Climate Change Vulnerability Assessments of selected species in the North Atlantic LCC Region

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Front cover photos:

Top photo: Boreal Ice-Scour Rivershore Habitat, St. John River, Allagash Wilderness Waterway State Park, August 2004 (Sue Gawler©)

Bottom photo: North Atlantic Coastal Plain Dune and Swale Habitat, Cape Cod National Seashore, September 2004 (Lesley Sneddon)

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Executive Summary

Sixty-four animal and plant species were selected for assessment of vulnerability to climate change using NatureServe's Climate Change Vulnerability Index (CCVI) tool. Working with North Atlantic Landscape Conservation Cooperative (LCC) staff, we assembled a team of reviewers to guide the species selection process, with the North Atlantic LCC being the arbiter of the final list. The list draws from three categories of importance: foundation species, species of high regional concern, and representative species. We define a foundation species as one that provides significant structure to a natural community by stabilizing local conditions for other species and the processes that support them. Species of high regional concern are drawn from a comprehensive list of Species of Greatest Conservation Need that occur in a majority of states from Maine to Virginia. Representative species were chosen from a list of 87 species that had been compiled by the U.S. Fish and Wildlife Service and partners for the North Atlantic LCC region to aid in strategic habitat conservation. Representative species are defined as those whose habitat needs, ecosystem function, or management responses are similar to a group of other species. Our final list comprises 20 plants, 19 birds, 9 invertebrates, 5 mammals, 4 fishes, 4 reptiles, and 3 amphibians.

Species were assessed by NatureServe ecologists and zoologists, aided by GIS analysts, who completed sections requiring calculations of historic as well as projected mid-century temperature and hydrologic exposure measurements across the range of each of the species within the LCC. We divided the North Atlantic LCC region into three subregions for analysis: Northern Appalachian / Maritime Canada, North Atlantic, and Mid-Atlantic. The regions were similar to the subregions devised by the North Atlantic LCC in selection of representative species. We researched natural history information for each of the species for entry into the CCVI tool. In this tool, vulnerability factors are divided into direct and indirect exposure, and species-specific sensitivity factors. Twenty-nine species were ranked as vulnerable to climate change in at least one subregion of analysis.

Fourteen species of High Regional Concern were ranked Presumed Stable, including three globally rare species: dwarf wedgemussel, New England cottontail (*Sylvilagus transitionalis*), and small whorled pogonia. Although all three species are highly vulnerable to a number of immediate threats, the additional effects of climate change are not expected to significantly exacerbate these threats in this LCC region.

In general, the species we found to be vulnerable to climate change were either coastal species affected by sea level rise and/or increased storm severity, or species of specialized or restricted habitat. In addition, species occurring at the edge of their ranges, especially the southern range

limit, were sometimes found to be vulnerable in portions of this region. In general, birds were not found to be vulnerable to climate change due to their dispersal abilities, but five birds we found to be vulnerable are limited to the sea coast, where dispersal ability is of little help along an entire coastline facing greater inundation and storm severity.

The vulnerabilities of foundation species varied under different circumstances. As expected, tree species of cold climates (balsam fir, spruce species, and northern white cedar) and other plants at their southern range limits in the region were found to be vulnerable. Plants growing in tidal situations (smooth cordgrass) were also found to be vulnerable to sea level rise. Some species, such as white pine and eastern hemlock, act as foundation species in part of the region but not in others, so their vulnerabilities may not have the same widespread impacts on habitat in all areas. Foundation species that we rated as relatively unaffected by climate change across their range in this region are not easily categorized: they occur in wetlands, mesic uplands, and dry uplands.

Vulnerabilities of representative species in comparison to those they represent were found to be largely consistent, but also indicated some mixed results. We agree with the premise that conservation actions taken to protect representative species will likely benefit other species with similar habitat requirements even if not targeted specifically, and that this may hold true for species vulnerable to climate change as well. However, we urge caution when extrapolating the results of non-vulnerable representative species to the species they represent. Differing life history requirements among species can have large impacts on responses to climate change, regardless of habitat similarities.

Vulnerability to other threats is expressly not taken into account by the CCVI so that an independent determination regarding climate change can be made. Identified vulnerabilities to climate change can then be integrated into a comprehensive Conservation Status Rank to aid in conservation planning. Globally rare species identified as vulnerable to climate change should be priority conservation targets.

Our assessments targeted a mid-century time frame. However, if climate change proceeds at the projected pace, vulnerabilities are likely to increase beyond 2050.

Introduction

The North Atlantic Landscape Conservation Cooperative (LCC) region is a diverse landscape, spanning 13 degrees in latitude, 20 degrees in longitude, and elevation ranges from sea level to 1917 m (6,289 feet) at the top of Mount Washington in New Hampshire. As a result, climate across the LCC is variable, and is expected to remain so. Mid-century temperatures are projected to warm by up to 5.5 ^{o} F in the interior of the LCC. Although the coast will also experience warming, the ameliorating effect of the maritime climate is projected to limit temperature increases to 3–4.5 ^{o}F in the US and Quebec and 3.1–4 ^{o}F in the maritime provinces (Figure 1).

Unfortunately, coastal proximity brings its own set of issues. Sea level rise, as well as storm intensity, is expected to affect coastal areas everywhere, but especially so in the northeastern US. Sea level rise from Cape Hatteras to Boston, Massachusetts is expected to proceed at a rate that is three to four times that of global projections (Sallenger et al. 2012; Boon 2012). Salt marshes, dunes, beaches, and the biodiversity that depends on them, will be significantly impacted.

The growing population of this region, particularly in southern New England and the Mid-Atlantic, will continue to pose a threat to biodiversity irrespective of climate change. Increasing temperatures, increased drying, and sea level rise will exacerbate the threats posed by high human population density. Northern displacement of many species from the south will likely be impeded, if not prevented outright, by anthropogenic alterations to the landscape.

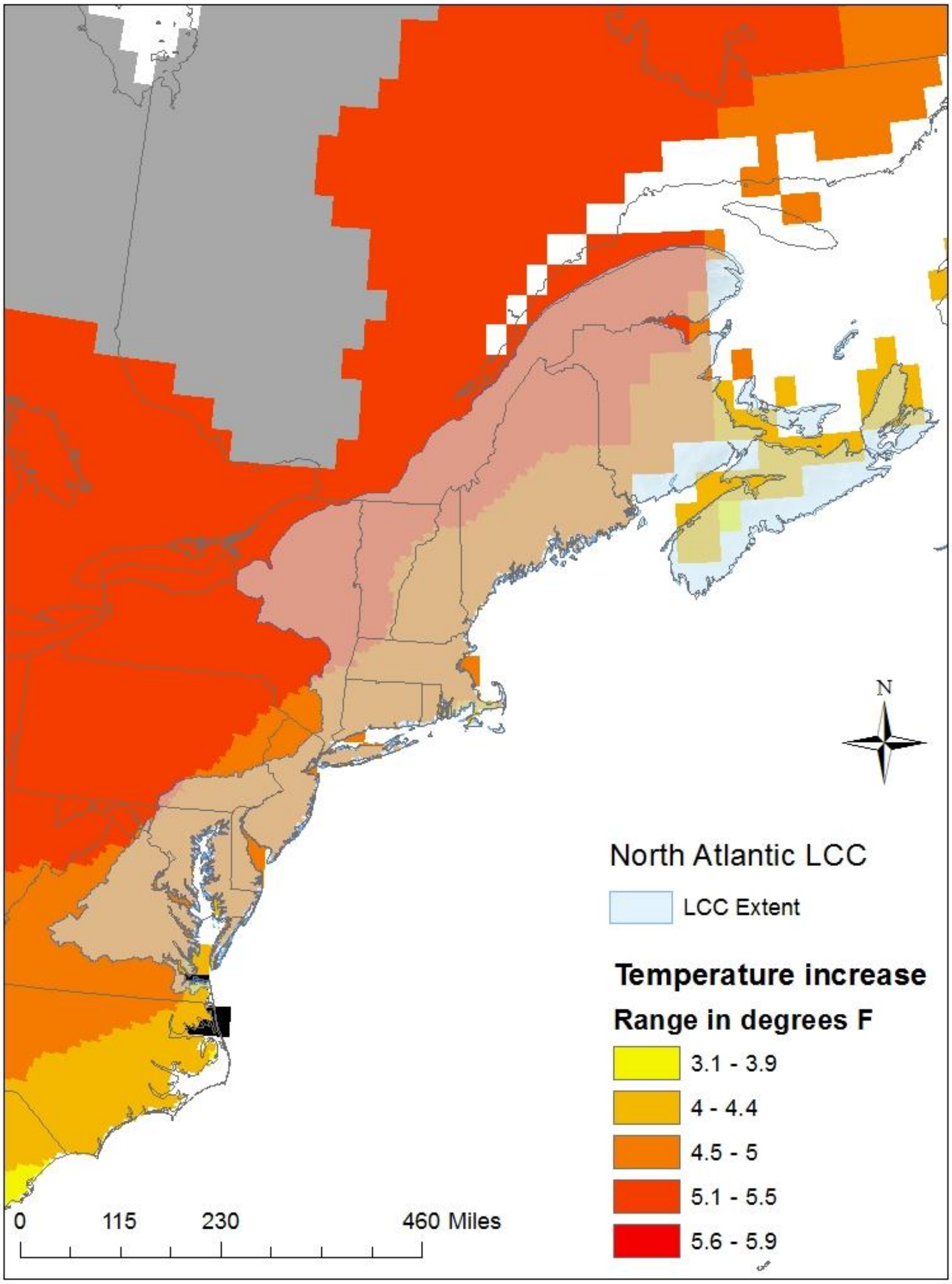

Figure 1. Projected mid-century temperature increases in the North Atlantic LCC based on IPCC Fourth Assessment, Medium A1B Emission Scenario, and ensemble average General Circulation Model.

United States lower 48 Future 12 km resolution in US portion of LCC; Global Future 50 km resolution in Canadian portion of LCC. Source: Climate Wizard (Girvetz et al. 2009).

The North Atlantic LCC is an organization that promotes collaboration among multiple conservation partners to understand and address major environmental and human-related vulnerabilities of species and habitats, including those due to climate change, and to develop appropriate and effective adaptation strategies. In 2011, the North Atlantic LCC formed a Science Technical Committee to identify top science needs for the coming year. Climate change vulnerability assessment of species and habitats was ranked as the second highest priority science need identified by the Terrestrial group of the Committee in June 2011. NatureServe was awarded a grant by the North Atlantic LCC in 2012 to conduct vulnerability assessments of selected species using NatureServe's Climate Change Vulnerability Index (CCVI) (Young et al. 2012).

Methods

Selection of species to be assessed

The large number of species occurring in the North Atlantic LCC region, or indeed in nearly any large geographic area, precludes assessment of all, or even most of them. The goal of this assessment was to identify the vulnerability of an array of selected species, using the results to extrapolate to other species not directly assessed. Several different approaches may be used to reach this goal, such as assessment of representative species, foundation or keystone species, rare or threatened species, and habitats. Companion studies conducted by Galbraith et al. (Manomet Center for Conservation Sciences and the National Wildlife Federation 2012) have addressed assessment of multiple species through the assessment of habitats for vulnerability to climate change. Our study selected 64 species from the other 3 groups noted above: foundation species, representative species, and species of high regional concern.

Foundation Species

There are several different definitions of this term, but we are referring here to the definition of Dayton (1972), as cited in Ellison et al. (2005): "a single species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes." Species upon which other species are dependent, or that modulate local environments, are particularly important in the face of climate change, and understanding their vulnerabilities will have implications for dependent species. Because plants contribute significantly to habitat, and because plants are under-represented in the other two categories, we restricted our selection of foundation species to plants.

