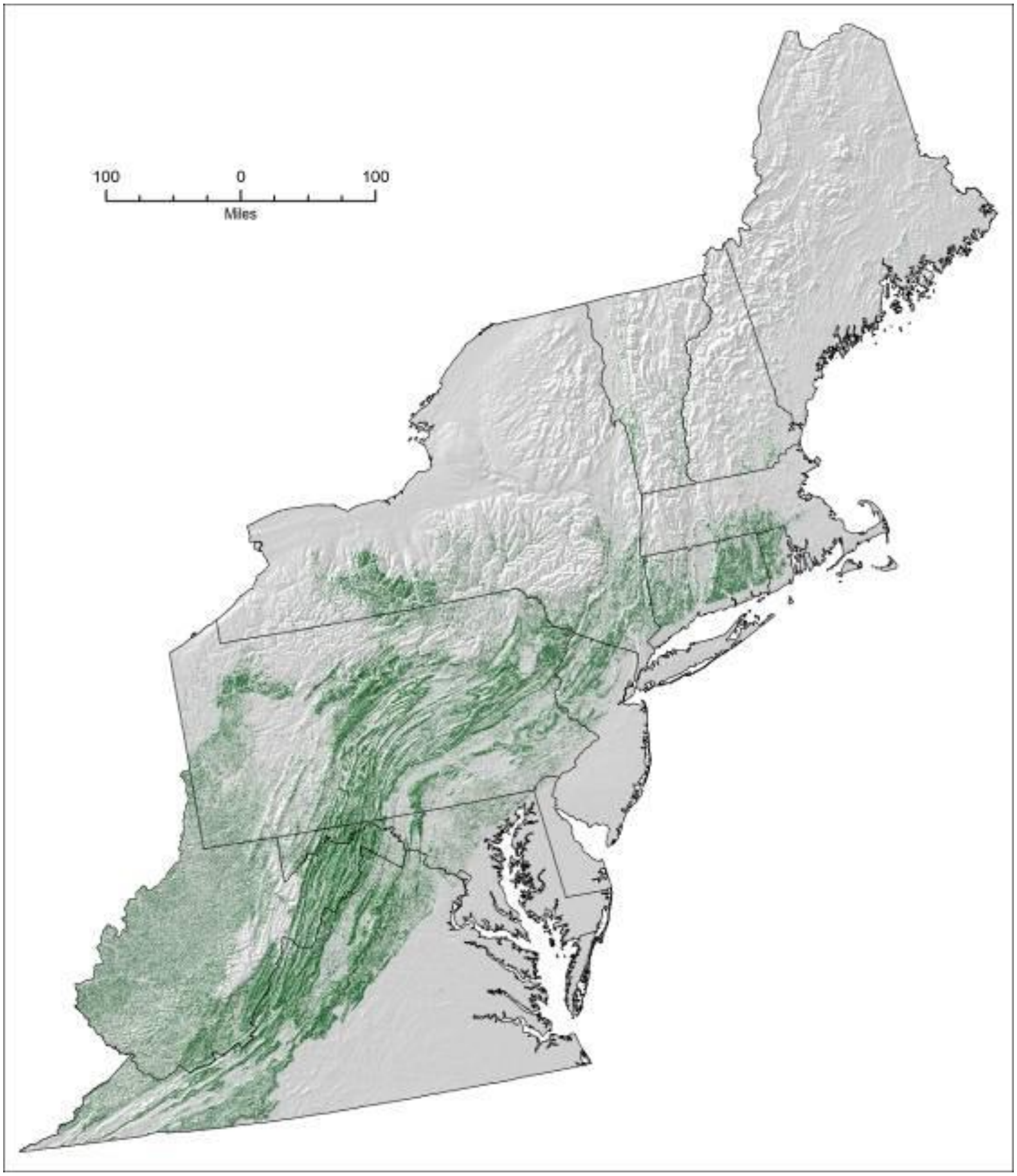

Figure 2. Distribution of Central Mixed Oak-Pine forests in the Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

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). Natural gas extraction from the Marcellus Shale is a new stressor that could impact large areas of this habitat type in Zones III and IV (see below). 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.

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. It should also be noted that the relative vulnerabilities of Zones III and IV due to non-climate stressors could be higher than we have assumed, due to the uncertain outcomes of the burgeoning development of the Marcellus Shales.

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 could 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[13]. If the concentrations are closer to or exceed a tripling we could see much greater changes 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.

Uncertainty Analysis

Based on our extensive knowledge about the ecology of this habitat, its distribution, and relationships with climate, we assigned a certainty score of High to our model projections. If climate change were the only stressor impacting this habitat type our confidence in these scores would be robust. As noted above, however, there are potentially great anthropogenic uncertainties in Zones III and IV, primarily habitat degradation and destruction due to natural gas extraction from the Marcellus Shale. If, as expected, the energy industry expands its activity in these regions, we could see major impacts on oak-hickory forests.

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 200 km from 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

[13] They also do not take into account the uncertain effects of Marcellus Shales development.

beyond 200 km of its southern range boundary. In contrast, this habitat in Zone IV is within 200 km 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. 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, scored 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 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 (although see comments below on Marcellus Shale development). 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. Also, the development that is currently taking place in the Marcellus Shale in Zones III and IV have the potential to increase greatly in the future. This could result in greater habitat loss in some areas. 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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Attachment 7. Habitat Vulnerability Evaluation: Pitch Pine Barrens

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

Summary of Results

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. Their canopies 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).

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)[14]. 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 escarpments and 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).

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.

[14] According to TNC/NEAFWA (2011), Pine Barrens do not occur in Virginia or West Virginia. However, interior Pine Barrens do, apparently, occur on high elevation escarpments at least in the latter (E. Byers, WVDNR, *pers comm*.)

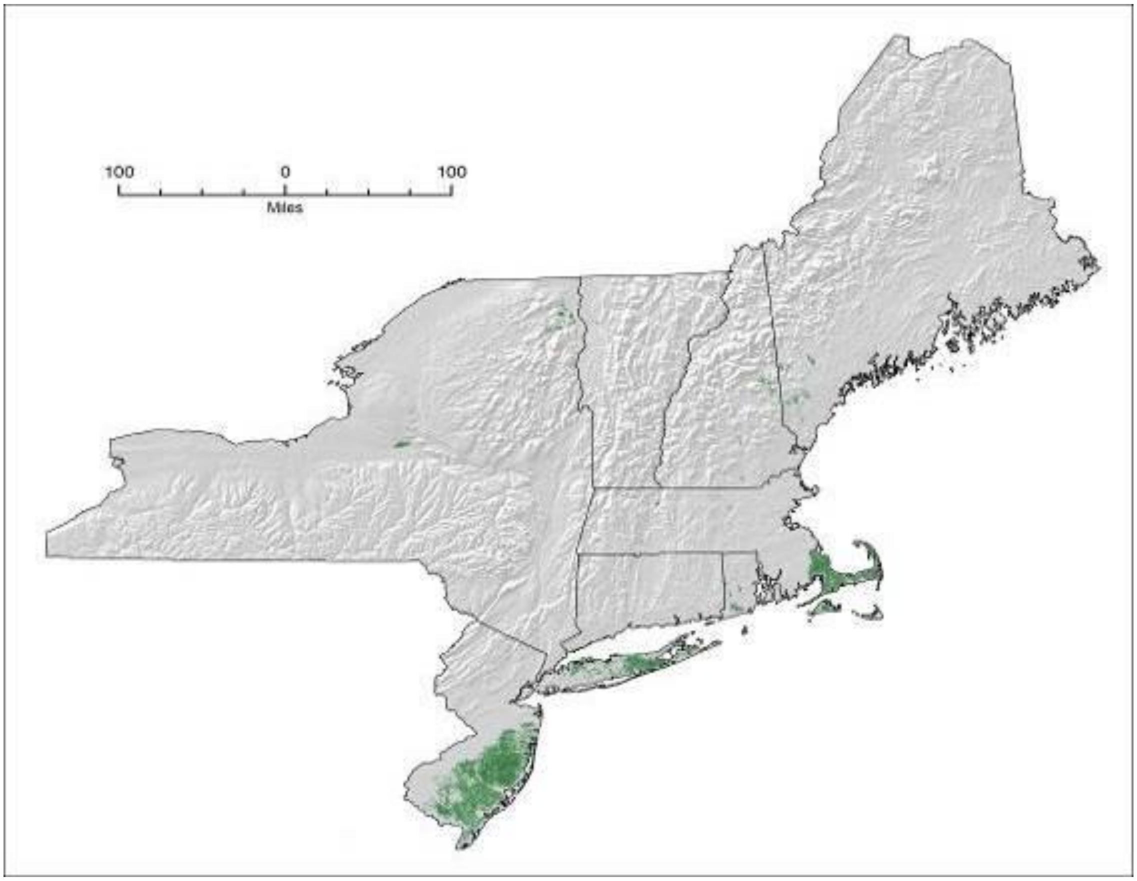

Figure 2. Distribution of pitch pine barrens in the northeastern states. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

Table 1. Extent of Pitch Pine Barrens in Region (TNC/NEAFWA, 2011).

State	Habitat acres in state	% of total habitat in Northeast
Maine	9,155	1.7
New Hampshire	5,718	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
Total acres	534,305	

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.

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 and increased drought 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.

Uncertainty Analysis

Our overall certainty score for this habitat is High. This reflects our extensive knowledge of the ecology, climate relationships, distribution, etc. of pine barrens. However, the vulnerability of this habitat to non-climate stressors, particularly societal responses to the changing climate, is higher than its vulnerability to climate change stresses. This habitat is already being impacted in many areas by loss and fragmentation due to 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. As always, projecting societal responses to the changing climate is an uncertain process.

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 200 km of the habitat range boundary. In contrast, in Zones III and II this habitat is at greater distances than 200 km 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 or middle 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 ability 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 of 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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Attachment 8. Habitat Vulnerability Evaluation: Central and Southern Appalachian Spruce-Fir Forest

Figure 1. Fraser fir forest close to the summit of Mount Rogers (>5,000 feet) in southern Virginia.

Summary of Results

Vulnerability to Climate Change	**Critically Vulnerable (Zone IV)**
Vulnerability to Non-climate Stressors	**Critically Vulnerable (Zone IV)**
Overall Future Vulnerability	**Critically Vulnerable (Zone IV)**

Habitat Ecology and Distribution

Central and Southern Appalachian Spruce-Fir Forest (Figure 1) is the southern equivalent of the more northern Acadian-Appalachian Montane Spruce-Fir Forest (NETHCS, 2008). Like the latter, it is confined to high elevation mountain ridges and summits (>4,500 feet above sea level) where, because the dominant conifer tree species are adapted to extreme weather conditions, high snowfall, and short growing seasons, it is able to outcompete the lower elevation northern hardwood forests (ABC, 1999). It differs floristically from the more northern version of Spruce-Fir Forest in that it lacks balsam fir, one of the dominant species in Acadian-Appalachian Montane Spruce-Fir Forest, which is replaced by the closely-related Fraser Fir.

Floristically, this habitat is typically dominated by red spruce and Fraser fir. The latter species, which is endemic to this habitat type, occurs with greater frequency at higher elevations, forming pure stands above 5,500 feet in the more southern parts of its range in North Carolina and Tennessee. However, this only occurs at one site in the Northeast Region – Mount Rogers in Virginia (http://www.dcr.virginia.gov/natural_heritage/natural_communities/ncTIa.shtml). Below 5,000 feet, this habitat transitions into Northern Hardwood Forests dominated by maples, beech, and birches. The shrub layer in Central and Southern Appalachian Spruce-Fir Forest usually consists of catawba rhododendron and witch hobble, with herbs (for example, Canada mayflower) ferns and mosses forming the herb layer (Hunter *et al*., 1999).

Immediately after the last glaciation, when temperatures were much lower than today, this habitat type extended more widely throughout the southern states of the Northeast Region (Delcourt and Delcourt, 1998). However, with the post-glacial climatic amelioration, it was replaced in lower elevation areas by broadleaf forests and its range contracted to the highest elevations. Today, this spruce-fir forest occurs in the Northeast Region only in Virginia and West Virginia (Figure 2), but its range extends south from these states along the Appalachian chain to North Carolina. The central northeastern states of Pennsylvania, Maryland, and Delaware separate this habitat type from the southernmost outliers of Acadian-Appalachian Montane Spruce-Fir Forest in the New York Catskills and the Massachusetts Berkshires. With some balsam fir, but lacking Fraser fir, the spruce-fir forests of the West Virginia Allegheny Mountains could be regarded as a transition form between the southern and northern versions of spruce fir forest (Barbour and Billings, 1988). However, for the purposes of evaluating vulnerability to climate change of the southern forms of the boreal forests we treat the Virginia and West Virginia forests as being similar. The greatest extent of this habitat type in the Northeast Region is in West Virginia, with only smaller fragments occurring in Virginia (Table 1).

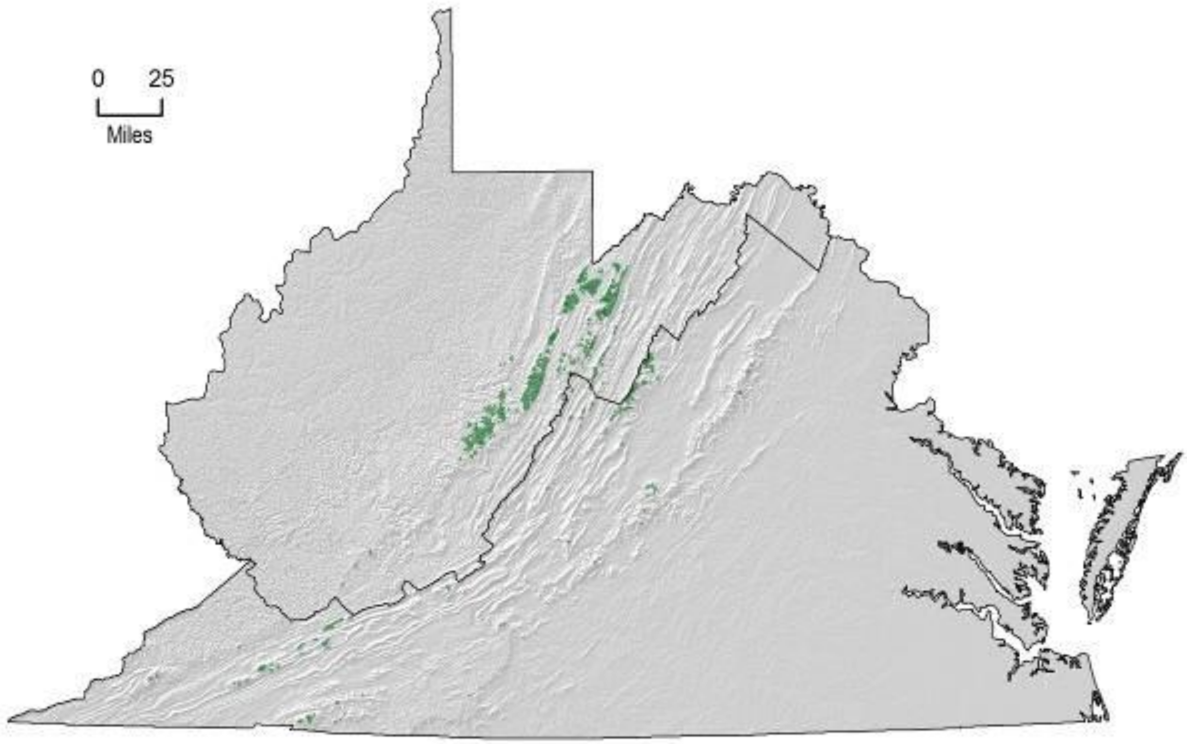

Figure 2. Distribution of Southern Appalachian Spruce-Fir forest in Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

Table 1. Extent of Central and Southern Appalachian Spruce-Fir forest in Northeast Region (TNC/NEAFWA, 2011).