In describing foundation species, we refer to the Northeast Terrestrial Habitat Classification System (Gawler 2008) to provide context for the question "foundation to what?" This classification is based on NatureServe's Ecological Systems Classification (Comer et al. 2003), defined as a group of biological communities occurring together spatially, influenced by a set of similar ecological processes. This classification was further augmented with information from each of the state wildlife classifications, additional structural components, as well as units not included in the Ecological Systems Classification, primarily those that are altered by human disturbance but that provide critical habitat to wildlife.

Species of High Regional Concern

Each individual state in the northeast has developed a list of those species deemed to be of species of greatest conservation need (SGCN) highlighted as part of their State Wildlife Action Plans. The definition of SGCN varies somewhat among states, but in general the concept encompasses elements of population decline, threat or potential threat, and state or regional responsibility. Lists of SGCN are derived from multiple sources, including species ranked as Critically Imperiled (G1), Imperiled (G2), or Vulnerable (G3) according to NatureServe's Global Conservation Status definitions (Master et al. 2012). Therres (1999) first compiled a list of wildlife species of conservation concern occurring in a majority of states from Maine to Virginia, deeming this list as regionally significant in the northeastern states. This list subsequently informed individual lists of species of conservation concern developed during the development of State Wildlife Action Plans, and has since provided the foundation for a comprehensive list of SGCN from all of the northeastern states (USFWS Region 5, Maine to Virginia) that was compiled in 2007. Species from the 2007 SGCN list had been grouped by major taxa and by state, which facilitated the elimination of species not occurring in the North Atlantic LCC region. Because only one northeastern state (Vermont) included plants in its SGCN list (Stein and Gravuer 2008), we added several globally rare plant species to this group. Our final list of species derived from this category is herein referred to as Species of High Regional Concern.

Representative Species

The U.S. Fish and Wildlife Service (USFWS) completed a study in collaboration with the University of Massachusetts, Amherst and other partners to compile a list of representative species. The goal of this work was to identify a group of species that will advance the design of conservation and management strategies in the North Atlantic LCC. Defined as "a species whose habitat needs, ecosystem function, or management responses are similar to a group of other species", the species are drawn from an initial list of 290 potential priority species compiled by the USFWS. An Executive Summary details the process by which the list of 87 terrestrial and 12 aquatic representative species was finalized: http://northatlanticlcc.org/resources/library-contents/representative-species-summary. Twenty-seven of these species were assessed using the CCVI. In addition, because the original representative species list was primarily restricted to federal trust species (migratory birds and endangered species), five additional species were added to better represent certain taxa and ecosystems. These were three bog species (bog elfin, incurvate emerald, and purple pitcher plant), and two species associated with streams (American water shrew and southern pygmy clubtail).

Final list compilation

The lists of species of high regional concern, representative species, and those considered to be foundation species were assembled into a single list. To ensure that species were chosen from a range of habitats, we assigned species to broad habitat groups that reflect individual or groups of habitats classified in the Northeast Terrestrial Habitat Classification System (Gawler et al. 2008), or of the Northeast Aquatic Habitat Classification System (Olivero and Anderson 2008).

In consultation with North Atlantic LCC staff, we contacted 29 potential technical review committee members from state wildlife agencies and natural heritage programs to help us to determine the process of species selection. We provided the list to the 11 respondents, and held a conference call, after which, a smaller team of 6 individuals volunteered to assist in finalizing the species selections. The smaller team collaborated on several conference calls and email exchanges to come to a final decision on the list of species to be assessed. A final list of species was assembled (Table 1), comprising 3 amphibians, 19 birds, 4 fishes, 9 invertebrates, 5 mammals, 4 reptiles, and 20 vascular plants (Table 2). These taxa included a total of 17 foundation species, 32 representative species (including one plant as a representative species of bog habitats), and 26 species of high regional concern (24 species from the 2007 list of SGCN and two globally rare plants). Twelve species are in two categories (species of high regional concern and representative species), resulting in a final sum of 64 species assessed for this project.

North Atlantic LCC staff served as arbiters of the final list, and the compilation was then provided to the larger advisory group. The list of species was divided into animals and plants for CCVI analyses by NatureServe zoologists and ecologists, with the spatial component of the CCVI conducted by NatureServe GIS conservation data analysts.

Table 1. List of species chosen for vulnerability analysis, indicating habitat and distribution among foundation, species of high regional concern, and representative categories.

Species	Foundation	High Regional Concern	Representative
Spruce - fir - hardwood forests			
Red spruce	X		
Balsam fir	X		
Bicknell's thrush		X	X
Moose		X	
Spruce grouse		X	X
Blackpoll warbler			X
Northern hardwood - hemlock forests			
Sugar maple	X		
Eastern hemlock	X		
Jefferson salamander		X	
Northern goshawk		X	
Small whorled pogonia		X	
Ovenbird			X
Oak - hickory - pine forests			
White oak	X		
White pine	X		
Wood thrush			X
Eastern red bat			X

Table 1. List of species chosen for vulnerability analysis, indicating habitat and distribution among foundation, species of high regional concern, and representative categories, continued.

Species	Foundation	High Regional Concern	Representative
Swamps			
Black gum	X		
Northern white cedar	X		
Atlantic white cedar	X		
Hessel's hairstreak		X	
Northern waterthrush			X
Freshwater marshes			
Woolgrass	X		
Pickerelweed	X		
American bittern		X	X
Least bittern		X	X
Marsh wren			X
American black duck			X
Coastal marshes			
Smooth cordgrass	X		
Saltmarsh sparrow		X	X
Diamond-backed terrapin			X
Coastal beaches and mudflats			
Least tern		X	
Piping plover		X	X
Common tern		X	X
American oystercatcher		X	X
Eastern beach tiger beetle		X	
Horseshoe crab			X
Streams to small rivers			
Tapegrass	X		
Brook floater		X	
Brook trout		X	X
Louisiana waterthrush			X
Southern pygmy clubtail			X
American water shrew			X

Table 1. List of species chosen for vulnerability analysis, indicating habitat and distribution among foundation, species of high regional concern, and representative categories, concluded.

Species	Foundation	High Regional Concern	Representative
Streams to small rivers, cont.			
Eastern hellbender		X	
Atlantic sturgeon		X	
Dwarf wedgemussel		X	X
Atlantic salmon			X
American shad			X
Bogs			
Leatherleaf	X		
Black spruce	X		
Bog elfin			X
Incurvate emerald			X
Purple pitcher plant			X
Ponds and vernal pools			
Spotted turtle		X	X
Barbedbristle bulrush		X	
Wood frog			X
Pine barrens			
Pitch pine	X		
Frosted elfin		X	
Northern pinesnake			X
Early successional			
New England cottontail		X	
Least weasel		X	

Table 2. Common and scientific names of assessed species by taxonomic group.

Taxonomic Group	Common Name	Scientific Name
Amphibian	Eastern hellbender	*Cryptobranchus alleganiensis*
Amphibian	Jefferson salamander	*Ambystoma jeffersonianum*
Amphibian	Wood frog	*Lithobates sylvaticus*
Bird	American bittern	*Botaurus lentiginosus*
Bird	American black duck	*Anas rubripes*
Bird	American oystercatcher	*Haematopus palliatus*
Bird	Bicknell's thrush	*Catharus bicknelli*
Bird	Blackpoll warbler	*Setophaga striata*
Bird	Cerulean warbler	*Setophaga cerulea*
Bird	Common tern	*Sterna hirundo*
Bird	Least bittern	*Ixobrychus exilis*
Bird	Least tern	*Sterna antillarum*
Bird	Louisiana waterthrush	*Parkesia motacilla*
Bird	Marsh wren	*Cistothorus palustris*
Bird	Northern goshawk	*Accipiter gentilis*
Bird	Northern waterthrush	*Parkesia noveboracensis*
Bird	Ovenbird	*Seiurus aurocapilla*
Bird	Piping plover	*Charadrius melodus*
Bird	Red-shouldered hawk	*Buteo lineatus*
Bird	Saltmarsh sparrow	*Ammodramus caudacutus*
Bird	Spruce grouse	*Falcipennis canadensis*
Bird	Wood thrush	*Hylocichla mustelina*
Fish	American shad	*Alosa sapidissima*
Fish	Atlantic salmon	*Salmo salar*
Fish	Atlantic sturgeon	*Acipenser oxyrhynchus*
Fish	Brook trout	*Salvelinus fontinalis*
Invertebrate	Bog elfin	*Callophrys lanoraieensis*
Invertebrate	Brook floater	*Alasmidonta varicosa*
Invertebrate	Dwarf wedgemussel	*Alasmidonta heterodon*
Invertebrate	Eastern beach tiger beetle	*Cicindela dorsalis*
Invertebrate	Frosted elfin	*Callophrys irus*
Invertebrate	Hessel's hairstreak	*Callophrys hesseli*
Invertebrate	Horseshoe crab	*Limulus polyphemus*
Invertebrate	Incurvate emerald	*Somatochlora incurvata*
Invertebrate	Southern pygmy clubtail	*Lanthus vernalis*

Table 2. Common and scientific names of assessed species by taxonomic group (concluded)

Taxonomic Group	**Common Name**	***Scientific Name***
Mammal	American water shrew	*Sorex palustris*
Mammal	Eastern red bat	*Lasiurus borealis*
Mammal	Least weasel	*Mustela nivalis*
Mammal	Moose	*Alces americanus*
Mammal	New England cottontail	*Sylvilagus transitionalis*
Plant	Atlantic white cedar	*Chamaecyparis thyoides*
Plant	Balsam fir	*Abies balsamea*
Plant	Barbedbristle bulrush	*Scirpus ancistrochaetus*
Plant	Black gum	*Nyssa sylvatica*
Plant	Black spruce	*Picea mariana*
Plant	Eastern hemlock	*Tsuga canadensis*
Plant	Leatherleaf	*Chamaedaphne calyculata*
Plant	Northern white cedar	*Thuja occidentalis*
Plant	Pickerelweed	*Pontederia cordata*
Plant	Pitch pine	*Pinus rigida*
Plant	Purple pitcher plant	*Sarracenia purpurea*
Plant	Red spruce	*Picea rubens*
Plant	Silver maple	*Acer saccharinum*
Plant	Small whorled pogonia	*Isotria medeoloides*
Plant	Smooth cordgrass	*Spartina alterniflora*
Plant	Sugar maple	*Acer saccharum*
Plant	tapegrass	*Vallisneria americana*
Plant	White oak	*Quercus alba*
Plant	White pine	*Pinus strobus*
Plant	Woolgrass	*Scirpus cyperinus*
Reptile	Diamondback terrapin	*Malaclemys terrapin*
Reptile	Northern pinesnake	*Pituophis melanoleucus melanoleucus*
Reptile	Spotted turtle	*Clemmys guttata*
Reptile	Wood turtle	*Glyptemys insculpta*

Climate Change Vulnerability Index

Vulnerability ratings were calculated using the Climate Change Vulnerability Index tool. The CCVI uses exposure-weighted scoring of multiple factors that can potentially affect species' vulnerability to climate change (Young et al. 2012). Potential results range from Extremely Vulnerable (loss of the species from the assessment area is projected to occur as a result of climate change) to Increase Likely (a positive response to increased warming and/or drying, such as by moving into the assessment area from farther south or experiencing population increases in current locations, is expected).

The CCVI is programmed in a Microsoft Excel® workbook and provides a relatively rapid means to assess the vulnerability of plant and animal species within a defined geographic area.[1] Factors are divided into two major components, exposure and sensitivity.

Exposure

Exposure refers to the degree of predicted change in temperature and moisture availability potentially affecting a species across its range within the assessment area. Direct exposure comprises the actual components of climate, temperature and available moisture that have an explicit impact on species. While temperature is relatively straightforward, precipitation is more complex in that the amount of rainfall alone does not provide adequate information on moisture that is actually available to living organisms in terrestrial habitats. Increased temperatures can increase the rate of evaporation and evapotranspiration, so that some areas may experience net drying in the next 50 years, even those where precipitation is also predicted to increase (Brooks 2009). We used a more nuanced measure, the Hamon AET:PET moisture metric (Hamon 1961). This metric is a ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) that integrates temperature and precipitation as they are influenced by total daylight hours and saturated vapor pressure.

In addition to direct exposure to climate change, three indirect measures are also included:

1) Sea level rise is an indirect result of climate change causing rapid melting of polar ice. Species of coastal zones, islands, and coral reefs are vulnerable to rapid loss of habitat and storm surge as a result.
2) Distribution relative to natural and anthropogenic barriers include geographical characteristics of the landscape such as mountains, rivers, and lakes that effectively prevent species from reaching new areas, either directly through physically insurmountable barriers or indirectly by imposing vastly different habitats unsuitable to

[1] Permanent resident and breeding ranges for birds were not assessed separately. Two species, blackpoll warbler and Bicknell's thrush, were also assessed in areas where they are passage migrants only.

survival of some species. Human-altered features of the landscape such as dams, agricultural areas, roads, and urban centers also limit dispersal capabilities of a number of species.

3) The predicted impacts of land use changes resulting from human responses to climate change are considered indirect exposure effects. These include solar farms, wind farms, and other large contiguous areas devoted to biofuel production or tree planting intended to be carbon sinks. These landscape features have the potential to impact species in both positive and negative ways. Indirect climate exposure, a component of realized adaptive capacity, refers to the effects of climate change on the landscape context of a species, or landscape factors that impact adaptive capacity.

Figure 2 illustrates the relationship of direct and indirect climate exposure and sensitivity factors in the CCVI.

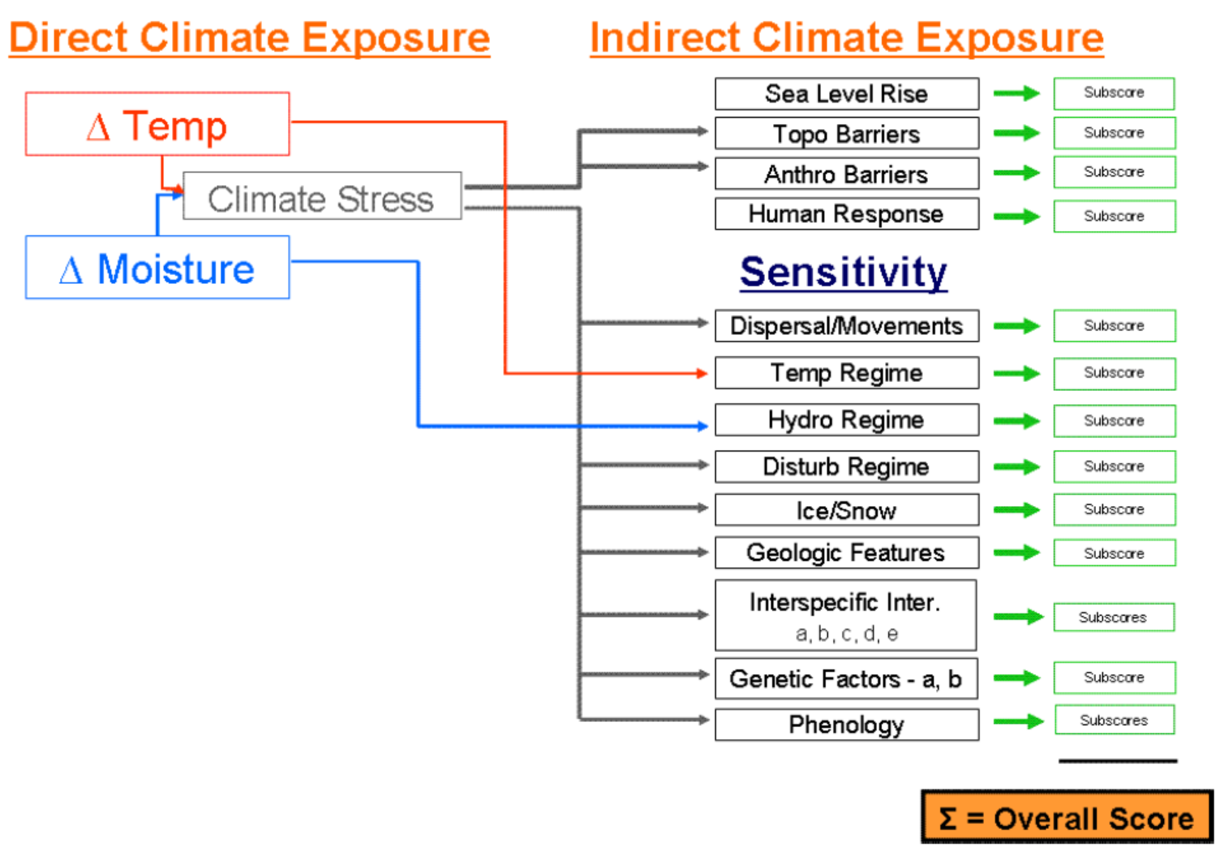

Figure 2. Relationship between exposure and sensitivity factors in the CCVI (from Young et al. 2012).

There has been a rapidly growing availability of increasingly sophisticated climate data since we conducted our initial analyses, and even the climate data available from Climate Wizard at the time provided a wide array of potential variables for analysis. These included average annual, seasonal, and monthly temperature and precipitation measures for historic and projected time periods, as well as choices of circulation models, and several different emissions scenarios. Different combinations of temperature and precipitation variables affect species and their interactions in different ways, such as the effect of maximum winter temperatures on pest species normally kept at bay by low winter temperatures. Researching the appropriate combinations of variables for each of 64 species, as well as conducting analyses with newer climate data, was beyond the scope of this project. Using the climate variables recommended by Young et al. (2015) allowed for interpretation using a single standard when comparing results conducted by other researchers (Ring et al. 2013, Schlesinger et al. 2011, and Furedi et al. 2011) using the same methods and same set of variables.

Sensitivity and Adaptive Capacity

Sensitivity refers to how tightly species are linked to specific microclimates and ecological conditions that might be affected by climate change. Adaptive capacity (AC) is the intrinsic ability of species to adjust to and persist in a changing climate. In acknowledging the sometimes ambiguous boundary between sensitivity and adaptive capacity, Beever et al. (2016) put forth a new paradigm that recognizes fundamental adaptive capacity (intrinsic ability to adjust to climate change), and realized adaptive capacity (limitations on adaptive capacity imposed by external factors). In the CCVI, sensitivity and adaptive capacity are assessed using up to 20 individual factors whose scores reflect species-specific sensitivity pertaining to individual species' biology and natural history.

Species-specific sensitivity or fundamental adaptive capacity factors include the following (Young et al. 2011):

1) Dispersal and movements: species with poor dispersal capabilities may not be able to keep up with rapidly-moving favorable climates.

2) Predicted sensitivity to temperature and moisture changes: species dependent on specific temperature and hydrologic conditions may not find other areas that replicate these requirements. Four subfactors are included, each scored separately: a) predicted sensitivity to changes in temperature; b) predicted sensitivity to changes in precipitation, hydrology, or moisture regime, c) dependence on a specific disturbance regime likely to be impacted by climate change, and d) dependence on ice, ice-edge, or snow-cover habitats.

3) Restriction to uncommon geological features or derivatives: species that require specialized substrates such as sand dunes and cliffs may be vulnerable if new areas with favorable climates no longer occur in areas with these substrates.

4) Reliance on interspecific interactions: species with tight relationships with other species may react differently to climate change, thus uncoupling the relationship and threatening survival. Five subfactors are scored individually: a) dependence on other species to generate habitat, b) dietary versatility (animals only), c) pollinator versatility (plants only), d) dependence on other species for propagule dispersal, and e) forms part of an interspecific interaction not covered by 4a-d.

5) Genetic factors: species must rely largely on existing genetic variation in order to evolve adaptations to conditions caused by climate change. Two subfactors in this factor are scored separately: a) measured genetic variation, and b) occurrence of bottlenecks in recent evolutionary history.

6) Phenological response to changing seasonal temperature and precipitation patterns:.

dispersal, dependence on unusual habitats or other species, factors affecting adaptive capacity such as genetic diversity, and documented or modeled responses to climate change, historical thermal and hydrologic niches, as well as physiological thermal and hydrologic niches. The latter measures the degree to which a species is particularly dependent on a narrow range of climatic variation, such as species that are dependent on cold climates. These species score higher in thermal physiological niche sensitivity than do species that have wider temperature tolerances. Similarly, species that are restricted to habitats that are dependent on a particular flooding regime, such as vernal pools, also score higher in this category.

Climate Change Vulnerability Index and Data Sources

The North Atlantic LCC extends from the maritime provinces in Canada, south to the Virginia coast, and west in New York. Because the existing climate patterns are highly variable from north to south, species' responses to climate change can also vary geographically. A species that is not likely to be affected by climate change in a portion of its range may be vulnerable elsewhere. To address this variability, we divided the North Atlantic LCC region into assessment subregions (Figure 3). These subregions, here referred to as Northern Appalachian / Maritime Canada, North Atlantic Coast, and Mid-Atlantic Coast, are based on Subsections as defined by the USFS Ecoregional Units (Keys et al. 1995). Subsections are land units sharing similar vegetation types occurring in broadly similar environmental settings. There are 50 subsections covering the US portion of the North Atlantic LCC. We aggregated the subsections into three assessment areas reflecting major vegetation patterns, and included the Canadian portion of the LCC with the Northern Appalachian subregion due to their shared dominance by northern conifers. The resulting subregions are similar to those used for the selection of representative species (U.S. Fish and Wildlife Service 2011a). The Northern Appalachian / Maritime Canada subregion is characterized by a northern flora and fauna, manifested most notably in the abundance of red spruce (*Picea rubens)*, balsam fir (*Abies balsamea)*, northern hardwoods (beech [*Fagus grandifolia]*, sugar maple [*Acer saccharum*], and yellow birch [*Betula alleghaniensis*]), and a host of other understory species of similar northern affinity. The North Atlantic Coast is characterized by the absence or rarity of these species, as well as the abundance of northern red oak (*Quercus rubra*), white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), pitch pine (*Pinus rigida*), and other temperate species. The Mid-Atlantic Coast shares many of the same species as in the North Atlantic Coast, but is also characterized by species of more southern affinity absent or rare in New England and New York, such as loblolly pine (*Pinus taeda*), tulip poplar (*Liriodendron tulipifera*), southern red oak (*Quercus falcata*), and sweetgum(*Liquidambar styraciflua*). Each species was assessed within each subregion where it occurs, resulting in up to three assessments per species.