State	Habitat acres in state	% of total habitat in Northeast
Virginia	6,398	9.8
West Virginia	59,010	90.2
Total acres	65,408	

Currently this habitat type exists throughout its range in the Appalachians as relatively small and fragmented patches. This is partly due to its limitation to the highest elevation areas, but is also due to past land use history and to the actions of current stressors, particularly insect pests. Logging in the early 20th century, particularly during World War I, greatly reduced the extent of this habitat type. However, beginning in the 1920s and

1930s much of the remaining forest was put under public ownership to protect it from further loss. This has resulted in approximately 90% of the remaining forest being conserved (Hunter *et al*., 1999).

Though logging of this forest type has been largely eliminated, other stressors continue to affect it. Ozone depletion and acidic deposition may be adversely affecting it, though the evidence for this remains equivocal. There is no doubt, however, about the ravages of the balsam wooly adelgid (Figure 3). This insect pest was introduced from Europe in about 1900 and the total area since damaged throughout the Appalachians has been estimated as 70,000 acres (Nicholas *et al*., 1999). The adelgid affects mainly Fraser firs, particularly older growth individuals. As yet, there are no effective control measures available for this pest species. Climate and temperature appear to exercise some influence over the distribution of the adelgid (http://www.na.fs.fed.us/pubs/fidls/bwa.pdf). In warmer areas, more generations of the insect can be produced each year. In areas with cooler summer temperatures, the adelgids are more limited in the numbers of generations that they can produce.

Because of its fragmentation, current threats, and relatively high rates of endemism, Noss *et al*. (1995) ranked this habitat type as the 2nd-most endangered ecosystem in the United States.

Figure 3. Fraser firs killed by balsam woolly adelgids in Great Smoky Mountains National Park

Model Results

The results of the model runs for Zone IV (the only zone in which this habitat type occurs) are shown in Table 3.

Table 3. Vulnerability modeling results.

Zone	Vulnerability to Climate Change	Vulnerability to Non-climate Stressors	Overall Vulnerability	Certainty
Zone IV	Critically Vulnerable	Critically Vulnerable	Critically Vulnerable	High

These results indicate that the vulnerability of this habitat type to future climate change in Zone IV is extreme. This is largely due to its limitation to high elevation cool areas where it can outcompete broadleaf forest species, the relative inability of this habitat type to migrate upslope (since it already exists only on the highest ridges and summits), its sensitivity to extreme climatic events, and the fact that the foundational species of this habitat (Fraser fir and red spruce) are adapted to cooler temperatures and short growing seasons. However, even discounting future climate change, this habitat is already extremely vulnerable to other stressors, particularly balsam wooly adelgids. When combined, these two risk levels render the habitat type as critically vulnerable. 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 and the effects of current stressors on this habitat type are well understood.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fates of the habitat type in Zone IV suggests that most, if not all, could be eliminated by future climate change, in conjunction with the continuing devastation caused by the balsam wooly adelgid. At best, we can expect significant reductions in the extent of this already limited habitat, and its replacement by lower elevation habitat types.

These projections are similar to those proposed by Prasad *et al*. (2007) who modeled the complete or almost complete elimination of red spruce in the Northeast, including in Zone IV.

Uncertainty Analysis

Given our extensive knowledge of the relationships between climate and the distribution and ecology of this habitat type, we determined that our level of certainty for the model scores should be High. The main uncertainty is not how adversely this habitat might be impacted but how rapidly this might happen. If the changing climate enables the balsam wooly adelgid to reproduce more rapidly (as is happening elsewhere with hemlock wooly adelgid), the degradation of this habitat type could occur over a timespan of a few decades. However, it is also feasible that effective controls on this pest species may be developed. Even if this were the case, the loss of habitat due to the changing climate itself would be likely to continue, though at a somewhat slower rate.

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 northern geographic limit for this habitat type is in the Virginian and West Virginian Appalachians. Various sources (e.g., Hunter *et al*., 1999; Barbour and Billings, 1988) place the southernmost edge of its distribution in North Carolina and Tennessee. All of the habitat patches in Zone IV are, therefore, approximately within 200 km of this southern range 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 short, where mean annual and summertime temperatures are lowest, where extreme winter climatic events frequently occur, and where snowpack is deep. Second only to its more northern equivalent, Central and Southern Appalachian Spruce-Fir Forest is adapted to the coldest and most extreme climatic conditions.

With a moist elevation-temperature lapse rate of 1.0 ºF 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, there is limited potential for upward migration under a warming climate. It would require a mean annual temperature increase of only about 3-4 ºF to entirely eliminate the climatic envelope in which most of this habitat exists in Virginia, and even less in West Virginia. 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 IV.

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 IV. 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. 90% of the remaining tracts of this habitat type exist in protected areas 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 may see humans responding to the increasing summer temperatures at low elevations by installing recreational facilities on the cooler mountain tops and ridges (for example, for mountain biking and off-road vehicles). However, such effects and impacts are likely to be limited in extent, given that most of the remaining patches of this habitat are protected. Nevertheless, it is possible that human recreational use of this habitat may increase as the temperatures rise.

Another potential future anthropogenic stressor in this habitat is the installation of mountain-top and ridge wind power facilities. This could represent a significant risk to patches of this habitat. However, as already described, most such patches exist on lands that have been set aside and protected for this habitat. It is, perhaps, unlikely, therefore, that wind power installations will have a significant effect on this habitat type. We have accordingly scored this habitat as being Less Vulnerable for both of these variables, but have assigned a certainty score of only Medium (to reflect uncertainty about future human activity and responses).

Module 1. Location relative to highest elevation. In Zone IV the upslope limit of this habitat type is determined by the height of the land. The highest elevation of Virginia is just over 5,700 feet above sea level, and just below 4,900 feet in West Virginia. In both states this habitat generally begins to appear at about 4,500 feet and extends up to the highest summits. Thus, in both states, there is little potential for upward elevational shift of this habitat type – it has nowhere to go. We therefore assigned a vulnerability score of 5 for this variable, with a certainty score of High.

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 three factors: (a) its regeneration time (the period between a major disturbance that results in habitat loss and recovery back to a mature stand) is likely to be protracted (as has already been shown for the similar Acadian Appalachian Montane Spruce-Fir Forest). This protracted recovery period will make the habitat vulnerable to repeat disturbances. (b) Tree growth rates, reproductive potentials, and recruitment are all likely to be slow because of the ecological, biochemical and biophysical constraints imposed by short growing seasons and low temperatures. (c) This habitat type is highly fragmented in its distribution into small, isolated patches. This lack of contiguity makes it unlikely that the habitat as a whole in Zone IV will be able to recolonize areas that have suffered habitat loss under either climate change or current stressors. These limitations will 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 Fraser fir. These are both trees that are highly adapted to short growing seasons and extreme weather conditions. Prasad *et al*. (2007) has shown that red spruce is likely to be highly vulnerable to a warming climate in the Northeast. We have, accordingly scored their vulnerability as High, with a certainty score also of High.

Module 1. Constraints on latitudinal range shifts. These spruce-fir forests in Zone IV exist on isolated mountain-tops that are widely separated by intervening and extensive tracts of lower-lying ground. North of its current distribution in Zone IV similar high elevation growing conditions do not occur until central and northern New England, and these areas are already occupied by Acadian Appalachian Montane Spruce-Fir Forests. It is extremely unlikely that this habitat will be able to shift north across such expanses of lower elevation land or bridge the gap to New England (where the same climatic conditions will be rendering current high elevation habitat less suitable. We have accordingly scored the vulnerability of this habitat type as Highly Constrained in Zone IV, with a certainty score of High.

Module 1. Likelihood of managing/alleviating climate change impacts. We have scored this variable as relatively infeasible. 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, the habitat is currently under severe stress from the invasive pest, balsam wooly adelgid. The distribution, productivity, and density of this pest are known to be at least partly a function of climate. Colder winters and summers and short growing seasons reduce the number of generations that the adelgid is capable of producing in any one reproductive season. In contrast, warmer conditions make it possible for the adelgid to have more generations, and, therefore, greater densities. One of the effects of the changing climate on this habitat is likely to be, therefore, to increase the frequency and intensity of adelgid outbreaks, resulting in greater injury to the trees, particularly to Fraser fir which is highly vulnerable to this pest. 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. This habitat in the Northeast region is confined to Virginia and West Virginia, where it exists in more or less highly fragmented and usually small mountain-top patches. Accordingly we have scored this variable in Module 2 as 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 protected land, current loss rates from logging or habitat destruction are minor. However, the balsam wooly adelgid outbreaks to which this habitat is vulnerable are causing widespread habitat injury and loss. For this reason we have scored this variable as More Limited Losses, with a certainty score of High.

Module 2. Likely future extent trend. We consider it likely that the losses that are currently being incurred by the balsam wooly adelgid will continue into the future (since no control measures have yet been developed). Accordingly, we have scored this variable as 3 (Some Losses). This may underestimate likely future losses due to this stressor; however, it is also possible that control measures may be developed. Thus we have scored our certainty as only Medium for this variable. Another uncertainty in this variable is the future of windpower development. Elsewhere in the Northeast these are often sited on exposed and high elevation summits and ridges – typical locations for Central and Southern Appalachian Spruce-Fir Forests. If windpower increases in its importance in the future, we could imagine Zone IV habitat losses due to the construction of the infrastructure associated with some developments.

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being affected by the non-climate stressor balsam wooly adelgid. Infestations by this pest have resulted in widespread injury to and loss of this habitat type. Accordingly we have scored this variable as 5 (Highly affected by non-climate change stressors) with a certainty score of High.

Module 2. Likely future stressor trends. Efforts to control balsam wooly adelgid have, thus far, met with no success. There is a high risk, therefore, that the impact of this stressor could continue to increase in the future. For this reason, we score this variable as 5 (Large Increase), with a certainty score of Medium (since it is possible that some control measures may eventually be developed).

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Attachment 9. Habitat Vulnerability Evaluation: Northern Atlantic Coastal Plain Basin Peat Swamp

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

Summary of Results

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 (Figures 3 through 5 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%.

In the Northeast, this habitat type is confined to coastal areas with 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 (Figure 1) 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*.).

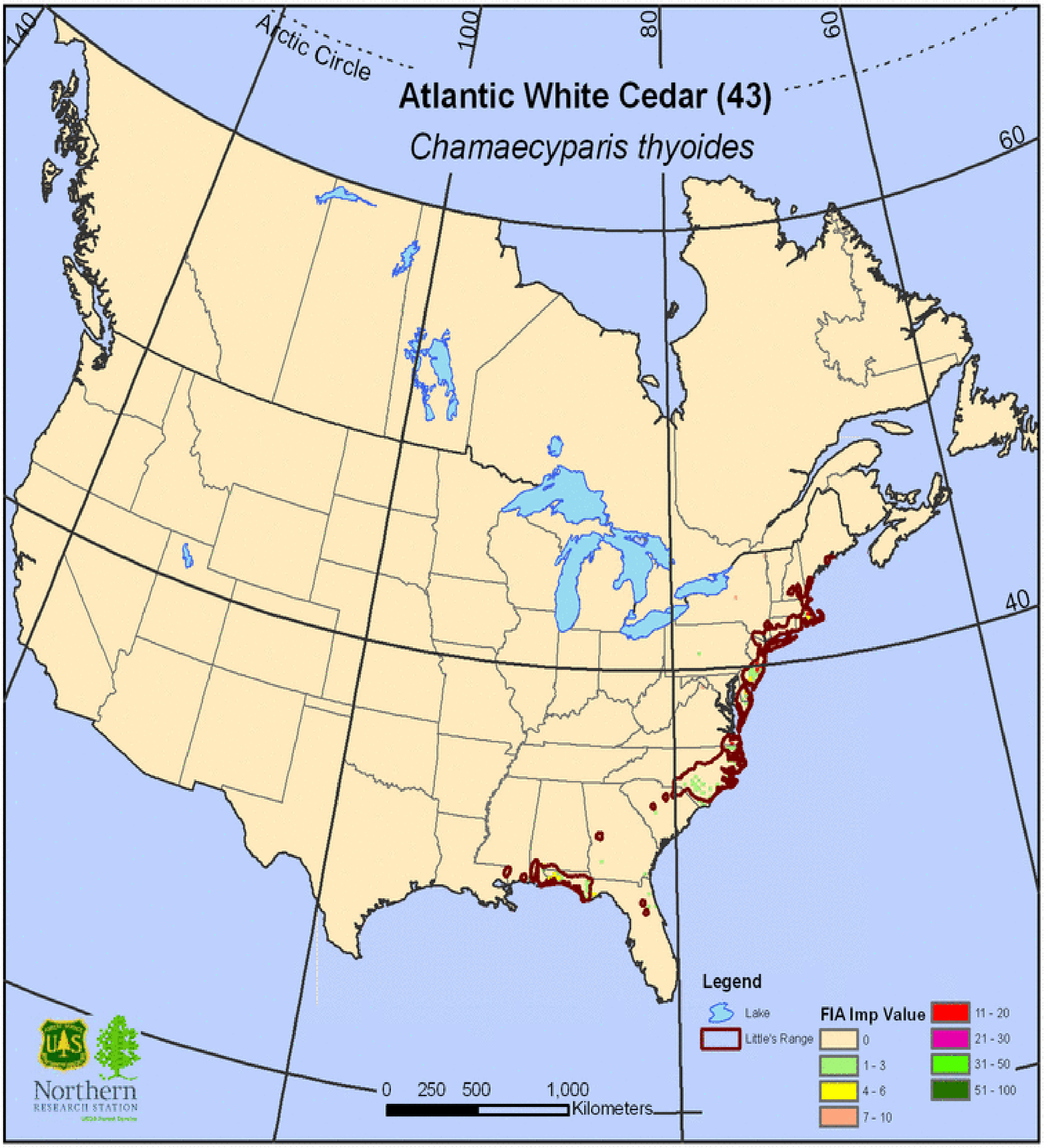

Figure 2. Distribution of Atlantic white cedar swamp in North America (Prasad *et al*. 2007).