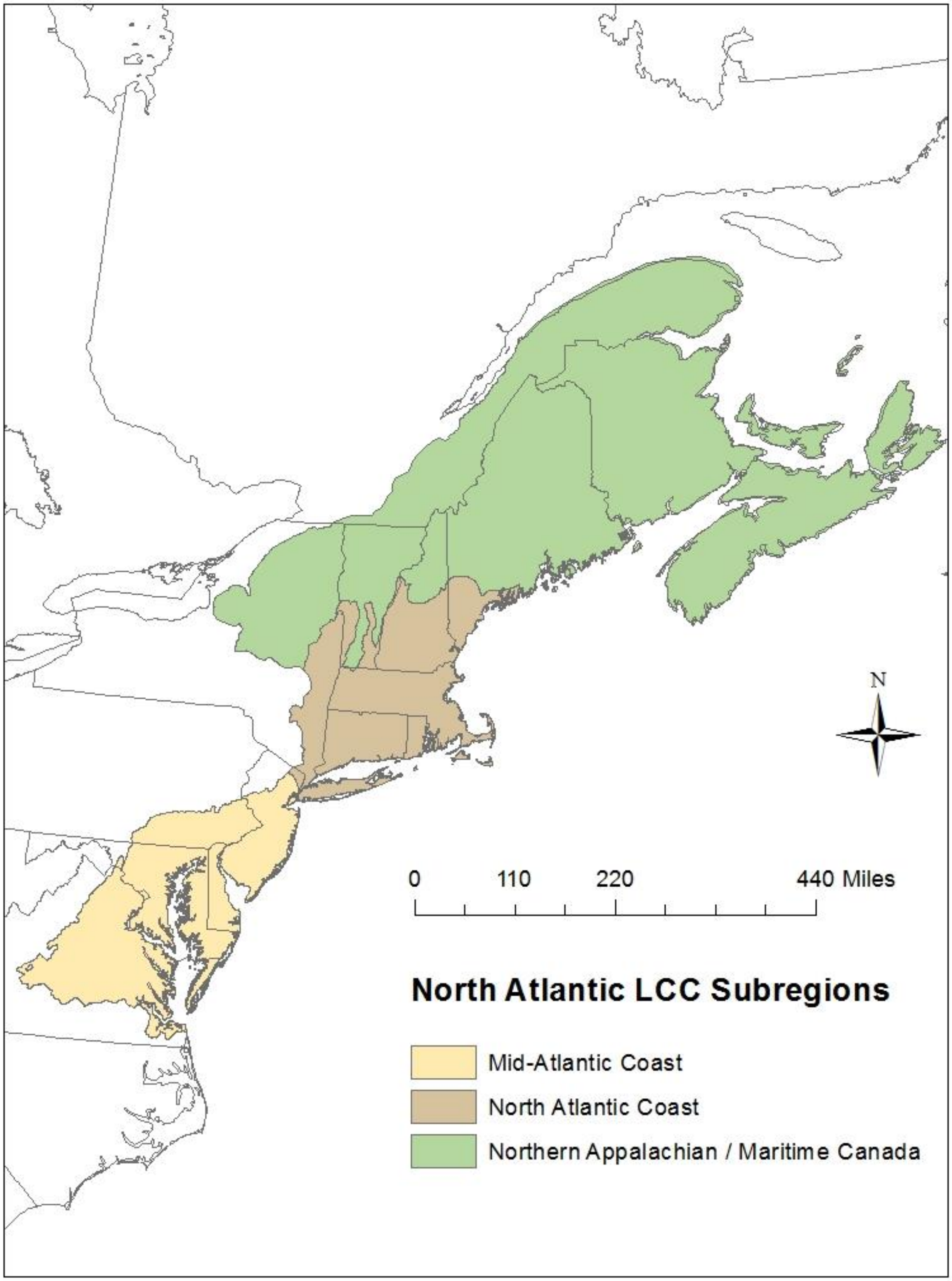

Figure 3. Subregions of the North Atlantic LCC used to conduct CCVI assessments.

Climate data

Direct exposure was measured using the downloaded future annual average projected temperature data available from Climate Wizard (http://climatewizard.org/; Girvetz et al. 2009), against a digital range map of the species. We used the data sets recommended by the CCVI (Young et al. 2012; Young et al. 2015), ensemble climate predictions that represent a median of 16 major global circulation models (GCMs) and a medium emission scenario (A1B) for mid-century (2050s). For available moisture, we used the Hamon AET:PET moisture metric available from NatureServe (http://www.natureserve.org/climatechange) and derived from Climate Wizard.

As of the date of the analysis, climate data were available at two different resolutions in the US and in Canada (Figure 4). For the US portion of the LCC, we used the Climate Wizard contiguous US data, which are available at a resolution of 4 km for current temperatures and precipitation and 12 km for future temperatures and precipitation. For Canadian temperature and precipitation data, we downloaded the Global dataset also available from Climate Wizard at a resolution of 50 km. Consequently, we have lower confidence in interpretations of exposure in the Northern Appalachian / Maritime Canada subregion than for the other two subregions.

Species data

Species' ranges and other natural history information were compiled from a variety of sources: NatureServe Explorer (http://explorer.natureserve.org/) provides state and province-of-occurrence ranges for all species tracked by natural heritage programs and Canadian Conservation Data Centres (CDC's), as well as more detailed shaded range maps for most animal species.

Range information for birds was calculated on North American breeding / permanent resident range and did not distinguish between the two. In all but two species, exclusively migratory ranges were outside the North Atlantic LCC region, and vulnerability outside the LCC area was not included in the analysis. Because migratory species are at risk in multiple locations across the range, the vulnerability score must be considered in this context. Breeding ranges of blackpoll warbler and Bicknell's thrush are confined to the Northern Appalachian / Maritime Canada subregion, and assessments were included for their migratory ranges, where they are not permanent residents, in the other subregions.

Additional literature research was needed for some species to obtain the needed information on dispersal, dependence on unusual habitats or other species, factors affecting adaptive capacity such as genetic diversity, and documented or modeled responses to climate change, as well as physiological thermal and hydrologic niches. Atlases for tree (Prasad et al. 2007–ongoing) and bird (Matthews et al. 2011) species for current and projected climates were used to document predicted responses to climate change for these taxa. Flora of North America (http://floranorthamerica.org/) was a source of range data for tapegrass (*Vallisneria americana*) and small whorled pogonia (*Isotria medeoloides*). Bird range data were adopted from Birdlife International through IUCN at (http://www.birdlife.org/datazone/info/spcdownload). A detailed range map of least weasel (*Mustela nivalis*) was obtained from IUCN Red List data (www.iucnredlist.org/), and the range map of horseshoe crab (*Limulus polyphemus*) was downloaded from Ocean Biogeographic Information System (http://iobis.org).

Species' ranges were compared to GIS data on natural and anthropogenic barriers. We used Ecological Land Units (Anderson et al. 2011) to identify natural barriers to migration, e.g. mountains, lakes, and other features that might pose a natural barrier to dispersal. Our source of anthropogenic barrier data was developed land use categories of the Northeast Terrestrial Habitat Classification and map (Gawler et al. 2008; Ferree et al. 2006), in comparison with individual species' ranges.

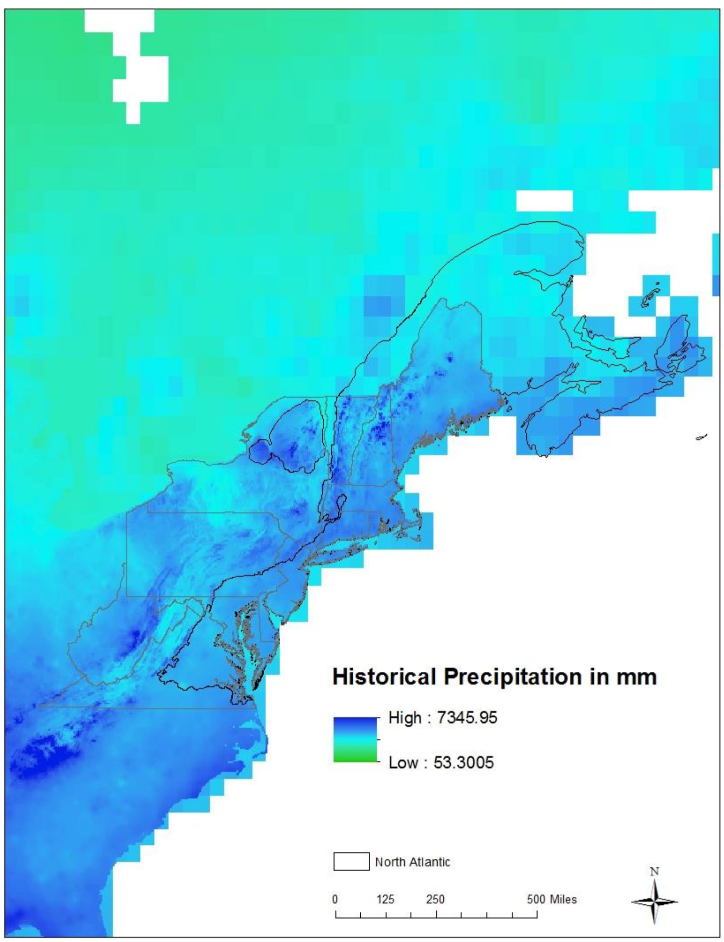

Figure 4. Average Annual Precipitation in mm for last 50 years. Note resolution difference between US (4 km) and Canada (50 km).

Results

Results of individual factors are included in Appendices 1 and 2. Of the 64 species assessed using the CCVI tool, 30 were rated as vulnerable (Extremely Vulnerable, Highly Vulnerable or Moderately Vulnerable) over their range in all or part of the North Atlantic LCC region, and 34 species were rated as Presumed Stable or Increase Likely (Table 3) in all the subregions where they occur. These figures include species occurring in only one or two subregions of the LCC. Variations in categories among subregions were within one level of difference, reflecting the change in exposure (either direct or indirect) with latitude. For example, species found to be Highly Vulnerable in one subregion were found to be Extremely Vulnerable (a single case), Highly Vulnerable, or Moderately Vulnerable in others where they occur. Apart from historical thermal and hydrological niches, sensitivity scores are specific to the taxon assessed and did not generally vary among subregions.

Viewing the results by selection category, 10 foundation species, 13 species of high regional concern, and 15 representative species were found to be vulnerable in all or part of the region. Those species rated as Presumed Stable or Increase Likely included 7 foundation species, 15 species of high regional concern, and 16 representative species (twelve species were in two categories). Eight species were rated Extremely Vulnerable or Highly Vulnerable. Hessel's hairstreak (*Callophrys hesseli*) was the only species found to be Extremely Vulnerable in our study, in the Northern Appalachian/Maritime Canada subregion. It was rated Highly Vulnerable in the other two subregions. Six species were rated Highly Vulnerable in at least one subregion.

At the other end of the scale, five species resulted in a rating of Increase Likely in at least one subregion. The red-shouldered hawk (*Buteo lineatus*) was the only species with this rating in all three subregions. Forty-one species were rated Presumed Stable in at least one subregion of occurrence. These included 6 birds, 3 fishes, 4 mammals, 8 plants, 2 mollusks, 3 invertebrates, 2 amphibians, and 3 reptiles.

Table 3 reports results directly from the CCVI. Other factors that may be important in determining vulnerability include some that are not accounted for in the CCVI. These include climate factors influencing timing, duration, and strength of flows in hydrological systems resulting from changes in temperature, winter precipitation types, and snowpack. Other factors such as pests or diseases likely to be exacerbated by changing temperatures are also not accounted for in the CCVI. Species that may be affected by these factors are noted in Table 3 and discussed later in this report.

Table 3. Vulnerability results of assessed species by subregion of the North Atlantic LCC. Species not occurring in a subregion are indicated by "—". Passage migrant only indicated by *. EV = Extremely Vulnerable; HV = Highly Vulnerable, MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

Species	Northern Appalachians and Maritime Canada	North Atlantic Coast	Mid-Atlantic Coast
Vulnerable throughout LCC			
American oystercatcher[23]	—	MV	MV
Atlantic salmon[3]	MV	MV	—
Balsam fir[1]	MV	HV	—
Bicknell's thrush[23]	MV	HV*	—
Black spruce[1]	MV	HV	—
Eastern beach tiger beetle[2]	—	HV	MV
Eastern hellbender[2]	—	—	MV
Hessel's hairstreak[2]	EV	HV	HV
Horseshoe crab[3]	MV	MV	MV
Least tern[2]	—	MV	MV
Northern white cedar[1]	MV	MV	HV
Piping plover[23]	MV	MV	MV
Purple pitcher plant[3]	MV	MV	MV
Red spruce[1]	MV	HV	—
Saltmarsh sparrow[23]	—	MV	HV
Smooth cordgrass[1]	MV	MV	MV
Spruce grouse[23]	MV	MV	—
Vulnerable in part of region			
American bittern[23]	MV	PS	PS
Atlantic white cedar[1]	PS	PS	MV
Barbedbristle bulrush[2+]	PS	PS	MV
Bog elfin[3]	PS	MV	—
Brook trout[23]	PS	MV	—
Common tern[23]	PS	PS	MV
Diamond-backed terrapin[3]	—	PS	MV
Eastern hemlock[1+]	PS	MV	MV
Leatherleaf[1]	PS	MV	MV
Northern waterthrush[3+]	PS	PS	MV
Ovenbird[3+]	PS	PS	MV
Pickerelweed[1]	PS	PS	MV
White pine[1]	PS	PS	MV

*migratory range only; +other factors not addressed by CCVI may warrant a different score; see additional discussion

[1]Foundation species; [2]Species of high regional concern; [3]Representative species

Table 3. Vulnerability results of assessed species by subregion, concluded.