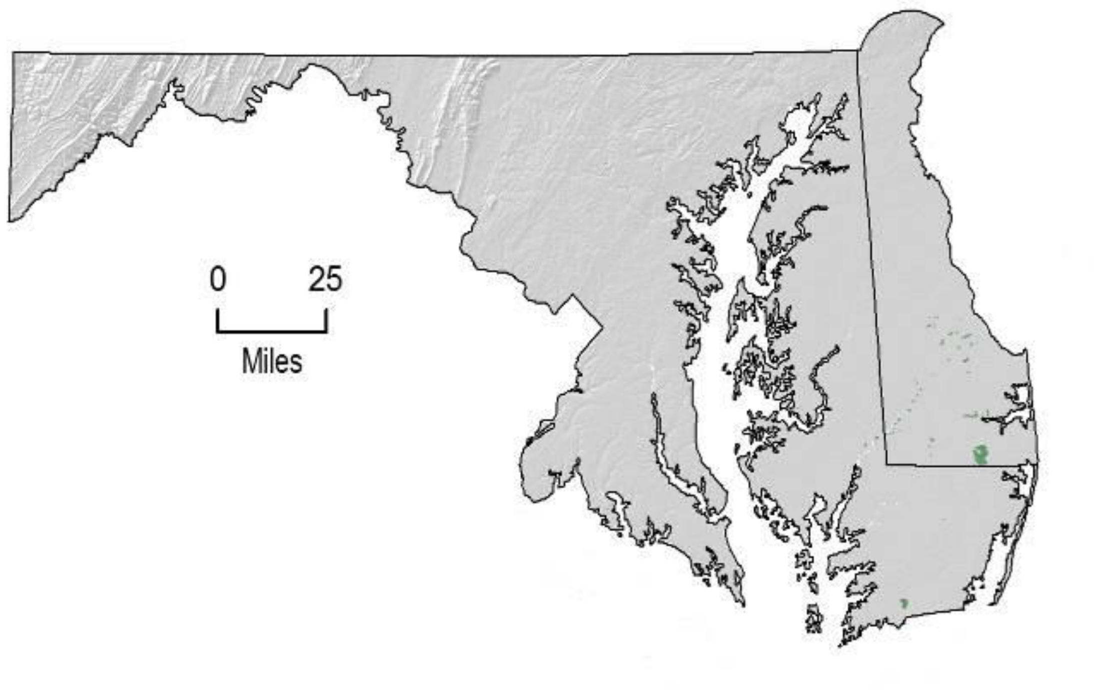

Figure 3. Distribution of Atlantic white cedar swamp in Delaware. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

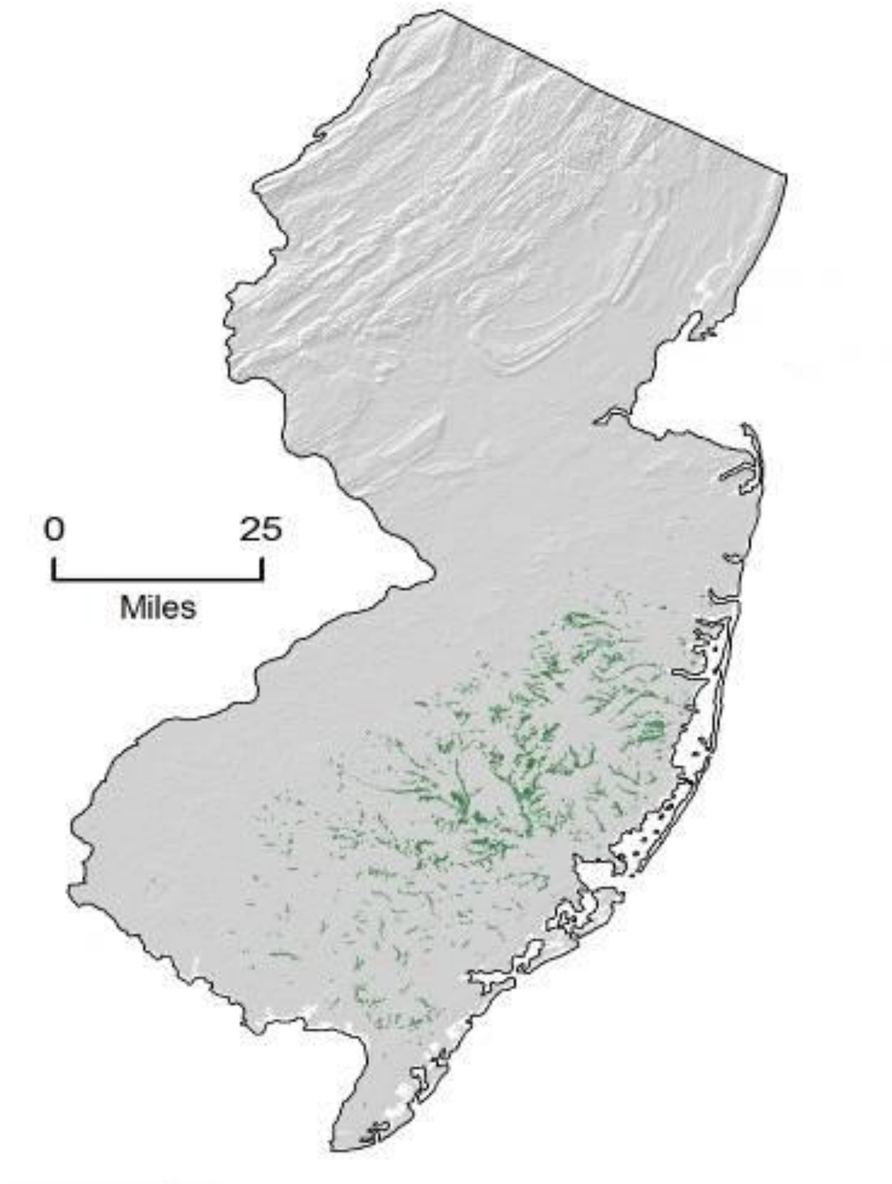

Figure 4. **Distribution of Atlantic white cedar swamp in New Jersey. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).**

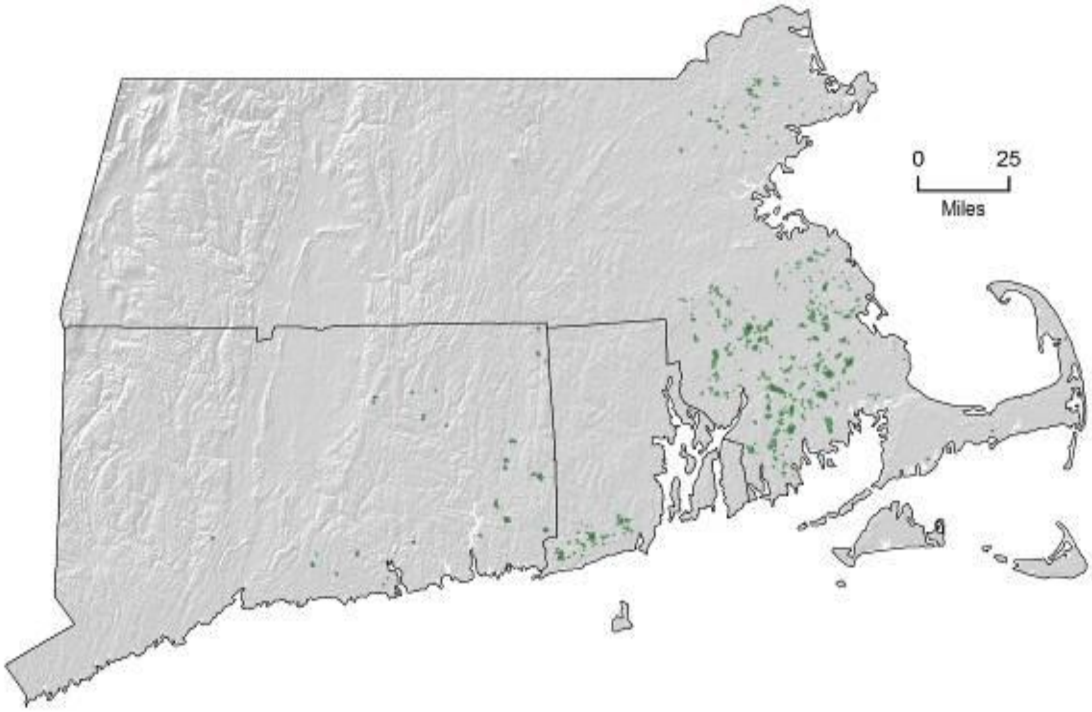

Figure 5. Distribution of Atlantic white cedar swamp in New England. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

(Atlantic white cedar swamp) in Northeast Region (TNC/NEAFWA, 2011).

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
Total acres	59,528	

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. The germination and growth of Atlantic white cedars in New Jersey are negatively correlated with the Palmer Drought Severity Index, but not temperature (Lavagnino *et al*., 2009).

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.

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.

Uncertainty Analysis

While our confidence in our projections about the vulnerability of this habitat type to climate change and other stressors is High, our greatest areas on uncertainty lie not in the ecology of the habitat or its relationships with climate, current or future, but in societal responses to the changing climate. The main non-climate stressor on the habitat in most areas today is due to fire suppression and the replacement of white cedar-dominated forest by one dominated by oaks. If, as we believe, the future climate will be characterized by longer and more severe droughts and soil drying, it is likely that the risk of fire will become greater. This need not necessarily have an adverse impact on the Atlantic white cedars, but increased fire suppression activities could.

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 950 km 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 200 km 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 million/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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Attachment 10. Habitat Vulnerability Evaluation: Boreal-Laurentian Bog; Boreal-Laurentian-Acadian Acidic Basin Fen; North-Central Interior and Appalachian Acidic Peatland

Figure 1. Boreal bog in New Hampshire. The surface vegetation is dominated by sphagnum mosses, leatherleaf and sheep laurel. Peatlands such as this often support both major plant communities (Boreal-Laurentian Bog and Boreal-Laurentian-Acadian Acidic Basin Fen), with the former comprising the raised, dome-shaped interior of the bog and the latter being restricted to the perimeter and areas nearer to surface water.

Summary of Results

Vulnerability to Climate Change	**Highly Vulnerable (Zones I and II)**
Vulnerability to Non-climate Stressors	**Less Vulnerable (Zones I and II)**
Overall Future Vulnerability	**Highly Vulnerable (Zones I and II)**

Habitat Ecology and Distribution

Boreal-Laurentian Bog, Boreal-Laurentian-Acadian Acidic Basin Fen, and North-Central Interior and Appalachian Acidic Peatland are three of the most characteristic, iconic, and readily identifiable wetland habitats of the Northeast. The common characteristics of all three community types are that they develop in poorly drained areas with a water table that is permanently at or close to the ground surface, that have cool growing season temperatures, short growing seasons, high precipitation rates, and whose substrate is mineral-deficient base rock. The combination of mineral deficiency, year-round saturation, and cooler temperatures result in anaerobic decomposition processes and high substrate acidity. The resulting slow rates of breakdown of dead plant material lead to a build up of a peat layer which can reach depths of several feet.

Peatland wetland vegetation communities in the Northeast extend over a spectrum from the large patch highly acidic Boreal-Laurentian Bogs to more alkaline fen communities (Thompson and Sorenson, 2000), and to small patch bog-dominated kettleholes. Water and nutrient input to Boreal-Laurentian Bog and North-Central Interior and Appalachian Acidic Peatland is entirely from precipitation – that is, such bogs are ombrotrophic. Boreal-Laurentian-Acadian Acidic Basin Fen differs in that it is more closely connected to groundwater and receives some limited mineral input from this source. The pH of most Boreal-Laurentian Bogs and North-Central Interior and Appalachian Acidic Peatlands ranges between 3.5 and 5. Boreal-Laurentian-Acadian Acidic Basin Fen (or poor fen as it is known in Vermont (Thompson and Sorenson, 2000), leatherleaf bog as it is identified in Maine (Gawler and Cutko, 2010) and dwarf shrub bog in New York (Edinger, *et al*., 2002)) is similar, but forms a transition community between the most acidic and ombrotrophic bogs to more basic and surface water-fed fens. Typically found on the perimeters of Boreal-Laurentian Bogs, it shares many of the characteristics of both bogs and fens, being acidic (pH of 3.5 to 5.0), but slightly mineral-enriched by groundwater seepage. They are basically Boreal-Laurentian Bogs with a tendency toward a more fen-like ecology.

The geographic distributions of these three habitats are limited by climatic, topographical, historical, and geological factors. They develop mostly in poorly-drained depressions in the land surface, such as basins, ponds, and kettleholes, and on mineral-poor granitic base rock. Boreal-Laurentian Bog and Boreal-Laurentian-Acadian Acidic

Basin Fen are large patch habitats that are largely confined to more northern and mid to high elevation areas with relatively high precipitation rates, cool temperatures, and brief growing seasons. Boreal-Laurentian Bog (Figure 1) is most widespread in Maine and New York (Table 1 and Figures 2-5), rare in Vermont where the base rock is more mineral-rich, and absent from New Hampshire and Massachusetts[15]. Boreal-Laurentian-Acadian Acidic Basin Fen is more widespread occurring in all five northern New England states (most widespread in Maine and New York), as far south as western and central Massachusetts (Table 1 and Figures 2-5). North-Central Interior and Appalachian Acidic Peatland (Table 1 and Figures 6 - 10) usually occurs as a small patch community, forming in isolated depressions, particularly kettleholes. Thus, the distribution of this community type in the Northeast is a function of previous glaciation and it extends further south (as far south as northern Pennsylvania) than Boreal-Laurentian Bog and Acidic Basin Fen. Together, these three habitat types cover almost 530,000 acres in the northern and central states of the Northeast Region (Table 1).

The vegetation of all three wetland types is similar in that it is dominated by a more or less continuous carpet of sphagnum mosses, sedges, and dwarf shrubs (including leatherleaf, sheep laurel, bog laurel, and Labrador tea). Tree cover is either absent or limited to a sparse growth of stunted black spruce and tamarack (Thompson and Sorenson, 2000; Gawler and Cutko, 2010; Edinger, *et al*., 2002; Larsen, 1982). The peat soils are usually saturated and often "quake" when walked on (Figure 1).

These three habitats are similar enough in their physical, chemical, topographical, and ecological characteristics to be considered as one "acidic bog" habitat when evaluating their vulnerabilities to a changing climate, and this is what we have done is this analysis.