Species	Northern Appalachians and Maritime Canada	North Atlantic Coast	Mid-Atlantic Coast
Presumed stable or increase likely throughout region			
American black duck[3]	PS	PS	PS
American shad[3]	PS	PS	PS
American water shrew[3]	PS	PS	PS
Atlantic sturgeon[2]	PS	PS	PS
Black gum[1]	PS	PS	PS
Blackpoll warbler[3+]	PS	PS*	PS*
Brook floater[2+]	PS	PS	PS
Cerulean warbler[2+]	—	PS	IL
Dwarf wedgemussel[23+]	PS	PS	PS
Eastern red bat[3]	PS	PS	PS
Frosted elfin[2]	PS	PS	PS
Incurvate emerald[3]	PS	—	—
Jefferson salamander[2+]	PS	PS	PS
Least bittern[23]	PS	PS	PS
Least weasel[2]	PS	—	PS
Louisiana waterthrush[3+]	PS	PS	PS
Marsh wren[3+]	PS	PS	PS
Moose[2+]	IL	PS	—
New England cottontail[2]	PS	PS	—
Northern goshawk[2]	IL	IL	PS
Northern pinesnake[3]	—	PS	PS
Pitch pine[1]	PS	PS	PS
Red-shouldered hawk[3]	IL	IL	IL
Silver maple[1]	PS	PS	—
Small whorled pogonia[2]	PS	PS	PS
Southern pygmy clubtail[3]	PS	PS	PS
Spotted turtle[23+]	PS	PS	PS
Sugar maple[1]	IL	PS	PS
Tapegrass[1]	PS	PS	PS
White oak[1]	PS	PS	PS
Wood frog[3+]	PS	PS	PS
Wood thrush[3+]	PS	PS	PS
Wood turtle[23+]	PS	PS	PS
Woolgrass[1]	PS	PS	PS

*migratory range only; +other factors not addressed by CCVI; see additional discussion

[1]Foundation species; [2]Species of high regional concern; [3]Representative species

Vulnerability of species by category

Foundation Species

We assessed 17 foundation species, all of them plants (see species marked with superscript 1 in Table 3). In this heavily forested region, the majority of foundation species are trees, of which we selected twelve. The other foundation species included one dwarf shrub providing substrate in nearly all bog habitats, one grass contributing substantial biomass in salt marshes, one sedge, one leafy forb often dominant in freshwater wetlands, and one aquatic plant.

Vulnerable throughout range in LCC

Of the 17 foundation species, five were found to be vulnerable throughout the region of their occurrence. Four of these are tree species of northern climates (black spruce, northern white cedar, balsam fir, and red spruce), of which three (all but northern white cedar) are at the southern limits of their ranges in the North Atlantic LCC.

In this sub-boreal region, black spruce (*Picea mariana*) is almost always confined to wetland environments, and it occurs widely in northern peat swamps discontinuously as far south as Connecticut, in both the Boreal-Laurentian Conifer Acidic Swamp and Boreal-Laurentian Bog habitats. Northern white cedar (*Thuja occidentalis*) is generally restricted to calcareous environments (where it occurs naturally; this species and a number of its cultivars are widely planted) in southern New England and to the south, in both wetland and upland sites. Northward from northern New England, northern white cedar regularly occurs in acidic spruce forests of both uplands and flats (Acadian Low-Elevation Spruce-Fir-Hardwood Forest Habitat), the North-Central Appalachian Circumneutral Cliff and Talus Habitat, as well as in the Laurentian-Acadian Alkaline Conifer-Hardwood Swamp habitat, but it is arguably a foundation species only in the latter habitat. Balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) are dominant in many wetland and upland habitats in northern New England and Canada, and in fact form the "matrix" forests of the Northern Appalachian / Maritime subregion as foundation components of the Acadian Low-Elevation Spruce-Fir-Hardwood Forest, Acadian-Appalachian Montane Spruce-Fir Forest Habitat, and the Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp Habitat. Important factors contributing to increased vulnerability of balsam fir, black spruce, and red spruce included physiological thermal niche (requirement of cold temperatures) and modeled response to change (Prasad et al. 2007–ongoing). Modeled response to change and historical hydrological niche were found to be important factors contributing to vulnerability of northern white cedar, particularly in the Mid-Atlantic subregion, where it occupies a very small area in the Maryland Piedmont. In this area, northern white cedar occurs as dwarfed and sparsely distributed individuals within the North-Central

Appalachian Circumneutral Cliff and Talus Habitat where it is not regarded to be a foundation species.

The fifth plant categorized as vulnerable throughout the region, smooth cordgrass (*Spartina alterniflora*), dominates low salt marshes along the eastern seaboard. It forms the matrix of the low tidal marshes of Acadian Coastal Salt Marsh and the Northern Atlantic Coastal Plain Tidal Salt Marsh habitats. Smooth cordgrass is often the sole vascular plant species to occur in the low salt marsh, where it withstands diurnal tidal flooding. Predicted exposure to sea level rise with associated increases in storm severity and erosion led to a rating of Moderately Vulnerable across the LCC. This rating was based largely upon SLAMM (Sea Level Affecting Marshes Model) predictions for the Chesapeake Bay region (Glick et al 2008), that showed an increase in salt marsh on the shores of tidal rivers currently dominated by brackish marshes. However, notable decreases were predicted for salt marshes located behind the barrier beaches of the Delmarva Peninsula, partially offsetting this predicted increase within tidal rivers (Nieves 2009).

Vulnerable in part of range in LCC

Five foundation species rated as vulnerable in part of the LCC region. These included three tree species (eastern white pine [*Pinus strobus*], Atlantic white cedar [*Chamaecyparis thyoides*]), and eastern hemlock (*Tsuga canadensis*), one bog species (leatherleaf [*Chamaedaphne calyculata*]), and one wetland herbaceous species (pickerelweed [*Pontederia cordata*]). White pine is a ubiquitous forest tree in the northeast, and occurs in all three subregions of the LCC. White pine occurs in several different habitats, depending on land use history. It can be found in monotypic stands, or co-dominant with oaks (to the south) and hemlock (to the north), and is an early pioneer of old fields. It functions as a foundation species in the Laurentian-Acadian Pine-Hemlock-Hardwood Forest in the Northern Appalachian/Maritime Canada subregion and the Central Appalachian Dry Oak-Pine Forest in the North Atlantic subregion and the piedmont portion of the Mid-Atlantic subregion. It occurs in scattered locations in the coastal plain portion of the Mid-Atlantic subregion, where it does not function as a foundation species. Modeled climate change response (Prasad et al. 2007–ongoing) predicts a decrease in suitable habitat for white pine in the piedmont of the Mid-Atlantic, and absence from the coastal plain of the Mid-Atlantic subregion by mid-century.

Atlantic white cedar is an obligate wetland tree occurring in acidic bogs and swamps, and functions as a foundation species in the Northern Atlantic Coastal Plain Basin Peat Swamp habitat. Sensitivity factors contributing to the rating of Moderately Vulnerable in the Mid-Atlantic subregion included a somewhat lower than average variation in precipitation and temperature in the past 50 years (historical hydrological and thermal niches), as well as anthropogenic barriers to dispersal northeastward imposed by human population density and development.

Leatherleaf is a dwarf shrub that forms the bog mat matrix along with *Sphagnum* mosses in nearly all northeastern bogs. It is a foundation species in the Atlantic Coastal Plain Northern Bog Habitat, and the North-Central Interior and Appalachian Acidic Peatland of the North Atlantic Coast subregion, as well as the Boreal-Laurentian Bog Habitat of the Northern Appalachian / Maritime Canada subregion. This species is generally fire-resistant, and establishes in bogs disturbed by both fire and peat removal (Pavek 1993). Its genetic variability was found to be relatively low (Wroblewska 2012). It rated Moderately Vulnerable in the Mid-Atlantic and North Atlantic subregions as a result of its restriction to bogs that are often isolated by anthropogenic barriers imposed by the dense human population of the northeast. It rated Presumed Stable in the Northern Appalachian / Maritime Canada subregion, where it currently occupies vast peatlands.

Pickerelweed is a wetland herbaceous plant that was found to be Moderately Vulnerable in the Mid-Atlantic subregion. It functions as a foundation species in the Northern Atlantic Coastal Plain Fresh and Oligohaline Tidal Marsh habitat. It is also a component of the Laurentian-Acadian Freshwater Marsh habitat, but it functions only arguably as a foundation species in this highly variable and patchy habitat. Glick et al. (2008) noted a 36% loss of freshwater tidal marshes in the Chesapeake Bay region with a 1-m rise in sea level by the end of the century, a primary factor contributing to the vulnerability of this species in the Mid-Atlantic subregion.

Eastern hemlock functions as a foundation species in the Laurentian-Acadian Pine-Hemlock-Hardwood Forest, south to the Piedmont portion of the Mid-Atlantic subregion. Hemlock occurs as isolated stands in scattered locations in the Coastal Plain portion of the Mid-Atlantic subregion, but it does not function there as a foundation species. Although it typically grows best in mesic, fertile soils, it can also tolerate a fairly wide spectrum of soil types, pH, and temperatures, as reflected in its wide geographic range from southern Canada to Florida and Oklahoma.

Presumed Stable or Increase Likely in LCC

Seven foundation species were ranked as Presumed Stable throughout their range within the North Atlantic LCC. These included five tree species (pitch pine [*Pinus rigida]*, white oak [*Quercus alba*], sugar maple [*Acer saccharum*], black gum [*Nyssa sylvatica*] and silver maple [*Acer saccharinum*]) and two herbaceous species (tapegrass [*Vallisneria americana*] and woolgrass [*Scirpus cyperinus*]). Pitch pine and white oak respond favorably to fire, an important ecological factor in dry habitats in the northeast (Patterson et al. 1983; Patterson et al. 1985, Gucker 2007; LANDFIRE 2007). Pitch pine ranges from southern New England to New Jersey, and functions as a foundation species in pitch pine—scrub oak barrens in the Northeastern Interior Pine Barrens and the Northern Atlantic Coastal Plain Pitch Pine Barrens habitats. Both habitats are dependent on fire for long-term persistence (Vogl 1997; Little 1953). Pitch pine is a fire-tolerant species with numerous fire adaptations, including bole and crown sprouting ability, thick bark, high resin content, and partially serotinous cones that open and disperse seeds following fire (Gucker 2007). Associated plant species include heaths such as blueberries (*Vaccinium* spp.) and huckleberries (*Gaylussacia* spp.) with high resin content, and scrub oak (*Quercus ilicifolia)*, a species that sprouts vigorously following fire (Gucker 2006). White oak is an abundant tree in many forest types in the eastern half of the United States, ranging in habitat from mesic coves to dry acidic soils. Within the LCC area, it functions as a foundation species in dry acidic environments in the Central Appalachian Dry Oak-Pine Forest habitat. Regeneration is stimulated by fire, by vigorous stump sprouting and by release of suppressed understory individuals (Van Lear et al. 1988; Pallardy et al. 1988). Prolific acorn production also occurs following fire (Boerner et al. 1988).

Sugar maple occurs in a variety of environmental conditions. This species is an important component of the Laurentian-Acadian Northern Hardwoods Forest Habitat. Sugar maple has several characteristics that may buffer its response to climate change. Experimental warming resulted in earlier bud burst over 4 years, demonstrating some ability to respond with phenotypic change (Norby et al 2003). Sugar maple has a high germination capacity (Godman et al. in Little 1977). In general, genetic variability is higher in wind-dispersed, late-successional trees of high fecundity (Hamrick and Godt 1996), such as the sugar maple.