[15] This may be a result of some confusion in classification (A. Cutko, D. Sperduto, and P. deMaynadier *pers. comm.*)

Table 1. Extent of Boreal-Laurentian Bog, Boreal-Laurentian-Acadian Acidic Basin Fen, and North-Central Interior and Appalachian Acidic Peatland in Northeast Region, given in acres. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011). Numbers in parentheses are percent representation of habitat in state of total Northeastern habitat acres.			
State	**Boreal-Laurentian Bog**	**Boreal-Laurentian-Acadian Acidic Basin Fen**	**North-Central Interior and Appalachian Acidic Peatland**
Maine	37,386 (82.4)	313,432 (78.1)	4,846 (5.8)
Vermont	153 (0.3)	6,443 (1.6)	2,452 (2.9)
New York	7,856 (17.3)	73,478 (18.3)	38,104 (45.5)
New Hampshire		7,326 (1.8)	2,896 (3.5)
Massachusetts		717 (0.2)	4,215 (5.0)
Connecticut			599 (<1)
New Jersey			164 (<1)
Pennsylvania			30,168 (36.0)
Rhode Island			355 (<1)
Total acres	43,395	401,396	83,799

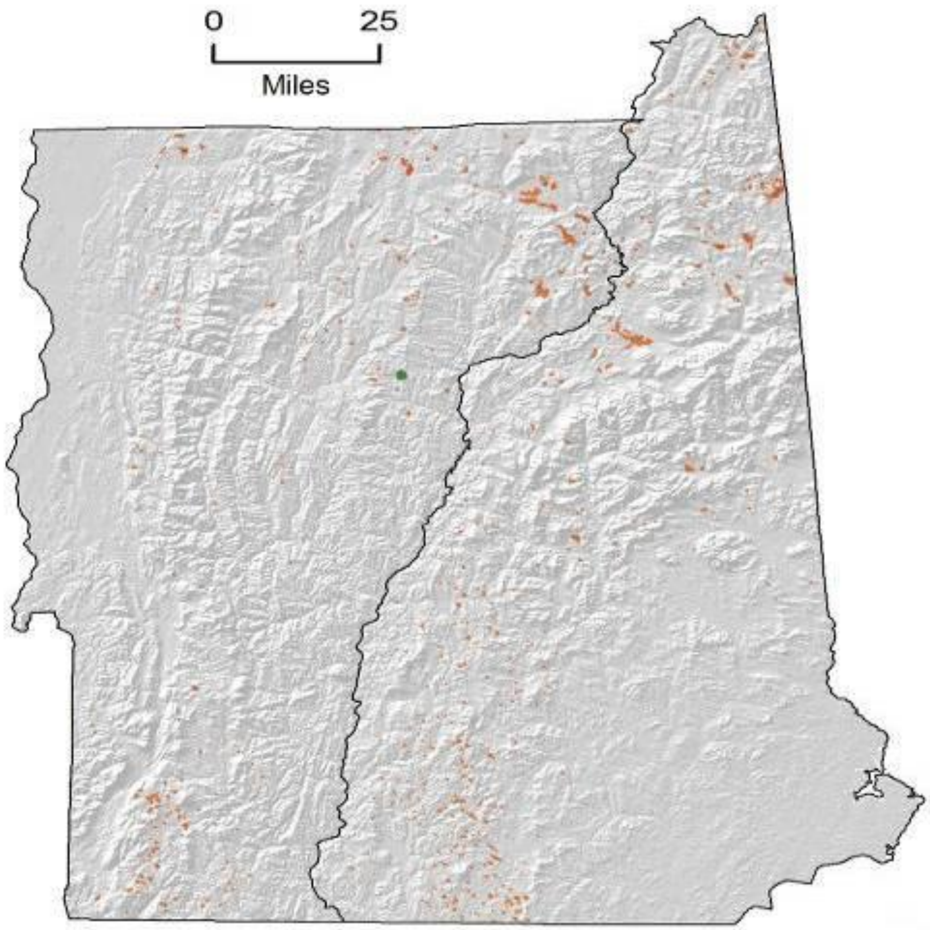

Figure 2. Distribution of Boreal-Laurentian Bog (green) and Boreal-Laurentian-Acadian Acidic Basin Fen (orange) in New Hampshire and Vermont. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

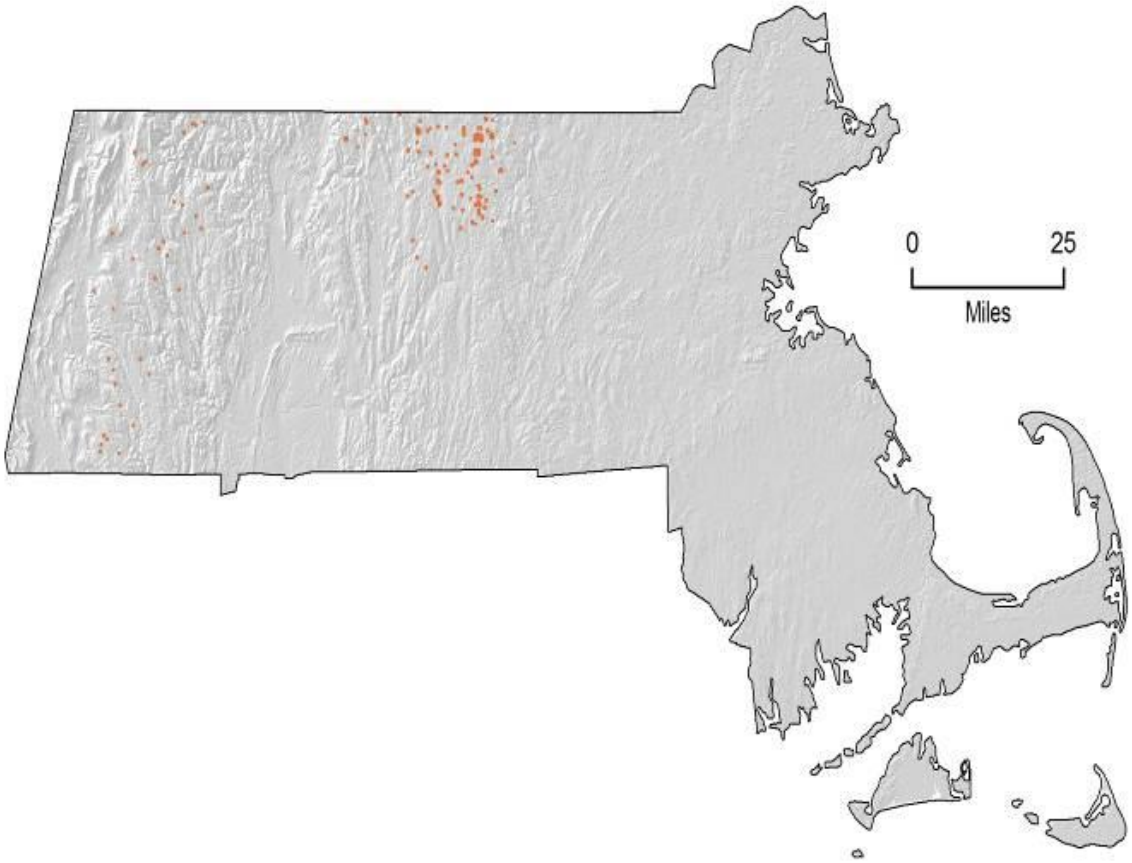

Figure 4. Distribution of Boreal-Laurentian Bog (green) and Boreal-Laurentian-Acadian Acidic Basin Fen (orange) in Massachusetts. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

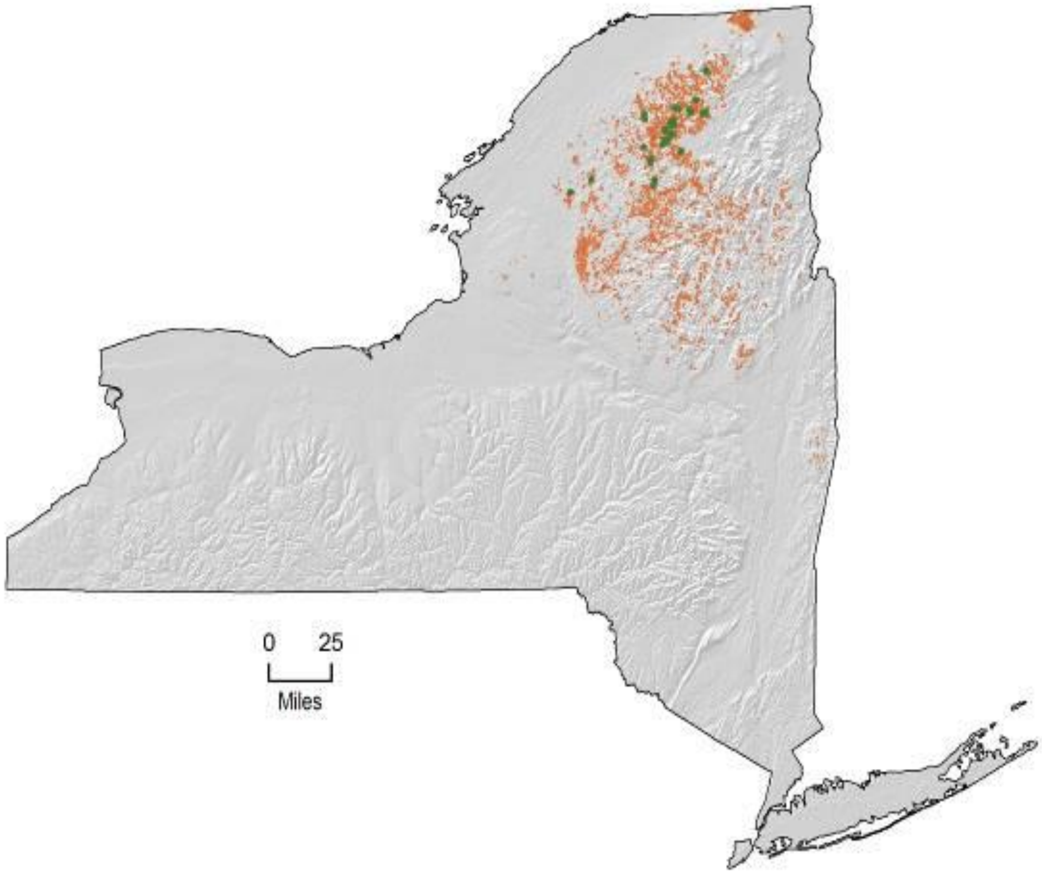

Figure 3. Distribution of Boreal-Laurentian Bog (green) and Boreal-Laurentian-Acadian Acidic Basin Fen (orange) in New York. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

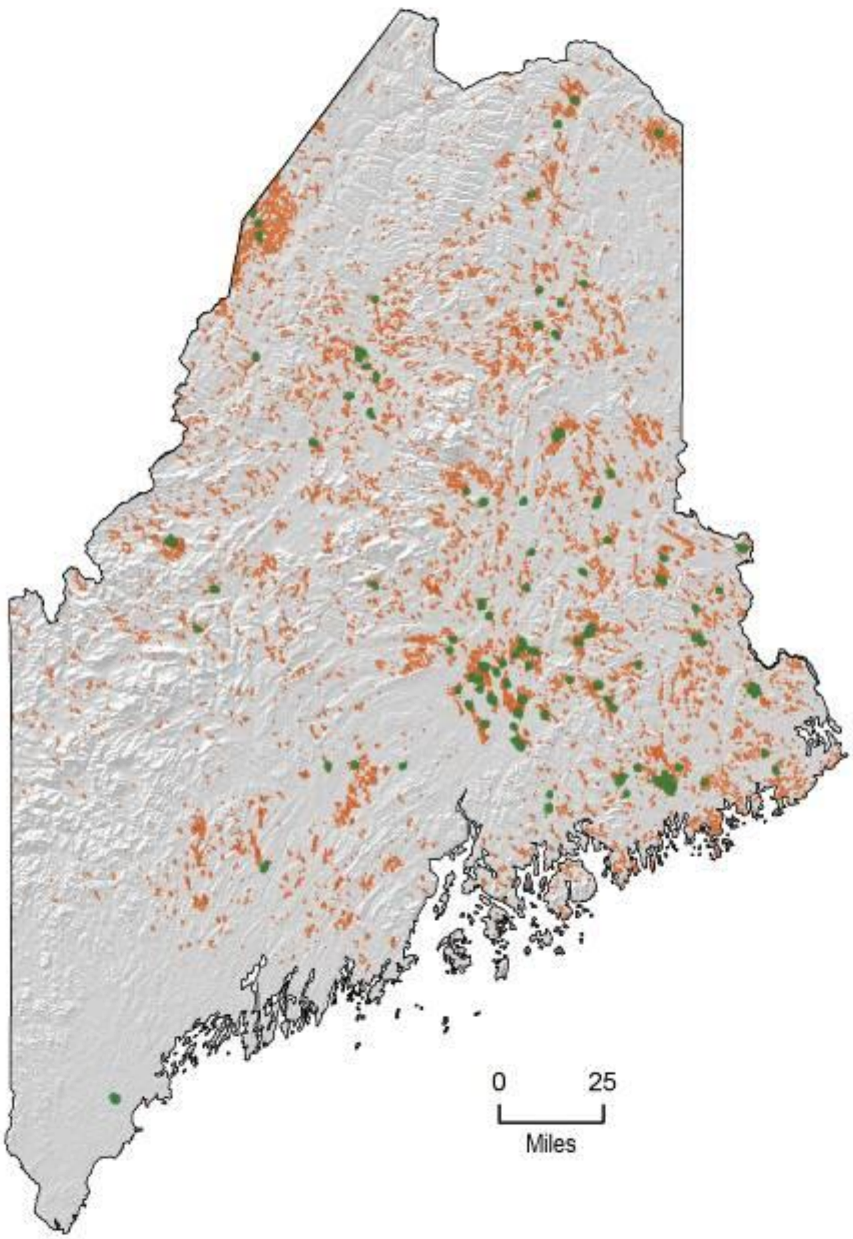

Figure 5. Distribution of Boreal-Laurentian Bog (green) and Boreal-Laurentian-Acadian Acidic Basin Fen (orange) in Maine. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

Figure 6. Distribution of North-Central Acadian and Appalachian Acidic Peatland in Maine. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

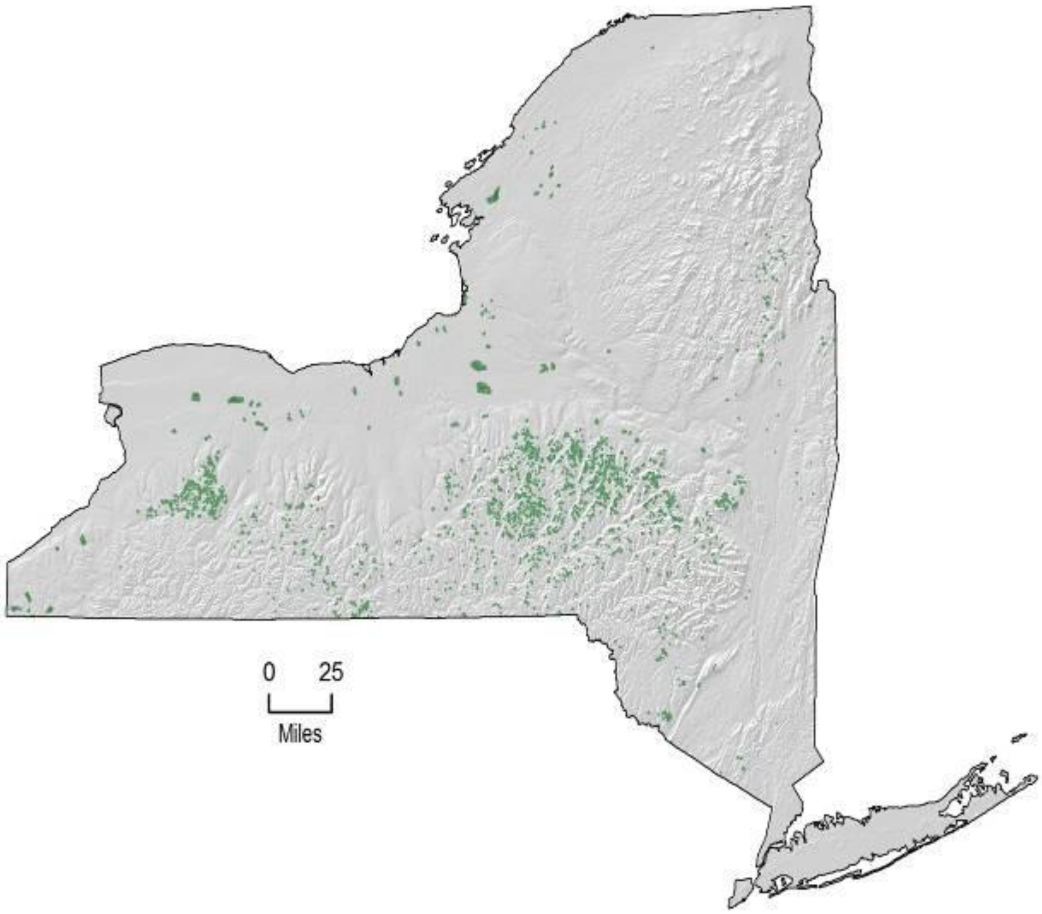

Figure 7. Distribution of North-Central Acadian and Appalachian Acidic Peatland in New York. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

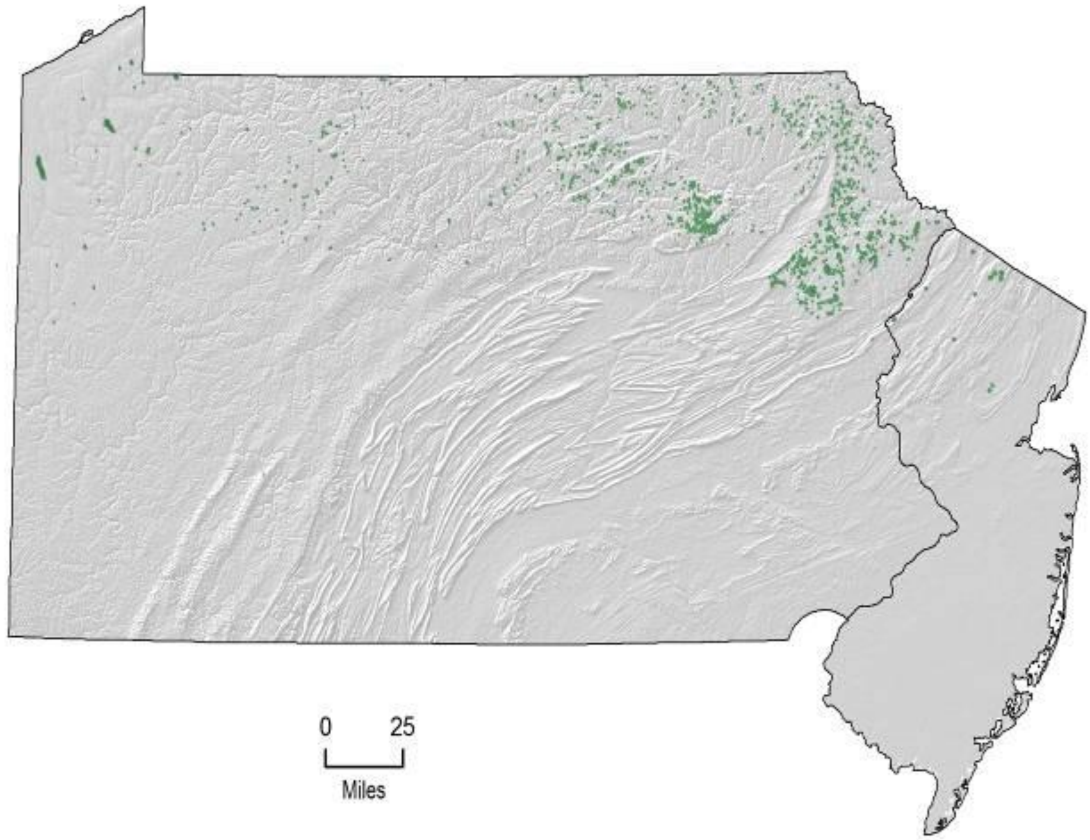

Figure 8. Distribution of North-Central Acadian and Appalachian Acidic Peatland in Pennsylvania. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

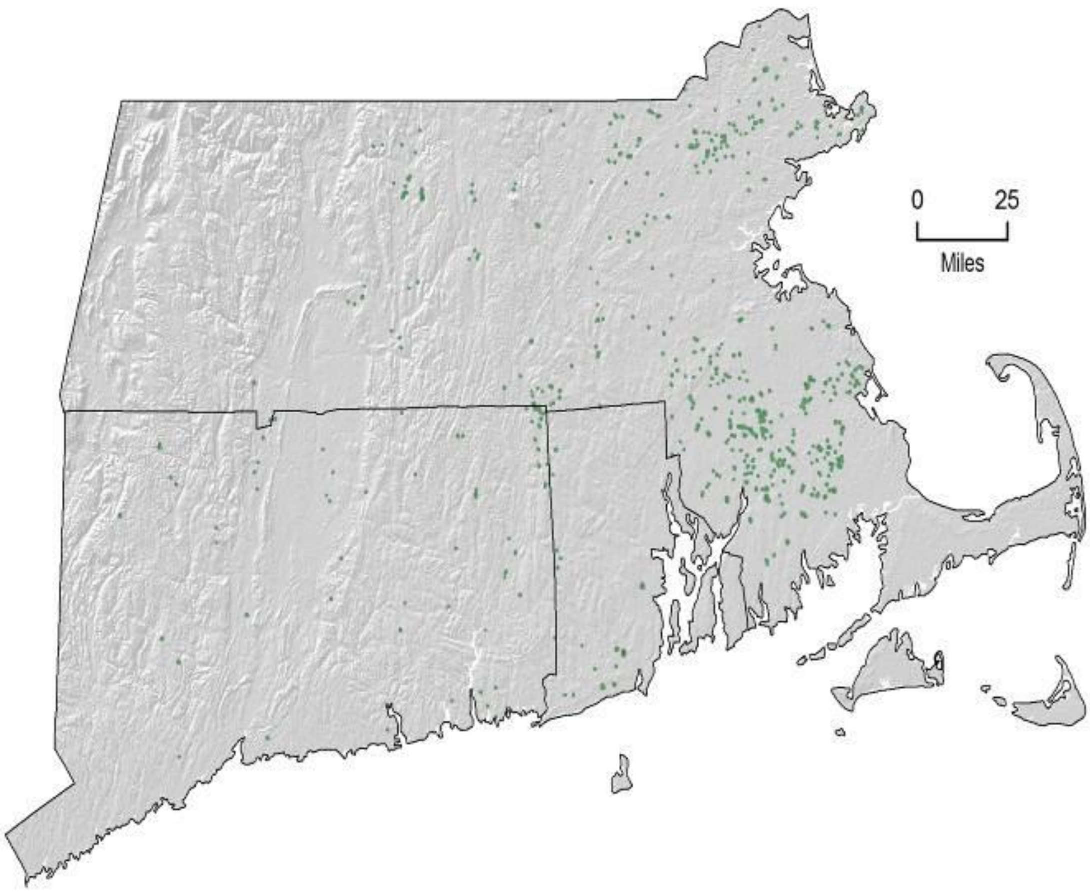

Figure 9. Distribution of North-Central Acadian and Appalachian Acidic Peatland in central New England. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

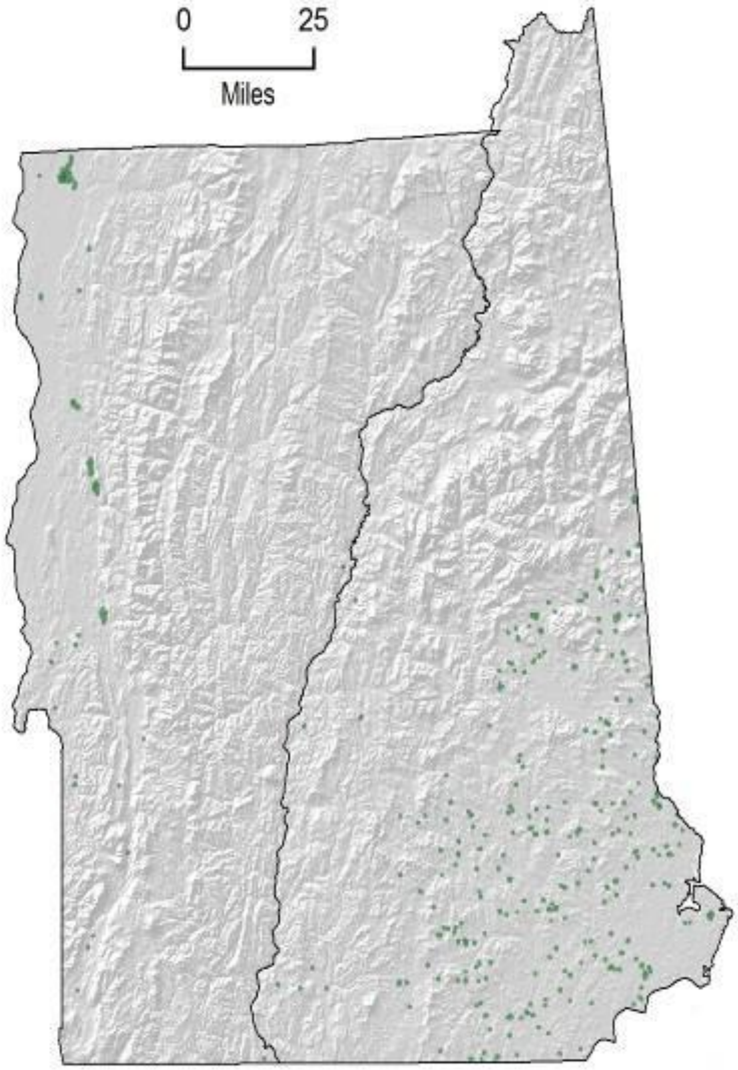

Figure 10. Distribution of North-Central Acadian and Appalachian Acidic Peatland in New Hampshire and Vermont. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

Model Results

The results of the model run for Zones I, II, and III (the only zones in which these peatlands occur) are shown in Table 2.

Table 2. Vulnerability modeling results.

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

These results indicate that these peatland habitats in the Northeast are likely to be vulnerable to the changing climate. This is particularly so in Zone III where they reach their southernmost limit and the numerical vulnerability score approaches Critically Vulnerable. These vulnerabilities are due to several factors: (1) the ability of the habitats to persist only in areas where the soils are more or less permanently saturated, are acidic, and promote peat formation; (2) their limitation to areas that are cool and with short growing seasons; (3) their vulnerabilities to drought and drying of the peat; (4) their potential vulnerabilities to fire; (5) their vulnerability to Nitrogen deposition and increased alkalinity of the peat; (6) and the fact that in Zone III these habitats are already at the southern edge of their range. Future warming could potentially result in the disruption of all of these conditions. Increasing temperatures may result in the (at least seasonal) drying of the peat substrate and an acceleration of the biochemical decay process that take place in this substrate. Such changes are likely to promote tree growth and, ultimately, the replacement of these peatlands with forest. Also, the longer, more frequent and more extreme droughts projected under climate change could result in the drying out of the peat substrate and an increased risk of wildfire. Currently, wildfire is not a major problem for these wetlands but if its frequency, duration, and intensity increases we could witness peat beds being eroded, exposing mineral substrates that could favor more tree growth. Finally, the boreal wetlands in the Northeast have seen over a century of Nitrogen deposition. This could eventually result in the increased alkalinity of the substrate, promoting colonization by trees and non-acidophilic vegetation, exacerbating the effects of climatic change.

Implications for Future Status and Distribution

Interpreting these results in terms of the future fate of these habitats bog in the Northeast Region suggests that these habitats in Zones II and III could be adversely affected and, potentially, greatly reduced in extent by future climate change, particularly North-Central Interior and Appalachian Acidic Peatland in Zone III. Support for this projection comes from the analysis by Prasad *et al*. (2007), which found that black spruce, one of the few tree species that inhabit boreal bogs, would be eliminated entirely from our Zone III and greatly reduced in Zone II under a doubling of greenhouse gases. The bog habitats in Zone I are less vulnerable and are likely to be able to persist, albeit with some habitat losses. Under a tripling of greenhouse gases, Prasad *et al*. (2007) project that all three Zones would lose all of their black spruce.

These results suggest that it is possible that most boreal bog habitat could 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 as isolated, smaller patches at higher elevations at the northernmost extents of Maine, New Hampshire, Vermont and New York.

Uncertainty Analysis

The certainty score for these habitats is High, because we know much about the distribution and ecology of the habitat types and their relationships with climate. The greatest uncertainties lie not in the ecologies of the habitats or the future climates, but in how humans may exploit or impact these habitats in the future. Peat mining, timber extraction, and development are all currently impacting the habitat types. It is feasible, though uncertain, that societal responses to the changing climate might include amplifying one or more of these stressors.

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[16], 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 Boreal-Laurentian Bog and Boreal-Laurentian-Acadian Acidic Basin Fen are limited to Zones I and II, and North-Central Interior and Appalachian Acidic Peatland extends further south into Zone III. All habitat patches in Zone III are within 200 km of this range boundary. Given these facts, for Zone III we have assigned a score of 5 (most vulnerable) for Variable 1 in Module 1, with a certainty score of High. For Zones II and I we have assigned a vulnerability score of 1 (to reflect greater distance from the southern range boundary), again with a certainty score of High.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Climate is the one of the major limitations on the distribution of boreal bog in the Northeast. Specifically, it only occurs in areas with relatively brief growing seasons, where the mean annual and summertime temperatures are low, and precipitation rates are high, resulting in saturated acidic peat soils.

[16] Though see previous comment about possible confusion in taxonomy in parts of Zone II.

Based on these factors, we have conservatively determined that this habitat type should score 3 for variables 2 and 3 for all three zones (degree of cold adaptation and vulnerability to extreme weather events) of Module 1. We did not assign even higher scores because we do not believe that these habitat types are as tightly dependent on or adapted to extreme climates as are (for example, tundra or high elevation spruce-fir 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. These habitat types occur in areas which, because of their vegetation, their soil characteristics, their degree of permanent saturation, and their remoteness do not come under high anthropogenic stress. There are few or no trees, so timber extraction is limited and the soils are too acidic for cultivation. Building residential or commercial structures on compressible peat soils is also not a development option. Limited peat mining has occurred in the past, particularly when oil prices were high. Thus, we assigned scores to this variable of 1 (Least Vulnerable) in all three Zones, but have assigned certainty scores of only Medium to reflect the considerable uncertainties that beset projections of future human behavior.

Module 1. Location relative to highest elevation. These vegetation communities occur mainly at middle or higher elevations. They do not occur at the highest elevations on well drained slopes, nor do they occur at the lowest elevations where the climate is milder or drier. We have accordingly assigned scores of 3 for this variable in all three zones, with certainty scores of High.