Two trees were among foundation species ranking Presumed Stable. Black gum occurs naturally in two distinctly different environments across its range. In the High Allegheny portion of the Appalachian LCC, black gum is a common component of dry, acidic, rocky environments, as well as a dominant or co-dominant swamp species. In the North Atlantic LCC and elsewhere, it functions as a foundation species of the Northern Atlantic Coastal Plain Basin Peat Swamp (in the Mid-Atlantic subregion) and the North-Central Appalachian Acidic Swamp habitats.

Silver maple is a common, and often dominant, component of floodplain forests on larger rivers of the northeast, in both the Laurentian-Acadian Floodplain Forest habitat and the Central Appalachian Stream and Riparian habitat. Modeled response to climate change resulted in a slight increase of suitable habitat for this species in the Northern Appalachian/Maritime Canada subregion (Prasad et al. 2007–ongoing).

The two remaining foundation herbaceous species (tapegrass and woolgrass) are associated with wetland or aquatic habitats. Tapegrass, in association with other aquatic plants, provides habitat for a large number of invertebrate taxa (Keast 1984), and the extensive root system of tapegrass in particular was found to provide a more stable substrate for benthic fauna than did other aquatic species (Gerking 1957). This species was scored Somewhat Decreased in physiological thermal niche because it can tolerate a range of environmental conditions

(Korschgen et al. 1988), even becoming a “nuisance” species in shallow water (Best and Boyd 2001) in warmer temperatures. Tough rooting structures allow this species to persist in shallow waters affected by substantial wave action.

Woolgrass is a common and abundant wetland sedge of the Laurentian-Acadian Freshwater Marsh habitat throughout the northeast. As an aggressive colonizer, its function as a foundation species is somewhat debatable, and might be better portrayed by the term “indicator species”. Woolgrass was scored Neutral in nearly all sensitivity factors; it can tolerate fluctuating water levels, including increased drying. It has been observed to increase at the expense of cattail (*Typha* spp.) with greater variability in hydrology (Kadlec 1958; Kadlec 1961). In addition, the prolific seed production, effective dispersal of bristled seeds by animals, viability of seeds in sediments, and dense tussock formation make it an effective colonizer; these characteristics also contribute to its becoming invasive in some situations (Wilcox et al. 1985).

Species of High Regional Concern

Twenty-seven of the species assessed in this study are designated to be of High Regional Concern, and of these, 12 were also among those identified as Representative Species (see species marked with superscript 2 in Table 3). Note that twelve animal species belong to two categories (high regional concern and representative).

Vulnerable throughout range in LCC

Nine species of high regional concern were found to be vulnerable throughout their range within the LCC. These included six birds (saltmarsh sparrow [*Ammodramus caudacutus*], American oystercatcher [*Haematopus palliates*], piping plover [*Charadrius melodus*], least tern [*Serna antillarum*], Bicknell’s thrush [*Catharus bicknelli*], spruce grouse [*Falcipennis canadensis*), two invertebrates (Hessel’s hairstreak [*Callophrys hesseli*] and eastern beach tiger beetle [*Cicindela dorsalis*]), and one amphibian (eastern hellbender [*Cryptobranchus alleganiensis*]). Four of the six birds are restricted to the immediate coast, and two (spruce grouse and Bicknell’s thrush) are at their southern range limit in the North Atlantic LCC. Two birds rated Highly Vulnerable in portions of their range: saltmarsh sparrow in the Mid-Atlantic subregion and Bicknell’s thrush in the North Atlantic subregion. The others rated Moderately Vulnerable in subregions where they occur.

Sea level rise was presumed to be a major factor contributing to the vulnerability of all the coastal bird species. Saltmarsh sparrow is a breeding resident of low and high salt marshes in the Acadian Coastal Salt Marsh and Northern Atlantic Coastal Plain Tidal Salt Marsh habitats; it is also a permanent resident of the latter habitat in the Mid-Atlantic subregion (NatureServe 2013). American oystercatcher, piping plover, and least tern are breeding residents of the Northern Atlantic Coastal Plain Sandy Beach habitat. Sea level rise and increased storm intensity associated with climate change are predicted to cause substantial erosion to both the salt marsh and sandy beach habitats as breeding habitats (Manomet 2014), and outright mortality during breeding season. Results of a vulnerability assessment of piping plover in Canada suggest this species will be negatively affected by climate change (Lundy 2008).

Bicknell's thrush and spruce grouse are associated with northern climates; factors contributing to their vulnerability include dependence on cool climate and dependence on northern conifers for winter diet and habitat. Spruce grouse is further impacted by its limited dispersal capability (Boag and Schroeder 1992). Bicknell's thrush has a very restricted breeding range, limited to montane spruce-fir forests, which are vulnerable to warming as deciduous trees migrate upward into the niche currently occupied by these northern conifers.

Hessel's hairstreak is a butterfly whose larvae are largely restricted to Atlantic white cedar swamps. This species was rated Highly Vulnerable in the North Atlantic Coast and Mid-Atlantic Coast subregions, and Extremely Vulnerable in the Northern Appalachian / Maritime Canada subregion. Major factors contributing to its vulnerability included its dependence on a single habitat type of isolated wetlands and its observed limited dispersal capabilities through upland habitats to reach other swamps. It is more limited in dispersal than its host plant, Atlantic white cedar, which is able to disperse readily by a number of vectors including wind and long-distance dispersal by birds (Kuzer et al. 1997).

Eastern beach tiger beetle, an inhabitant of coastal sand dunes and beaches, is at the northern range limit in the North Atlantic subregion of the North Atlantic LCC, where it is rated Highly Vulnerable. It is rated Moderately Vulnerable in the Mid-Atlantic subregion; in both regions, sea level rise was seen as a major contributor to its vulnerability. Its occurrence on narrow barrier beaches in the North Atlantic subregion contributed to its relatively greater vulnerability imposed by largely impassable barriers isolating these habitats.

The hellbender is a large aquatic amphibian restricted to the Piedmont portion of the mid-Atlantic subregion of the LCC, where it occupies cool, clear rivers with abundant shelter rocks. It was rated Moderately Vulnerable as a result of slight increases in vulnerability for a number of factors, rather than any single predominant factor. These included anthropogenic barriers (dams), human response to climate change (dams and water withdrawals), diet (dependence on relatively few crayfish taxa), and habitat requirements.

Vulnerable in part of range in LCC

Four species of high regional concern were found to be vulnerable in portions of the LCC. These included two bird species (American bittern [*Botaurus lentiginosus*] and common tern [*Sterna hirundo*]), one fish (brook trout [*Salvelinus fontinalis*]), and one plant (barbedbristle bulrush [*Scirpus ancistrochaetus*]). American bittern is a breeding resident across the North Atlantic LCC region. It is restricted to wetlands that are generally dominated by tall graminoids (sedges, rushes, cattails, and grasses) in the Laurentian-Acadian Freshwater Marsh Habitat. It was rated Moderately Vulnerable in the Northern Appalachian / Maritime Canada subregion. Modeled response to climate change (Matthews et al. 2007–ongoing) indicated a decrease in abundance of this species in the Northern Appalachian / Maritime Canada subregion by the end of the century. Model reliability was reportedly low, however. The common tern is a resident along the immediate Mid-Atlantic coast, where it is vulnerable to sea level rise, and a migrant in the remainder of the LCC region. It is rated Presumed Stable in the other two subregions, where it does breed in some inland locations.

Brook trout was rated Moderately Vulnerable in the North Atlantic, its southern range limit in the east (it ranges farther south in the Appalachians). The combination of barriers (dams, waterfalls) and greater exposure to projected temperature increase contributed to its vulnerability rating there.

Barbedbristle bulrush has a global conservation rank of G3, a species of regional concern. This species occurs in a number of wetland habitats characterized by fluctuating water levels, including seasonally flooded basins and vernal pool habitats. Physiological and historical hydrologic niche were important factors contributing to its vulnerability in the Mid-Atlantic.

Presumed Stable or Increase Likely in LCC

Fourteen species of high regional concern were categorized as Presumed Stable or Increase Likely in the LCC region. These spanned taxonomic groups: 3 birds (least bittern [*Ixobrychus exilis]*, cerulean warbler [*Setophaga cerulea*], northern goshawk [*Accipiter gentilis*]), 3 mammals (least weasel [*Mustela nivalis]*, New England cottontail [*Sylvilagus transitionalis*] and moose [*Alces americanus]*), 2 reptiles, (spotted turtle [*Clemmys guttata*] and wood turtle [*Glyptemys insculpta]*), 1 amphibian (Jefferson salamander [*Ambystoma jeffersonianum*]), 1 fish (Atlantic sturgeon [*Acipenser oxyrhynchus*]), 3 invertebrates (frosted elfin [*Callophrys irus*], dwarf wedgemussel, and brook floater [*Alasmidonta varicosa*]), and 1 plant (small whorled pogonia [*Isotria medeoloides*]).

The least bittern occupies graminoid marshes with scattered shrubs, usually in fresh water in the Laurentian-Acadian Freshwater Marsh Habitat, but is also found in brackish marshes in the Northern Atlantic Coastal Plain Brackish Tidal Marsh habitat. The cerulean warbler inhabits swamp forests and riparian corridors as well as uplands, spanning numerous habitats, as does the northern goshawk, but in overall more northerly regions. All three of the bird species were rated Presumed Stable in all or portions of their range; cerulean warbler and northern goshawk rated Increase Likely in portions of their ranges. Dispersal capability was the major factor contributing to the stability or increase of these species.

The least weasel occupies a wide variety of upland and wetland habitats, and has a relatively high dispersal capability (NatureServe Explorer 2013). Its range within the LCC is discontinuous, occurring in Quebec (although only province-level data were available) and absent from the maritime provinces and New England. It also occurs in the piedmont portion of the Mid-Atlantic subregion. This species scored Neutral in nearly all individual factors.

New England cottontail favors dense shrublands that offer protective cover (Litvaitis et al. 2006); in general these are early successional habitats that are established following disturbance, although it also includes shrub swamps of natural origins. It has a narrow geographic range essentially restricted to the two northern subregions of the LCC. Dispersal capability largely accounts for its apparent lack of vulnerability to climate change. A recent study, however, predicted the loss of this species at its southern range limit in southeastern New York as a result of barriers and loss of habitat (Howard and Schlesinger 2013).

Moose is also rated as Not Vulnerable in the North Atlantic subregion and Increase Likely in the Northern Appalachian / Maritime Canada subregion. This species' dispersal capacity was a primary factor in its vulnerability rating. It has a broad northerly range across North America, a documented migration distance of up to 179 km (LeResche 1974), and an ability to disperse across highways and even through towns and cities. However, other indirect effects of climate are not accounted for in this rating, such as host-parasite relationships and their potential impacts on this species (Rodenhouse et al. 2009.) Moose are declining in all northern US states except Colorado, with declines attributed at least in part to warming temperatures. Winter tick and brainworm, in combination with warmer temperatures, are very likely impacting the moose population and affecting its growth rate. We address this issue further in the discussion section. Both spotted turtle and wood turtle occupy a number of wetland habitats, and can disperse through upland habitat (NatureServe Explorer 2013). Their dispersal capability and broad habitat tolerances resulted in a rating of Presumed Stable in the LCC as a whole. Jefferson salamander is dependent on vernal pools for breeding, and climate-induced drying of some of these habitats increases its vulnerability to climate change for this factor. However, its general lack of vulnerability in other measured factors resulted in its rating of Presumed Stable. In all three species, the possibility of range expansion in the Northern Appalachian / Maritime Canada subregion offset noted vulnerabilities.

Frosted elfin is a butterfly that inhabits Northeastern Interior Pine Barrens and Northern Atlantic Coastal Plain Pitch Pine Barrens Habitats. Although it is restricted to a specialized habitat, this habitat is expected to respond favorably to climate change with increased drying, as well as increased incidence and intensity of fire.