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 topography, by historical glacial disturbance, and by a cold wet climate. Any climatic amelioration may favor drying of soils and is likely to shift the competitive balance in favor of colonization by trees, shifting the community to a forest-dominated one. It is difficult to see how these peatlands could adapt to warmer conditions when they are being invaded by conifer forest. Accordingly, we have scored this variable as 5 (unlikely to be significant) for all three zones, with a certainty score of Medium (since our understanding of the true adaptive capacity of this habitat may be incomplete).

Module 1. Dependence on specific hydrologic conditions. These are wetland habitats that are dependent on more or less permanent soil saturation and a groundwater table that is continually at or close to the surface. Without these specific hydrologic conditions the habitats would change to either a drier, tree-dominated community or to pond or marsh. We have, accordingly, scored this variable as 5 (dependent on specific hydrological conditions) for all three zones, with a certainty score of High.

Module 1. Vulnerability of Foundation/Keystone species to climate change. These peatlands are neither floristically complex nor diverse and are typically dominated by a few hydrophitic foundation species of sphagnum moss. By absorbing and retaining high moisture content, it is the sphagnum cover that creates the conditions within which all of the other peatland species can survive. These mosses are vulnerable to a reduction in the amount of water going into the system or more severe, frequent, or prolonged droughts, such as may occur under a changing climate. We have, accordingly scored its vulnerability as 5 (Foundation/Keystone species likely to be vulnerable) for all three zones, but have assigned a certainty score of only Medium, to reflect that we may not know as much about the future survival of these hydrophitic species under climate change as desired, and the uncertainty surrounding future precipitation rates and drought.

Module 1. Constraints on latitudinal range shifts. We have assumed that in all three zones these habitats would be constrained in their abilities to shift northward or to higher elevations. This is because they occur typically on granitic and mineral-poor baserocks and are also largely limited to basin, kettlepond, or flats surface topography. Given these limitations the abilities of these habitats to shift and colonize other areas is restricted. We have accordingly scored the vulnerabilities of these habitat types as Somewhat Constrained in Zone I and Highly Constrained in Zones II and III, with a certainty score of High.

Module 1. Likelihood of managing/alleviating climate change impacts. The integrity of this habitat type is largely governed by precipitation rates and local topography. It is difficult to see, therefore, how we would be able to manage these factors and promote the survival of bogs. Also, we have little past experience of managing such habitats (since they are relatively unexploited by humans). 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. Fire is not a major current stressor on boreal bog habitats because the soil is permanently waterlogged. However, if the peat soils dried the risk of catastrophic fires (and their effects on vegetation) would become much more serious. Climate change, through increased temperatures, elevated evapotranspiration rates, and more severe droughts, could result in this risk being greatly increased in the future, with consequent peat soil loss and adverse impacts on the vegetation communities. Also, if the effect of the changing climate was to cause drying of the peat substrate, peat mining for horticultural use, and residential development could increase in some areas. Accordingly, we have scored the potential for this as 5 (High 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 and the data presented in Figures 2 through 5, we have scored this variable in Module 2 as 3 (somewhat fragmented in distribution and existing as small patches), with a certainty score of High. We do not consider this habitat to merit a score of Highly Fragmented (5) because it is certainly not as fragmented as other habitat types (for example, alpine tundra).

Module 2. Current extent trend. Since this habitat type exists largely in the Northeast on land that is less valued for agriculture or development, current losses are likely to be local. 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 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 1 (Stable or Increasing) with a certainty score of Medium.

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being affected by non-climate stressors (see above). However, much of the remaining habitat is on protected areas or is not the target of agriculture or development (although peat mining is a commercially viable industry in parts of Canada and could be reconsidered in the US if oil prices rise dramatically). We have, therefore, 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 some non-climate stressors that currently affect boreal bog habitat could increase in their impacts in the future (e.g., peat mining, recreational overuse, timber harvesting, and wind energy development). However, it is unlikely that these effects will be extensive across the geographic range of the habitat. For this reason, we score this variable as 3 (Some Increase) with a certainty score of Medium.

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Attachment 11. Habitat Vulnerability Evaluation: Laurentian-Acadian Freshwater Marsh

Figure 1. Laurentian Acadian Freshwater Marsh along the Connecticut River in southern New Hampshire and Vermont. The surface vegetation is dominated by typha, bulrush, carex species, pickerel weed, and white waterlily.

Summary of Results

Vulnerability to Climate Change	**Less Vulnerable**
Vulnerability to Non-climate Stressors	**Vulnerable**
Overall Future Vulnerability	**Vulnerable**

Habitat Ecology and Distribution

Laurentian-Acadian Freshwater Marsh (Figure 1) is one the most widespread of the northeast's emergent wetland habitat types. Covering a total of over 340,000 acres (Table 1), its distribution extends from Northern Maine south to Virginia and West Virginia (Table 1 and Figure 2). This habitat type occurs inland, or in coastal areas that are not tidally influenced. In coastal areas that are tidally influenced it is replaced by Northern Atlantic Coastal Plain Fresh and Oligohaline Tidal Marsh (NETHCS, 2008). Though structurally similar and with similar floristic composition, we do not include Northern Atlantic Coastal Plain Fresh and Oligohaline Tidal Marsh in this analysis. Rather, it is included in a separate analysis of coastal, tidally influenced habitats (Galbraith, in prep).

One of the most familiar of the region's wetland types, Laurentian-Acadian Freshwater Marsh can occur as extensive fringing wetlands surrounding large lakes (e.g., Lake Champlain in New York and Vermont), or as smaller wetlands fringing smaller lakes and ponds and rivers. It is an emergent community type that is it is restricted to areas of standing water from which the vegetation emerges during the growing season. During the winter months the vegetation dies back. Floristically, this community type is dominated by herbaceous vegetation; shrubs or trees are sparse or entirely absent. Dominant species vary with the hydrologic regime: in areas where standing water is deeper and year-round the community may largely comprise bulrushes, wild rice, and cattails. In areas with shallower standing water, or where standing water is absent during the driest periods, the community may be dominated by grasses and sedges, with scattered forbs including irises, joe-pye weed, and pickerelweed. (Thompson and Sorenson, 2000; Gawler and Cutko, 2010; Edinger *et al*., 2002, Mitsch and Gosselink, 2007; Niering, 1985; Collins and Anderson, 1994). Zonation of shallow and deeper emergent marshes is typical, with the former occurring at the upper elevations, grading into the latter where the standing water is deeper.

Invasive species can also dominate Laurentian-Acadian Freshwater Marsh, particularly Phragmites (common reed), which is able to withstand hydrological fluctuations and drying that might eliminate native species, or purple loosestrife, which crowds out native species.

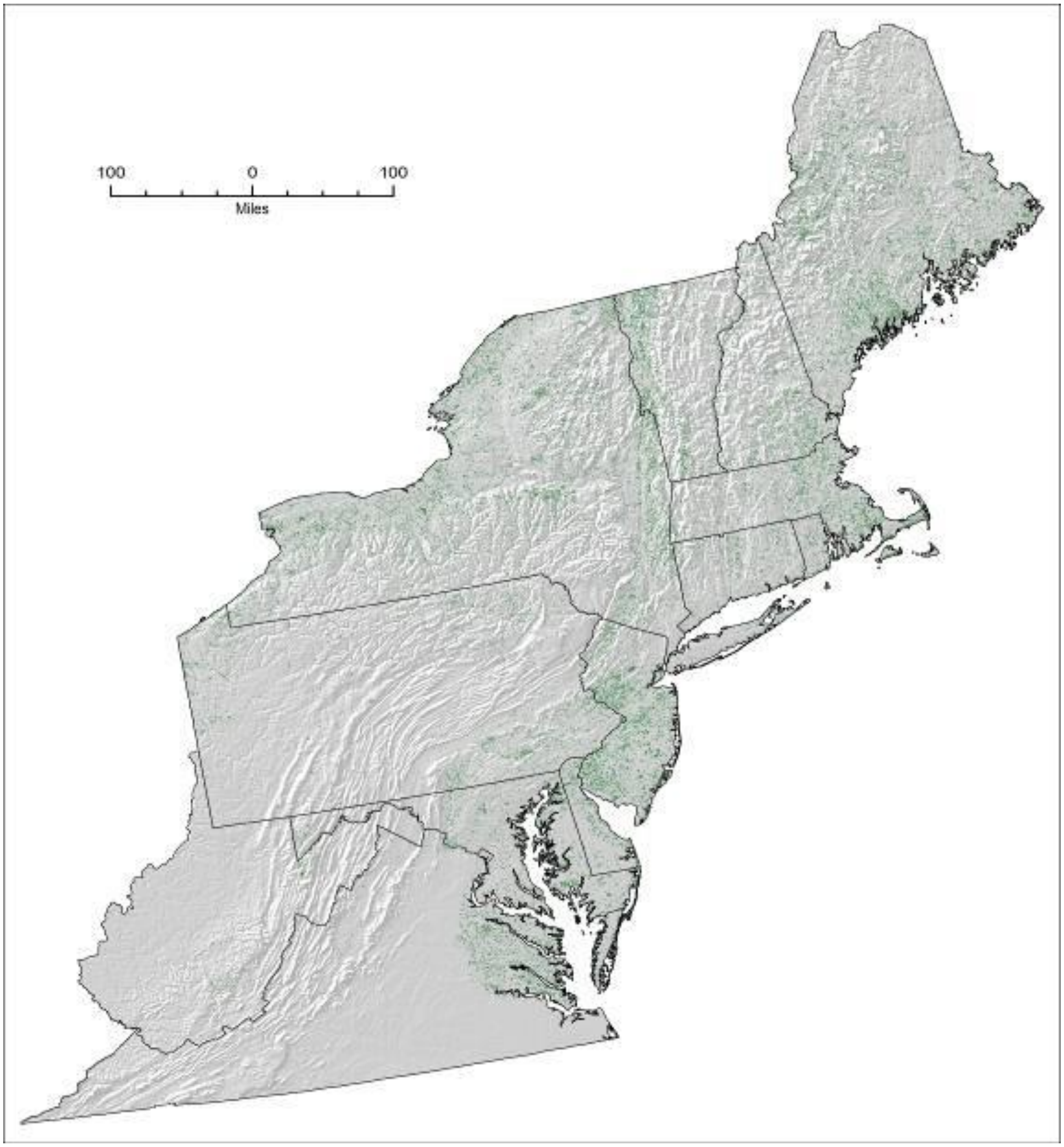

Figure 2. Distribution of Laurentian-Acadian Freshwater Marsh in Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

Emergent wetlands in the Northeast provide essential summer habitat for a large variety of invertebrates and vertebrates including herons, waterfowl, songbirds, mammals (e.g., muskrat, mink and beaver), amphibians and reptiles, fish, and odonates. Many of these species are state and/or federally listed. During the migration seasons they can support large populations of migratory wildlife. During winter, the reedbeds that persist may provide communal roost sites and hunting areas for many bird species.

Table 1. Extent of Laurentian-Acadian Freshwater Marsh in Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).		
State	**Acres in state**	**% of total habitat in Northeast**
Maine	76,820	23.3
Vermont	21,454	4.7
New York	89,672	23.3
New Hampshire	35,936	4.6
Massachusetts	25,630	5.7
Connecticut	6,763	1.7
Rhode Island	3,306	<1
New Jersey	35,936	10.1
Pennsylvania	20,187	5.8
Maryland	16,579	7.4
Delaware	6,385	2.3
District of Colombia	56	<1
Virginia	20,022	9.2
West Virginia	2,318	1.5
Total acres	340,306	

Model Results

The results of the model run for Zones I through IV are shown in Table 2.

Table 2. Vulnerability modeling results for Laurentian-Acadian Freshwater Marsh in Northeast Region.

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

These results indicate that Laurentian-Acadian freshwater Marsh is one of the less vulnerable to climate change of the northeast's habitat types. Its vulnerability to non-climate, "traditional" stressors (e.g., habitat loss and fragmentation) is higher. This may, then, be an example of a habitat that will continue to be most affected by non-climate change stressors, unlike some other habitat types analyzed in this study (e.g., alpine tundra, high elevation spruce-fir forests, and northern hardwood forests).

Implications for Future Status and Distribution

The low climate change vulnerability scores assigned in this analysis may not mean that emergent freshwater marsh will be entirely unaffected by the changing climate. In more marginal areas where the hydrology only barely supports this community type, or in smaller and more fragmented marshes with limited watershed catchment areas, the adaptive capacities and resiliencies of this habitat may be sufficiently low to result in local habitat loss due to the changing hydrology and drying out. Thus, there could be local loss of this habitat type across all of the latitudinal zones. This conclusion is, however, complicated by a relatively high degree of uncertainty about the impacts that climate change will have on local hydrologic processes and wetlands, as described in the next section.

Uncertainty Analysis

Although the main conclusion of this analysis is that emergent marshes may have only relatively low and local vulnerabilities to the changing climate, it should be viewed in the light of the degree of uncertainty assigned to this score (an overall certainty score of Medium). Previous analyses (Manomet and Massachusetts Department of Fish and Wildlife, 2009) have indicated that confidence scores for wetland habitats may be generally lower than those for, for example, forests. This is substantially because of the uncertainty surrounding global circulation models' projections about the quantity and timing of future precipitation, and the effects that this low level of confidence has when scoring the other variables in the vulnerability model.

While general circulation models (and their downscaled versions) show a high relatively high degree of uniformity in their future temperature projections, they are less consistent in their precipitation results. For the same area some models might show increases in precipitation, others may show decreases, while others show no change (Hayhoe *et al*., 2006). Also, the actual on-the-ground effect of changes in precipitation will be translated into ecologically important forcings through changing evapotranspiration rates, which again are affected by our uncertain assumptions about future precipitation patterns, compounded by a smaller degree of uncertainty about future temperature regimes. These uncertainty factors reduce our confidence when projecting the resilience and adaptive capacities of wetlands, in general, under a changing climate.

Uncertainty about future precipitation regimes is unlikely to be substantially reduced in the near future by modifying the climate models. The real question that we are faced with as conservationists and land managers is the extent to which we are able to make decisions about restoring and managing habitats despite moderate to high levels of uncertainty. In this light, it is important to realize that our level of certainty for this habitat type is Medium, not Low, and it is close to the highest edge of the Medium numerical range, approaching a High score. Also, any management actions that we undertake to safeguard habitats under a changing climate need not be unchanging. For all habitat types it will be important to monitor the changes in the habitats over time so that we can be sure of trajectories under the changing climate. If it is found that the system is responding differently to climate change than anticipated, more adaptive management strategies can be implemented. Thus, vulnerability analyses such as this should be viewed as first approximations of how habitat types <u>may</u> be affected in the future. They need to be tested and confirmed or rejected by monitoring data.

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 database, 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 Laurentian-Acadian Freshwater Marsh is widespread in its distribution across all four latitudinal zones. All habitat patches in Zones I through III are beyond 200 km of its southern range boundary. In Zone IV, however, this same database shows that this habitat type comes close to its southernmost limit. Given this, we have assigned scores of 1 (more distant than 200 km) for this factor for Zones I through III, but 5 (within 200 km) for Zone IV. Certainty scores of High are assigned to all of these scores.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Occurring from Maine to Virginia across areas that are very different in their temperature regimes, tolerance of widely different temperature regimes seems to be a characteristic of this habitat type. The degree of cold adaptation can therefore be considered to be low and is assigned a score of 1 in the habitat model (with a certainty score of Medium to reflect the fact there are some uncertainties about the specific sensitivities of many of the plant species that make up this community type to climatic regime).

Given its dependence on soil saturation and inundation, an increased frequency, severity or duration of droughts and floods could have adverse effects on this habitat type. Drying of the soil would result in its replacement by shrub-dominated or more forested wetlands or non-wetland habitats, while longer durations of immersion could result in the replacement of emergent marsh by open water. We have conservatively assigned a score of 3 (Less Vulnerable) to this factor in the model. However, our certainty score for this variable is only 1 (Low), since we do not know, given the imprecision of the precipitation and extreme events outputs from climate models, exactly how much more severe these future stochastic events may be.

Module 1. Vulnerability to maladaptive human responses. If the climatic future is one of drying and more extreme drought then it is likely that at least local losses of this habitat and its replacement with non-wetland habitats will occur. If that is the case we may see humans respond by extending development or agricultural footprints into areas that were hitherto wetlands. It is difficult to imagine, however, any other scenarios in which human societies could exacerbate wetland loss under climate change, since the legislative protections that currently exist would probably be still in force. Accordingly, we have scored this variable as 1 (not vulnerable to maladaptive human response). However, we have assigned a certainty score of only Low to reflect the considerable uncertainties that beset projections of future human behavior.

Module 1. Location relative to highest elevation. These vegetation communities occur mainly at middle or lower elevations. They do not occur at the highest elevations. We have accordingly assigned scores of 1 for this variable in both zones, with certainty scores of High.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type is significant and have scored it as 1. This is largely because: the habitat type is abundant and widespread; it is dominated by vegetation that is fast-growing with short regeneration times (and able, therefore, to recover rapidly from short-lived adverse impacts); it can respond rapidly to changing hydrologic conditions and move into areas hitherto dominated by either shrub swamps or open water. However, we have assigned a certainty score of only Low to reflect the general uncertainty associated with predictions about adaptive capacity until they are put to the test.

Module 1. Dependence on specific hydrologic conditions. This is a wetland habitat that is dependent on permanent soil saturation and immersion. Without these specific hydrologic conditions the habitat would change to either a drier, shrub-dominated community or to open water. We have, accordingly, scored this variable as 5 (dependent on specific hydrological conditions), with a certainty score of High.

Module 1. Vulnerability of Foundation/Keystone species to climate change. This habitat type is floristically complex and it is not dominated by a small number of foundational species. Nor does it depend on keystone species for its continuance (except in cases where beaver create and maintain the habitat type). 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 future survival of these hydrophitic species under climate change as we would wish, and the uncertainty surrounding future precipitation rates and drought.

Module 1. Constraints on latitudinal range shifts. We have assumed that in all four zones this habitat will be able to shift northward as the climate changes. This is because it is a low or middle elevation habitat that may be readily able to colonize adjacent areas as the hydrology changes. We have accordingly scored the vulnerability of this habitat type as Low Level of Constraint, with a certainty score of Medium to reflect our uncertainties about future precipitation patterns.

Module 1. Likelihood of managing/alleviating climate change impacts. If, as we suspect, the main impact of climate change on this habitat will be soil drying due to increased evapotranspiration rates and droughts, the main management activity may be water level control. This could include diverting water to the wetland to maintain the soil hydrology and the inundation regime required by the constituent plant species. However, except in a few small areas that may have high conservation value, it is unrealistic to expect that this will become a widely applied management technique. First, the habitat is abundant and widespread, and second, it would be expensive in terms of time and other resources. Water is likely to become a much more valuable commodity under climate change and there may be increased competition among sectors (agriculture, municipalities, etc.) to maintain their accustomed adequate supply. This would not benefit water-dependent habitats. Accordingly, we have scored the vulnerabilities to this variable as 5 (unlikely that management actions would be feasible) and assigned a certainty score of Low to reflect uncertainty about future precipitation patterns and societal priorities and responses.

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. A number of non-climate stressors are currently stressing wetlands in the Northeast. These include habitat destruction and fragmentation (though not at as rapid a rate as occurred before wetland protections were put in place), and colonization by invasive species such as purple loosestrife and phragmites. It is possible that these invasives (since they outcompete native species under heightened stress levels) could spread further throughout shrub swamps and come to dominate. Accordingly, we have scored the potential for this as 1 (Low Potential) with a certainty score of only Medium.

Module 2. Current extent of habitat. Based on what we know about the distribution of this habitat type and the data presented in Table 1 and Figures 2 through 4, it is a relatively widespread and abundant habitat type. Accordingly we have scored this variable in Module 2 as 3 (somewhat fragmented and limited in distribution) for all

Zones. We assign a certainty score of High, since the TNC/NEAFWA database and map tells us much about the habitat's distribution.

Module 2. Current extent trend. Prior to effective legislative controls being put in place, loss rates of wetland habitats in the Northeast were high. Now, however, although anthropogenic losses still occur, they are at a much reduced rate. For this reason we have scored this variable as 3 (Limited losses) for all Zones, with a certainty score of Medium to reflect the fact that greater wetland losses may be occurring in areas where such effects are not monitored well.

Module 2. Likely future extent trend. We consider it unlikely that the limited rate of loss that currently affects this habitat type will increase markedly in the future (since the legislative controls will continue to be in place). Thus, we have conservatively assigned a vulnerability score of 3 (Some losses), with a certainty score of Medium (to reflect difficulties in projecting future loss rates).

Module 2. Current impacts of non-climate change stressors. This habitat type is currently being little affected by non-climate stressors. There is still some anthropogenic loss and invasive species continue to affect the habitat in some areas. However, much of the habitat is either in protected areas or is not the target of agriculture or development. We have, therefore, assigned a score for this variable of 3 (Less affected), with a certainty score of Medium.

Module 2. Likely future stressor trends. It is feasible that some non-climate stressors that currently affect shrub swamp habitat could increase in their impacts in the future (e.g., invasive plant species). However, it is unlikely that these effects will be extensive. For this reason, we score this variable as 3, but with a certainty score of only Medium to reflect the intrinsic uncertainty in projecting future species interactions.

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Attachment 12. Habitat Vulnerability Evaluation: Laurentian-Acadian Wet Meadow Shrub Swamp

Figure 1. Laurentian-Acadian Wet Meadow Shrub Swamp in New Hampshire. The emergent vegetation is dominated by shrubs, including buttonbush and highbush blueberry, with royal and cinnamon ferns. The trees are red maple.

Summary of Results

Vulnerability to Climate Change	**Less Vulnerable (all zones)**
Vulnerability to Non-climate Stressors	**Vulnerable (all zones)**
Overall Future Vulnerability	**Vulnerable (all zones)**

Habitat Ecology and Distribution

Covering over 1.1 million acres across the 13 states (Table 1), Laurentian-Acadian Wet Meadow Shrub Swamp (Figure 1) is one of the Northeast Region's most widespread wetland habitat types
[1]. Although this habitat extends across all of the northeastern states and in the District of Colombia (Figures 2 through 4), within this broad area it generally has a northern distribution, with more than 55% of the total acreage in Central and Northern New England and less than 10% in the southernmost states of Virginia, West Virginia, Maryland and Delaware and the District of Colombia (Table 1). South of Virginia and West Virginia it is replaced by the evergreen-dominated Pocosin wetlands (Mitsch and Gosselink, 2007; Niering, 1985).

Shrub swamp habitat typically occurs as wetland bordering lakes, ponds or rivers and in areas where the soils are permanently waterlogged, but not subject to prolonged periods of inundation (Swain and Kearsley, 2001; Mitsch and Gosselink, 2007; Thompson and Sorenson, 2000; Collins and Anderson 1994; Gawler and Cutko, 2010; Edinger *et al*., 2002; VANHP, 2011). In drier, upslope areas it is often replaced by forested wetlands (the trees of which are less tolerant of perpetually waterlogged soil conditions). In areas of shallow standing water it is replaced by emergent marshes dominated by reeds, sedges or forbs. Thus, whether an area is dominated by this habitat type or by wetland forest or emergent marsh is primarily a function of the local hydrology, particularly the degree of soil saturation and the inundation regime. Laurentian-Acadian Wet Meadow Shrub Swamp is classified by the TNC/NEAFWA habitat mapping project (TNC/NEAFWA,

[1] In West Virginia a number of wetland types can be considered analogues of Laurentian-Acadian Wet Meadow Shrub Swamp: Central Appalachian River Floodplain; Central Appalachian Stream and Riparian; Central Interior Highlands and Appalachian Sinkhole and Depression Pond; Cumberland Riverscour; High Allegheny Wetlands; South-Central Interior Large Floodplain; and South-Central Interior Small Stream and Riparian (E. Byers, WVDNR, *pers. comm*.). For this analysis, we include these as types of Laurentian-Acadian Wet Meadow Shrub Swamp.

2011) as a large patch habitat, but it is typically embedded in matrix communities of conifer or broadleaf forest. Unlike shrub-dominated bogs that occur in the northern part of the region on peat soils, shrub swamps are typical of mineral soils, though often with a high organic content (Thompson and Sorenson, 2000; Mitsch and Gosselink, 2007).

The distribution of Laurentian-Acadian Wet Meadow Shrub Swamps extends to the southern states in the northeastern region. In Virginia and West Virginia it transitions into shrub swamps with broadly similar ecological characteristics, but which are floristically divergent enough to merit their own classification (see footnote above). These floristic differences, notwithstanding, these communities are structurally, hydrologically, and functionally similar to the shrub swamp habitats in the northern part of the Northeast Region.

In the more northern states, these shrub swamp wetlands are typically dominated by shrubs such as buttonbush, highbush blueberry, alders, willows, winterberry, and dogwoods. Shrub height is usually less than about 10 feet, and tree cover is generally less than 20%. The herbaceous layer typically comprises ferns (e.g., ostrich fern), and forbs, such as asters, Joe-pye weed, and goldenrods. Further south, the shrub layer may comprise alders, hypericum, buttonbush and rubus species.

Shrub swamps may be either transitional communities moving toward either emergent wetlands or forested wetlands, as the hydrology dries out or becomes wetter. Alternatively, they can be stable and long-lasting communities in areas where the hydrology is not changing.

Table 1. Extent of Laurentian-Acadian Wet Meadow Shrub Swamp in Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

State	Habitat Acres in State	Percent of Total Habitat Acres in Northeast Region
Maine	354,023	31.7
New Hampshire	63,547	5.7
Vermont	53,396	4.8
New York	319,883	6.3
Massachusetts	79,112	7.1
Connecticut	24,184	2.2
Rhode Island	5,285	<1
Pennsylvania	46,905	4.2
New Jersey	69,926	6.3
Delaware	11,674	1.0
Washington, DC	11	<1
Maryland	32,550	2.9
Virginia	44,458	4.0
West Virginia	10,447	<1
Total acres	1,115,401	

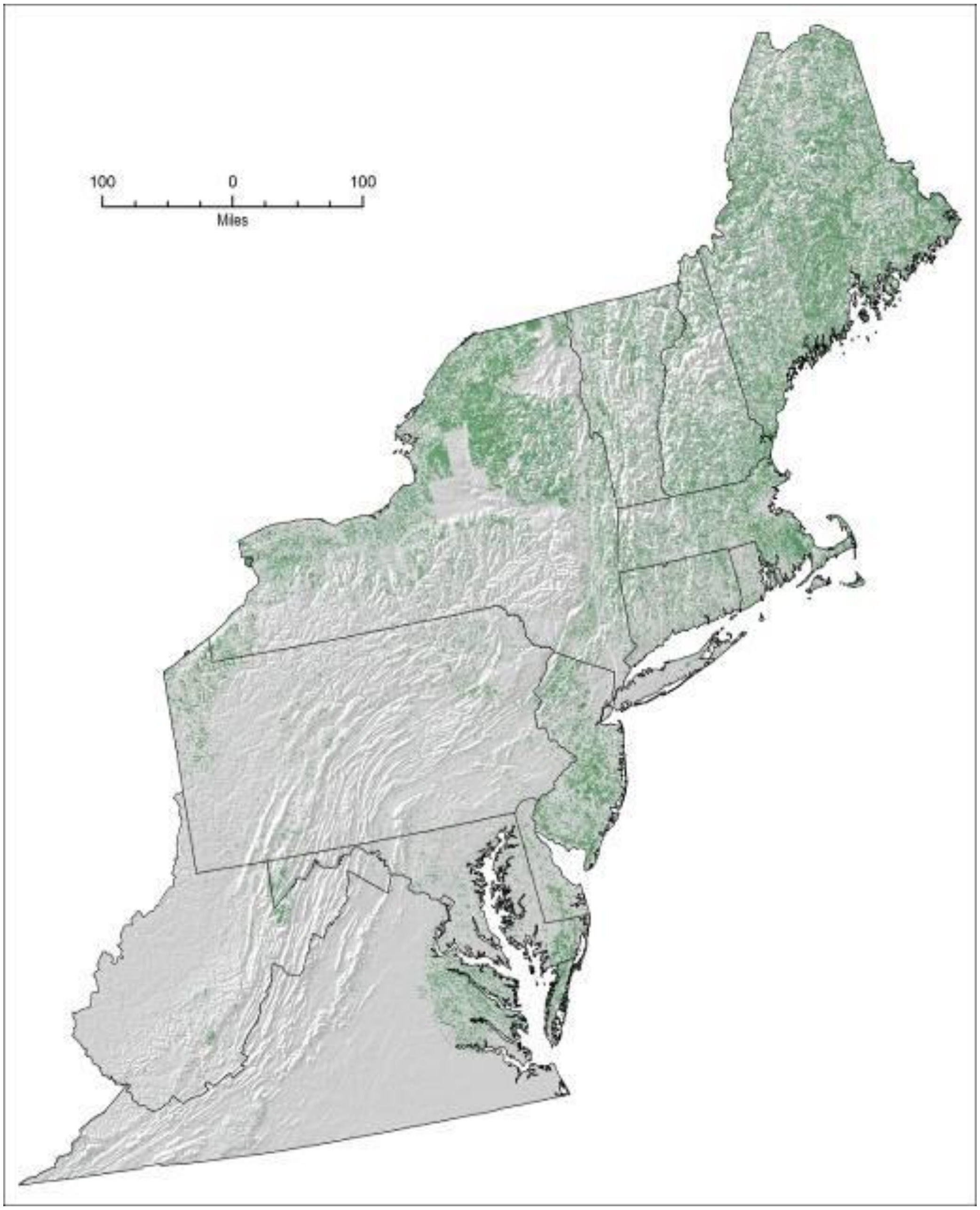

Figure 2. Distribution of Laurentian-Acadian Wet Meadow Shrub Swamp in the Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