The other two invertebrates are freshwater mussels inhabiting streams and rivers. The dwarf wedgemussel is a rare species, but like the brook floater of the same genus, was not found to be vulnerable to climate change due to larval dispersal capability (up to a kilometer) via its fish host.

Small whorled pogonia is an orchid of wide distribution but rare across its entire range. It inhabits second-growth deciduous and mixed deciduous-evergreen forests, and has been observed to respond favorably to small canopy openings (NatureServe Explorer 2013). This species generates tiny wind-dispersed seeds that usually land close to the parent, but can also travel several kilometers in rare long-distance dispersal events (Stone et al. 2012). Its dispersal capability and stability in physiological hydrologic and temperature factors contributed to its rating, as did its scoring of Neutral in most other factors.

Representative Species

Vulnerable throughout range in LCC

Eight representative species (identified with a superscript 3 in Table 3) were rated Vulnerable throughout their ranges in the LCC; five of these are also species of high conservation need and were discussed in the previous section: saltmarsh sparrow, American oystercatcher, piping plover, all inhabiting coastal regions, and spruce grouse and Bicknell's thrush, both inhabiting spruce-fir forests. The remaining three were all ranked Moderately Vulnerable in the subregions where they occur. Horseshoe crab (*Limulus polyphemus*), a coastal marine species that breeds on beaches of the Northern Atlantic Coastal Plain Tidal Salt Marsh habitat, was rated Moderately Vulnerable largely due to the effects of sea level rise on breeding habitat. Purple pitcher plant (*Sarracenia purpurea*) is a carnivorous plant restricted to acidic *Sphagnum* bogs in the Acadian Maritime Bog, Boreal-Laurentian Bog, and North-Central Interior and Appalachian Acidic Peatland Habitats. It was rated as Moderately Vulnerable in all three subregions, largely due to its dependence on specific habitat and poor dispersal capabilities. Seed dispersal averages were noted to be 5 cm from the parent plant (Ellison and Parker 2002). Atlantic salmon (*Salmo salar*) was rated Moderately Vulnerable in the two northern subregions where it occurs, largely due to physiological thermal niche (Elliott and Elliott 2010) and documented response to climate change (Beaugrand and Reid 2003).

Vulnerable in part of range in LCC

Seven representative species were found to be vulnerable in part of the LCC. These include three species of high regional concern (American bittern, common tern, and brook trout), as well as two additional birds (northern waterthrush [*Parkesia noveboracensis*] and ovenbird [*Seiurus aurocapilla*]), an invertebrate (bog elfin [*Callophrys lanoraieensis*]) and one reptile (diamond-backed terrapin [*Malaclemys terrapin*]). Northern waterthrush is at the southern edge of its range in the Mid-Atlantic subregion, where the modeled response resulted in probable loss from this region by mid-century (Matthews et al. 2007–ongoing). The diamond-backed terrapin breeds on coastal and estuarine beaches and was rated Moderately Vulnerable in the Mid-Atlantic subregion due to the impacts of sea level rise on breeding habitat, with accompanying hardening of shorelines as a human response to rising sea levels. The dispersal capability of this turtle will allow it to avoid these areas, but could result in lower population densities in the Mid-Atlantic.

Presumed Stable or Increase Likely in LCC

Seventeen representative species were rated as Presumed Stable in the LCC region; these include four species of high regional concern: least bittern, dwarf wedgemussel, spotted turtle, and wood turtle. The remaining thirteen species include six birds (American black duck [*Anas rubripes*], marsh wren [*Cistothorus palustris*], wood thrush [*Hylocichla mustelina*], Louisiana waterthrush [*Parkesia motacilla*], blackpoll warbler [*Setophaga striata*], and red-shouldered hawk [*Buteo lineatus*]), two mammals (eastern red bat [*Lasiurus borealis*], American water shrew [*Sorex palustris*]), one fish (American shad [*Alosa sapidissima*]), two invertebrates (southern pygmy clubtail [*Lanthus vernalis*]and incurvate emerald [*Somatochlora incurvata*]), one reptile (northern pinesnake [*Pituophis melanoleucus melanoleucus]*), and one amphibian (wood frog [*Lithobates sylvaticus*]). Five of the birds ranked Presumed Stable in all subregions of occurrence, and one (red-shouldered hawk) ranked Increase Likely. Dispersal capability largely accounted for low vulnerability, and the red-shouldered hawk also had a modeled response indicating expansion into the entire LCC region (Matthews et al. 2007–ongoing).

American shad, southern pygmy clubtail, incurvate emerald, and eastern red bat ranked as Presumed Stable throughout the LCC region, mostly due to their dispersal capabilities. The remaining species, American water shrew, northern pinesnake, and wood frog, were ranked as Presumed Stable throughout their ranges in the LCC largely because they lacked significant vulnerabilities in any of the factors assessed, and are generalists in habitat. American water shrew occupies a variety of wetland and aquatic habitats but its dispersal capabilities are not well studied (NatureServe Explorer 2013). The northern pinesnake occupies dry to xeric open pine habitats in the Northern Atlantic Coastal Plain Pitch Pine Barrens and is at the northern range limit in the LCC; the mapped range is southern New Jersey and extreme southeastern New York, the latter likely as a result of an introduction (NatureServe Explorer 2013). Wood frog occupies a variety of wetland habitats and can migrate several hundred meters in upland forests between breeding pools.

Discussion

The species we found to be vulnerable to climate change were in large part either coastal species affected by sea level rise and/or increased storm severity (nine species) or species of specialized or restricted habitat such as montane habitats in New England and the Adirondacks. In addition, species occurring at the edge of their ranges, especially southern range limit, were sometimes found to be vulnerable in portions of the North Atlantic LCC. Five bird species we found to be vulnerable are limited to the sea coast, where dispersal ability is of little help along an entire coastline facing greater inundation.

Rodenhouse et al. (2009) noted that species of northeastern forests that are most impacted by the least amount of climate change are those that are restricted to specific habitats or disturbance regimes. In the North Atlantic LCC, seven species not already accounted for in coastal habitats are confined to high elevation or cool climate (red spruce, balsam fir, spruce grouse), and four are restricted to isolated wetlands (black spruce, pitcher plant, barbed-bristle bulrush, and Hessel's hairstreak). In this region, black spruce is confined almost entirely to bogs and swamps, and purple pitcher plant is confined entirely to bogs. Hessel's hairstreak is limited to subset of Atlantic white cedar swamps, so its range is considerably smaller than that of Atlantic white cedar.

In some cases, the CCVI yielded results that should be taken with more caution because of factors not explicitly included in the analysis. For example, birds are often not found to be vulnerable to climate change due to their dispersal abilities. However, the CCVI assesses migratory species only within the study area, so vulnerabilities may be higher than reported because of potential climate change impacts throughout their ranges. Small-Lorenz et al. (2013) discuss this "blind spot" in many CCVAs that also focus only on a portion of the migratory range.

Another example is that our climate data does not fully account for local seasonal trends in hydrology, and the threats to species dependent on habitats with fluctuating water levels may be scored too low as a result. Barbed-bristle bulrush occurs in isolated, seasonally flooded basins, including some vernal pool habitats. Lentz and Dunson (1999) found that ponds supporting barbed-bristle bulrush were characterized by greater size, higher organic soil content, lower water level, and lower tree canopy cover than nearby ponds where this species was absent, suggesting that this species may have more exacting environmental requirements than the universe of vernal pool habitats. Surface versus subsurface water inputs were noted to be significantly negatively related to percent change in population area during dry years and showed positive trends during wet years (Lentz-Cippolini and Dunson 2006). It was rated as Moderately Vulnerable in the Mid-Atlantic subregion and Presumably Stable in the other two subregions. Other species sensitive to seasonal hydrological changes, especially during breeding, include Jefferson's salamander and wood frog. Both species were scored as Presumed Stable in all three subregions.

Flooding regimes in streams and rivers may change dramatically as a result of a potential change in precipitation patterns. Although the dwarf wedge mussel was scored as Presumed Stable throughout the LCC, this score does not account for extremes in precipitation patterns that may cause increased flooding intensity. Increased scour and sedimentation could impact the clear water and riffle patterns required by this species.

In some cases, interactions among factors complicate the results of the CCVI. Two examples include eastern hemlock and moose. Eastern hemlock has experienced significant loss due to the decimating effects of woolly adelgid (*Adelges tsugae*) in the east, particularly where warm temperatures accelerate insect feeding and dispersal (Dukes et al. 2009). Although it rated as Presumed Stable in the Northern Appalachian / Maritime Canada and North Atlantic Coast subregions, increasing temperatures will likely remove limits of woolly adelgid invasion in significant portions of this species' range (Paradis et al. 2008), likely causing higher vulnerability than that reported by the CCVI.[2]

A look at the individual factor rankings in the CCVI for moose reveals a potential vulnerability that warrants further consideration. Interspecific interactions for moose were rated as Slightly Increase – Increase impact on climate sensitivity in the CCVI, but most other factors were rated as having either Neutral or Decreased impact on climate sensitivity, resulting in an overall rank of Presumed Stable. This was the same rank derived by Schlesinger et al. (2011) in New York. However, Rodenhouse et al. (2009) note that heat intolerance at their southern range limit, as well as host-parasite relationships, may have a significant impact on large mammals facing climate change. They note that lesser snow accumulation may foster a greater overlap between the ranges of moose and white-tailed deer, the latter of which is currently limited in the north by deep snow. This range overlap could result in increased exposure of moose to the meningeal parasite *Paralaphostrongylus tenuis*, which causes paralysis and death in moose but has no effect on deer. Rodenhouse et al. (2009) also note that winter tick (*Dermacentor albipictus*) is limited by heavy snow and cold temperatures, but milder temperatures and less snow accumulation could increase winter tick infestation and contribute to moose die-off.

Foundation Species

What are the ramifications of climate change vulnerability of foundation species? Sudden loss of a major forest canopy dominant, as might happen from pathogens or pests favored by warming climate, would presumably cause substantial change to habitat composition and

[2] A subsequent release of the CCVI addresses these issues in part

structure with innumerable ripple effects throughout the ecosystem. Death of overstory trees would expose the understory plant species, and the fauna dependent on them, to significantly more sun, causing temperature increases and drying of the forest floor with the associated changes to soil organic content and moisture. Greater sun exposure of shade-requiring understory species could cause their stress or death, allowing significant inroads to be made by tolerant invasive species. In addition to providing shade and structure, many canopy species such as red spruce and balsam fir are significant food sources for both herbivores (insects) and higher consumers, such as insectivorous warblers and woodpeckers.

Even gradual loss of canopy trees and dispersal of other canopy trees into openings, or emergence of shade-tolerant species into the canopy can also cause significant change. Primarily coniferous forest may transition to a mixed composition of deciduous trees, or completely, to deciduous forest, causing differences in light availability to the forest floor as well as associated changes in soil pH and nutrient availability (Reich et al. 2005). We already see evidence of this change; climate change-induced decrease of red spruce has been surmised through time-series observations of radial growth (McLaughlin et al. 1987), and an upward elevational movement of northern hardwood forests in the Green Mountains of Vermont (Beckage et al. 2008).

How do we predict the impacts of changing environmental conditions on foundation species that are not expected to be vulnerable to climate change? One cannot infer by extension that associated species are therefore not vulnerable. For example, leatherleaf is not expected to be vulnerable to climate change in the Northern Appalachian/Maritime Canada subregion, yet purple pitcher plant and black spruce, usually growing in close association with leatherleaf in bogs, were both ranked Moderately Vulnerable in this subregion. Purple pitcher plant has a very limited dispersal capability, and black spruce is dependent on cooler climates. Even if the bog mat persists with leatherleaf intact, these two species are likely to be heavily impacted by climate change, and the habitat will change as a result. Another example is Hessel's hairstreak, a species ranked Highly Vulnerable or Extremely Vulnerable throughout its range in the LCC. This species is restricted to swamps dominated by Atlantic white cedar, which was ranked Moderately Vulnerable in one subregion and Presumed Stable in the other two. Atlantic white cedar has a wider range, and presumably tolerates a somewhat broader range of environmental conditions than does Hessel's hairstreak, since this species is absent from many Atlantic white cedar swamps, especially north of New Jersey. So although Atlantic white cedar may persist as a foundation species, it does not guarantee the persistence of species dependent upon it.