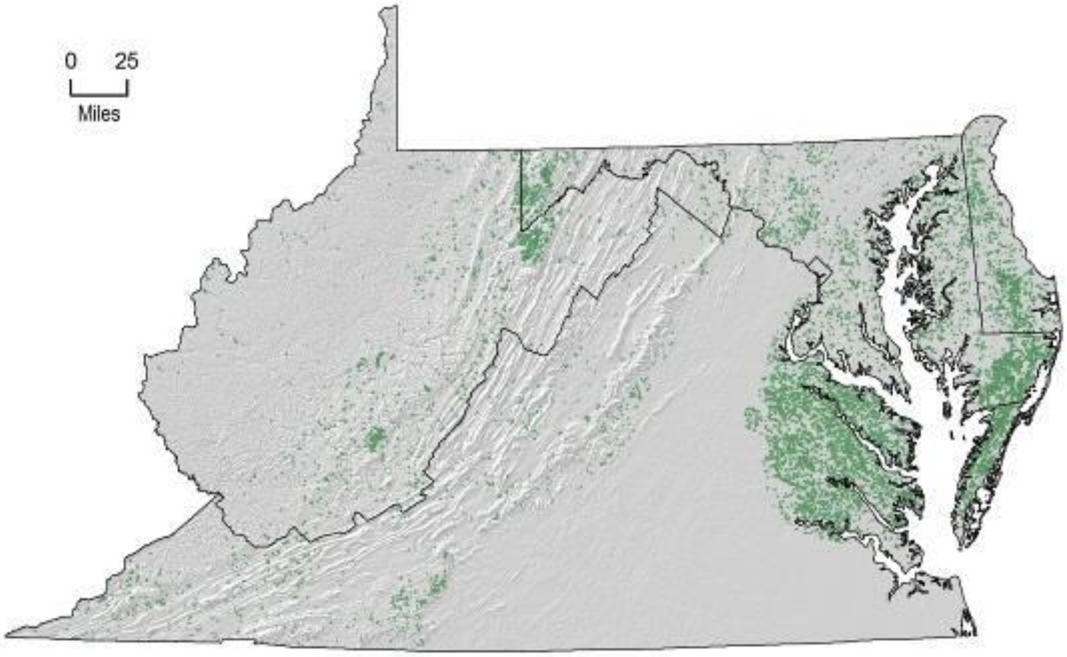

Figure 3. Distribution of Laurentian-Acadian Wet Meadow Shrub Swamp in the southern states of the Northeast Region. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

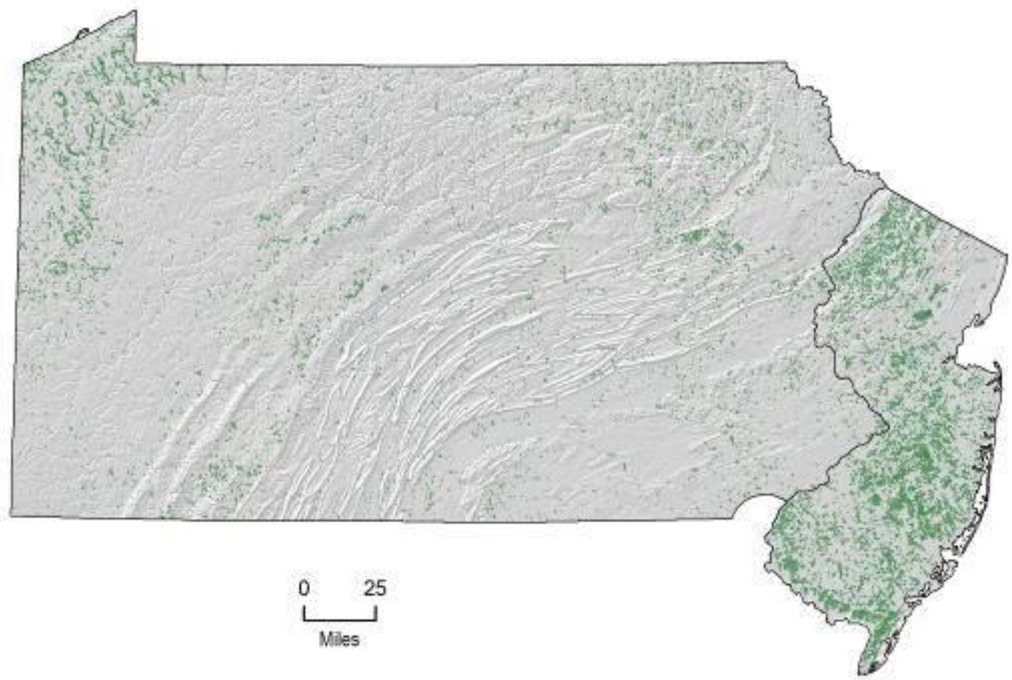

Figure 4. Distribution of Laurentian-Acadian Wet Meadow Shrub Swamp in Pennsylvania and New Jersey. Data from Northeast Terrestrial Habitat Mapping Project (TNC/NEAFWA, 2011).

Model Results

The results of the model run for Zones I through IV are shown in Table 2.

Table 2. Vulnerability modeling results.

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

These results indicate that Laurentian-Acadian Wet Meadow Shrub Swamp is one of the less vulnerable of the northeast's habitat types to climate change. Its vulnerability to non-climate, "traditional" stressors (e.g., habitat loss and fragmentation) is higher. Shrub swamp may, therefore, be an example of a habitat that will continue to be most affected by non-climate change stressors, unlike some other habitat types analyzed in this study (e.g., alpine tundra, high elevation spruce-fir forests, and northern hardwood forests).

Implications for Future Status and Distribution

The low climate change vulnerability scores assigned in this analysis may not mean that shrub swamp will be entirely unaffected by the changing climate. In more marginal areas where the hydrology only barely supports this community type, or in smaller and more fragmented swamps with limited watershed catchment areas, the adaptive capacities and resiliencies of shrub swamps may be sufficiently low to result in local habitat loss due to the changing hydrology and the drying out of the swamps. Thus, there could be local loss of this habitat type across all of the latitudinal zones. This conclusion is, however, complicated by a relatively high degree of uncertainty about the impacts that climate change will have on local hydrologic processes and wetlands, as described in the next section.

Uncertainty Analysis

Although the main conclusion of this analysis is that shrub swamps may have only relatively low and local vulnerabilities to the changing climate, it should be viewed in the light of the only Medium degree of certainty assigned to this score. Previous analyses (Manomet and Massachusetts Department of Fish and Wildlife, 2009) have indicated that certainty scores for wetland habitats may be generally lower than those for, for example, forests. This is substantially because of the uncertainty surrounding global circulation models' projections about the quantity and timing of future precipitation, and the effects that this low level of confidence has when scoring the other variables in the vulnerability model.

While general circulation models (and their downscaled versions) show a high relatively high degree of uniformity in their future temperature projections, they are less consistent in their precipitation results. For the same area some models might show increases in precipitation, others may show decreases, while others show no change (Hayhoe *et al*., 2006). Also, the actual on the ground effect of changes in precipitation will be translated into ecologically important forcings through changing evapotranspiration rates, which again are partly functions of our uncertain assumptions about future precipitation patterns, compounded by a smaller degree of uncertainty about future temperature regimes. These uncertainty factors reduce the confidence that we can assume when making assumptions about the resilience and adaptive capacities of wetlands under a changing climate.

Uncertainty about future precipitation regimes is unlikely to be substantially reduced in the near future by modifying the climate models. The real question that we are faced with as conservationists and land managers is the extent to which we are able to make decisions about restoring and managing habitats despite moderate to high levels of uncertainty. In this light it is important to realize that our level of certainty for this habitat type is Medium, not Low, and it is close to the highest edge of the Medium numerical range, approaching a High score. Also, any management actions that we undertake to safeguard habitats under a changing climate need not be unchanging. For all habitat types it will be important to monitor the changes in the habitats over time so that we can be sure of trajectories under the changing climate. If it is found that the system is responding differently to climate change than anticipated, more adaptive management strategies can be implemented. Thus, vulnerability analyses such as this should be viewed as first approximations of how habitat types <u>may</u> be affected in the future. They need to be tested and confirmed or rejected by monitoring data.

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 database, 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 Laurentian-Acadian Wet Meadow Shrub Swamp is widespread in its distribution across all four latitudinal zones. All habitat patches in Zones I through III are beyond 200km of this range boundary. In Zone IV, however, this same database shows that this habitat type comes close to its southernmost limit. Given this, we have assigned scores of I (more distant than 200 km) for this factor for Zones I through III, but 5 (within 200 km) for Zone IV. Certainty scores of High are assigned to all of these scores.

Module 1. Degree of cold-adaptation, and *Sensitivity to extreme climatic events.* Occurring from Maine to Virginia across areas that are very different in their temperature regimes, tolerance of widely different temperature regimes seems to be a characteristic of this habitat type. The degree of cold adaptation can therefore be considered to be low and is assigned a score of 1 in the habitat model. However, the sensitivity of this habitat to extreme climatic events may be higher. Given its dependence on soil saturation and inundation characteristics, an increased frequency, severity or duration of droughts and floods could have adverse effects on this habitat type. Drying of the soil would result in its replacement by more forested wetlands or non-wetland habitats, while longer durations of immersion could result in the replacement of shrub swamp by emergent wetlands. We have conservatively assigned a score of 3 (Less Vulnerable) to this factor in the model. However, our certainty score for this variable is 1 (Low), since we do not know, given the imprecision of the precipitation and extreme events outputs form climate models, exactly how much more severe these future stochastic events may be.

Module 1. Vulnerability to maladaptive human responses. If the climatic future is one of drying and more extreme drought then it is likely that at least local losses of this habitat and its replacement with non-wetland habitats will occur. If that is the case we may see humans respond by extending development or agricultural footprints into area that were hitherto wetlands. It is difficult to imagine, however, any other scenarios in which human societies could exacerbate wetland loss under climate change, since the legislative protections that currently exist would probably be still in force. Accordingly, we have scored this variable as 1 (not vulnerable to maladaptive human response). However, we have assigned a certainty score of Low to reflect the considerable uncertainties that beset projections of future human behavior.

Module 1. Location relative to highest elevation. These vegetation communities occur mainly at middle or lower elevations. They do not occur at the highest elevations. We have accordingly assigned scores of 1 for this variable in both zones, with certainty scores of High.

Module 1. Intrinsic adaptive capacity. We have assumed that the intrinsic adaptive capacity of this habitat type is significant and have scored it as 1. This is largely because: the habitat type is abundant and widespread; it is dominated by vegetation that is fast growing with short regeneration times (and able, therefore, to recover rapidly from short-lived adverse impacts); it can respond rapidly to changing hydrologic conditions and move into areas dominated by either forested swamps or emergent marshes. However, we have assigned a certainty score of Low since we do not know, given the imprecision of the precipitation and extreme events outputs form climate models, exactly how much more severe these future stochastic events may be.

Module 1. Dependence on specific hydrologic conditions. This is a wetland habitat that is dependent on more or less permanent soil saturation and a groundwater table that is continually at or close to the surface. Without these specific hydrologic conditions the habitat would change to either a drier, tree-dominated community or to an emergent marsh. We have, accordingly, scored this variable as 5 (dependent on specific hydrological conditions), with a certainty score of High.

Module 1. Vulnerability of Foundation/Keystone species to climate change. This habitat type is floristically complex and it is not dominated by a small number of foundational species (it is dominated by a diversity of shrub species). Nor does it depend on keystone species for its continuance (except in cases where beaver create and maintain the habitat type). We have, accordingly scored its vulnerability as 1 (Foundation/Keystone species unlikely to be vulnerable), but have assigned a certainty score of Medium, to reflect that we may not know as much about the future survival of these hydrophitic species under climate change as we would wish, and the uncertainty surrounding future precipitation rates and drought.

Module 1. Constraints on latitudinal range shifts. We have assumed that in all four zones this habitat will be able to shift northward as the climate changes. This is because it is a low or middle elevation habitat that may be readily able to colonize adjacent areas as the hydrology changes. We have accordingly scored the vulnerability of this habitat type as Low Level of Constraint, with a certainty score of Medium to reflect our uncertainties about future precipitation patterns.

Module 1. Likelihood of managing/alleviating climate change impacts. If, as we suspect, the main impact of climate change on this habitat will be soil drying due to increased evapotranspiration rates and droughts, the main management activity may be water level control. This could include diverting water to the shrub swamp to maintain the soil hydrology that the constituent plant species require. Except in a few small areas that may have high conservation value, it is unrealistic to expect that this will become a widely applied management technique. First, the habitat is abundant and widespread, and second, it would be expensive in terms of time and other resources. Water is likely to become a much more valuable commodity under climate change and there may be increased competition among sectors (agriculture, municipalities, etc.) to maintain their accustomed adequate supply. This would not benefit water-dependent habitats. Accordingly, we have scored the vulnerabilities to this variable as 5 (unlikely that management actions would be feasible) and assigned a certainty score of Low to reflect uncertainty about future precipitation patterns and societal priorities and responses.

Module 1. Potential for climate change to exacerbate impacts of non-climate stressors. A number of non-climate stressors are currently stressing shrub swamps in the Northeast. These include habitat destruction and fragmentation (though not at as rapid a rate as occurred before wetland protections were put in place), and colonization by invasive species such as purple loosestrife and phragmites. It is possible that these invasives (since they outcompete native species under heightened stress levels) could spread further throughout, and come to dominate shrub swamps. Accordingly, we have scored the potential for this as 5 (High Potential) with a certainty score of Medium to reflect considerable uncertainties about invasive species might respond under climate change.

Module 2. Current extent of habitat. Based on what we know about the distribution of this habitat type and the data presented in Table 1 and Figures 2 through 4, it is a relatively widespread and abundant habitat type. Accordingly we have scored this variable in Module 2 as 3 (somewhat fragmented and limited in distribution) for all

Zones. We assign a certainty score of High, since the TNC/NEAFWA database and map tells us much about the habitat's distribution.

Module 2. Current extent trend. Prior to effective legislative controls being put in place, loss rates of wetland habitats in the Northeast were high. Now, however, although anthropogenic losses still occur, they are at a much reduced rate. For this reason we have scored this variable as 3 (Limited losses), with a certainty score of Medium.

Module 2. Likely future extent trend. We consider it unlikely that limited rate of loss that currently affects this habitat type will increase markedly in the future (since the legislative controls will continue to be in place). Thus, we have conservatively assigned a vulnerability score of 3 (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. There is still some anthropogenic loss and invasive species continue to affect the habitat in some areas. However, much of the habitat is either in protected areas or is not the target of agriculture or development. We have, therefore, assigned a score for this variable of 3 (Less affected), with a certainty score of Medium.

Module 2. Likely future stressor trends. It is feasible that some non-climate stressors that currently affect shrub swamp habitat could increase in their impacts in the future (e.g., invasive plant species). However, it is unlikely that these effects will be extensive. For this reason, we score this variable as 3, but with a certainty score of only Medium to reflect the intrinsic uncertainty in projecting future species interactions.

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Attachment 13. Model Results

This attachment is an Excel spreadsheet, which accompanies the report. All results for habitat types analyzed in this report are available using the file 'Habitat Vulnerability Evaluation Results.' The original Excel files used to analyze each unique habitat-zone combination are also available as a zipped folder, 'HabitatVulnerabilityEvaluations-All.' These files contain additional descriptions of model variables.