Long-lived foundation species that are not vulnerable to climate change may provide suitable habitat for other species shifting northward as climate warms. Many foundation tree species have very broad ranges, tolerate a broad range of environmental conditions, and are associated with different understory species across the range of the tree. For example, black gum is a dominant part of a group of at least six more locally-defined acidic swamp types also characterized by red maple, ranging from Maine to Virginia. The northernmost of these associations[3] is characterized by the presence of red spruce, black spruce, mountain holly (*Nemopanthus mucronata*), and goldthread (*Coptis trifolia*). From New Jersey south to Virginia, another association of this alliance is characterized by southern associates such as sweetbay (*Magnolia virginiana*), loblolly pine, and swamp pink (*Hellonius bullata*), and the absence of northern species. Another alliance characterized by black gum occurs in the Ozarks, well outside the North Atlantic LCC region. Here, other species not typical of the LCC region are common species of the associations in this alliance, including lizardtail (*Saururus cernuus*), holly (*Ilex opaca*), and persimmon (*Diospyros virginiana*). In all cases, environmental conditions exclusive of temperature are similar: groundwater seepage causing saturated hydrology, often in isolated basin wetlands, acidic to circumneutral in pH, with accumulations of peat. It is conceivable that the same environmental conditions would be preserved by black gum and red maple in more northerly regions by providing shade that could ameliorate adverse climate effects on local microclimates. These environments would then be available for colonization by species of similar habitats moving from the south, particularly those that are not limited by dispersal capabilities. Conservation of northern examples of habitats dominated by long-lived foundation species may prove to be especially important over time as conditions for southern species decline with climate change.

Species of High Regional Concern

Species of high regional concern are classified as such in large part because they face a number of threats and are vulnerable to decline as a result. In many cases, we can assume that declines independent of climate change will be exacerbated by warming and drying, as well as increased storm intensity. The coastal species assessed in this study already face threats imposed by human activity. For example, the saltmarsh sparrow is threatened by continued draining and filling of salt marshes for development. The other six coastal species are all dependent on beach and mudflat habitats. Eastern beach tiger beetle is currently impacted by off-road vehicle traffic on dunes, and American oystercatcher, piping plover, least tern, and common tern are also affected by off-road vehicle traffic, as well as predation by domestic cats and dogs, raccoons, foxes, opossums, gulls, and other native predators whose populations are increasing as a result of human activity. For example, the coyote *(Canis latrans)* population has greatly increased and expanded into the northeast as a result of extermination of the wolf (NatureServe Explorer

[3] This variation is often reflected in the National Vegetation Classification (NVC) (Vegetation Subcommittee, FGDC 2008). The basic unit of the NVC, the association, comprises the NVC alliances that generally range more broadly geographically.

2013). U.S. Fish and Wildlife staff at Monomoy National Wildlife Refuge reported that the stomach contents of a coyote killed on this coastal island was found to include over 60 tern chicks (U.S. Fish and Wildlife Service, 2011b, personal communication). Additional loss of habitat due to sea level rise, as well as outright mortality due to the increased severity of coastal storms, will almost certainly negatively impact these already vulnerable species.

Still, a surprising number of species of high regional concern (14 of 27) or having high conservation status ranks (G1 to G3 using NatureServe's ranking system) were ranked Presumed Stable or Increase Likely. Northern goshawk, moose, and cerulean warbler all ranked Increase Likely in at least one subregion. In general, wide-ranging species of high dispersal capability and a tolerance for habitat diversity have the potential to adapt to climate change by relocating or dispersing to suitable habitat within the assessment area[4]. This includes most birds, many marine fishes and turtles, and a number of Lepidoptera. From our list, these include least bittern, Atlantic sturgeon, and frosted elfin in addition to the three species already mentioned. Other species include dwarf wedgemussel, brook floater, least weasel, spotted turtle, wood turtle, Jefferson salamander, and small whorled pogonia. Two of these species are federally listed, one endangered and one as threatened; a third is a candidate. Dwarf wedgemussel is globally rare, ranked G1G2 and is currently reduced to a few occurrences of good viability (NatureServe Explorer 2013). Major threats to this species are impoundments and dams, as well as water quality declines by a wide array of agricultural and domestic pollutants. Small whorled pogonia is ranked G3, federally listed as threatened. It faces habitat destruction for residential or commercial development, logging, recreational activities, and herbivory by an ever increasing deer population (NatureServe Explorer 2013). New England cottontail is ranked G3 and is threatened by loss of early successional habitat as a result of maturing forests, and change in forest understory composition by deer herbivory. Yet climate change *per se* is not expected to add significantly to the numerous immediate threats facing any of these regionally rare species.

Although species that have high dispersal capabilities are generally thought of as having relatively higher adaptive capacity in response to climate change, it should be noted that this assessment does not necessarily imply that their adaptive capacity will ensure survival in their new locations.

Representative Species

This category of species performs "double duty" in a manner similar to that of foundation species in that, in theory, the results may be extrapolated to a larger number of species with similar habitat requirements. Unlike foundation species, however, representative species are

[4] Note that this rating applies only to the assessment area in question. In cases when the species is predicted to leave the assessment area entirely, the results cannot be applied to these areas outside the assessment area.

not necessarily dominant, but rather, share similarities to other species in their ecological or life cycle requirements (U.S. Fish and Wildlife Service 2012). The representative species concept was developed in the North Atlantic LCC to aid conservation planning, with the assumption that conservation of representative species will also conserve other species not explicitly planned for (North Atlantic LCC 2012). Although this concept was not designed explicitly for application to climate change vulnerability analyses, we examined our results for similarities as well as differences in ratings to evaluate whether representative species that we rated as vulnerable may be thought of as potential indicators of the vulnerability of the represented species sharing similar habitats in the subregion.

We compared our results for representative species against those of species indicated by the North Atlantic LCC to be represented by them in similar habitats (Table 4) and found them to be largely consistent. All six species associated with floodplains were rated either Presumed Stable or Increase Likely for both representative and represented species, and those of hardwood forests were consistent in all but one instance. In the case of salt marsh species, the representative species (saltmarsh sparrow) was rated Moderately Vulnerable in the North Atlantic and Highly Vulnerable in the Mid-Atlantic, whereas the common tern was rated as Presumed Stable in the North Atlantic and Moderately Vulnerable in the Mid-Atlantic.

The results of species of sandy beach and mudflat habitats were inconsistent. Two representative species, piping plover and least tern, were rated Moderately Vulnerable, as was the represented species eastern beach tiger beetle. However, the representative species American black duck was rated Presumed Stable in all three subregions.

What conclusions can we draw from these comparisons? We urge caution in assuming that non-vulnerable representative species imply that those represented by them are also not vulnerable to climate change, and it is difficult to determine what actions to take when there are disparities between the vulnerability ratings of representative species within the same habitats. However, we agree with the premise that conservation actions taken to protect representative species will likely benefit other species with similar habitat requirements even if not targeted specifically, and that this may hold true for species vulnerable to climate change as well.

Table 4. Comparison of CCVI results for representative species and those they represent by broad habitat type. Results are listed in subregion order: Northern Appalachian / Maritime Canada, North Atlantic, Mid-Atlantic**.** Species not occurring in a subregion are indicated by "—". Passage migrant only indicated by *. Remaining codes are as follows: EV = Extremely Vulnerable; HV = Highly Vulnerable, MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

Representative species	CCVI result	Represented species	CCVI result
Hardwood forests			
Louisiana waterthrush	PS, PS, PS	Cerulean warbler	—, PS, IL
Ovenbird	PS, PS, MV	Jefferson salamander	PS, PS, PS
Wood thrush	PS, PS, PS	Northern goshawk	IL, IL, PS
Eastern red bat	PS, PS, PS	Red-shouldered hawk	IL, IL, IL
		Small whorled pogonia	PS, PS, PS
Salt marshes			
Salt marsh sparrow	MV, HV, —	Common tern	PS, PS, MV
		Least tern	—, MV, MV
Sandy beaches / mudflats			
Piping plover	MV, MV, MV	Eastern beach tiger beetle	—, HV, MV
American black duck	PS, PS, PS		
Least tern	—, MV, MV		
Floodplain Forests			
Eastern red bat	PS, PS, PS	Cerulean warbler	—, PS, IL
Louisiana waterthrush	PS, PS, PS	Jefferson salamander	PS, PS, PS
		Red-shouldered hawk	IL, IL, IL
		Wood turtle	PS, PS, PS

Results compared to other related studies

We compared our results to other climate change vulnerability assessments completed in the northeast, including habitat assessments (Manomet Center for Conservation Sciences and the National Wildlife Federation 2013a, 2013b, and 2014, subsequently referred to as MCCS) as well as species assessments (Furedi et al. 2011; Schlesinger et al. 2011, Virginia Department of Natural Heritage 2010).

Comparison to habitat studies

Our goal in comparing our species assessment results with those of associated habitat assessments is to test our results and to identify apparent inconsistencies. Our rating of Presumed Stable for a species that is closely tied with a particular habitat judged to be Vulnerable suggests a possible inconsistency in rating that should be explored further. None of the species that we assessed are entirely restricted to a single habitat, so we do not expect complete agreement between ratings of species and ratings of their habitats. A species rated as Vulnerable may be rendered so by limited dispersal, barriers, or other factors, even though it depends on a Least Vulnerable habitat. Conversely, a habitat rated as Vulnerable, supporting a species assessed as Presumed Stable, does not necessarily imply that either result is incorrect; the species may inhabit a number of other more stable habitats.

The ratings and geographic areas of assessment used in both methods are comparable, but not entirely coincident. Both methods employ five rating categories, the definitions of which are provided in Table 5.

Table 5. Comparison of climate change vulnerability ratings between Manomet Center for Conservation Sciences and the National Wildlife Federation 2013a and 2013b (MCCS), and NatureServe Climate Change Vulnerability Index (CCVI).

MCCS		CCVI	
Rating	Definition	Rating	Definition
Critically Vulnerable	Likely to be eliminated	Extremely Vulnerable	Abundance and/or range extent extremely likely to substantially decrease or disappear by 2050.
Highly Vulnerable	Likely to be reduced	Highly Vulnerable	Abundance and/or range extent likely to decrease significantly by 2050
Vulnerable	Likely to be relatively unaffected	Moderately Vulnerable	Abundance and/or range extent likely to decrease by 2050
Less Vulnerable	Likely to extend range	Presumed Stable	Available evidence does not suggest that abundance and/or range will increase or decrease substantially by 2050
Least Vulnerable	Likely to greatly extend range	Increase Likely	Available evidence suggests that abundance and/or range extent is likely to increase by 2050

The latitudes of our subregions of assessment are also largely comparable to the latitudinal zones of assessment used by MCCS (Figure 5). Our North Atlantic Coast subregion is similar in latitude to MCCS Zone II, and our Mid-Atlantic Coast subregion extends from MCCS Zone III to part of Zone IV. Our Northern Appalachians and Maritime Canada subregion southern boundary is roughly equivalent in latitude to that of MCCS Zone I. The geography of the assessment areas is different, however. MCCS latitudinal zones II, III and IV extend to the western boundaries of New York, Pennsylvania, West Virginia, Maryland, and Virginia, whereas our comparable subregions are restricted to the coastal region. Another major difference is the inclusion of the Gaspé Peninsula and Maritime Canada in our northernmost subregion of assessment.

Figure 5. Assessment subregions (left) compared to Latitudinal zones of MCCS 2012 (right).

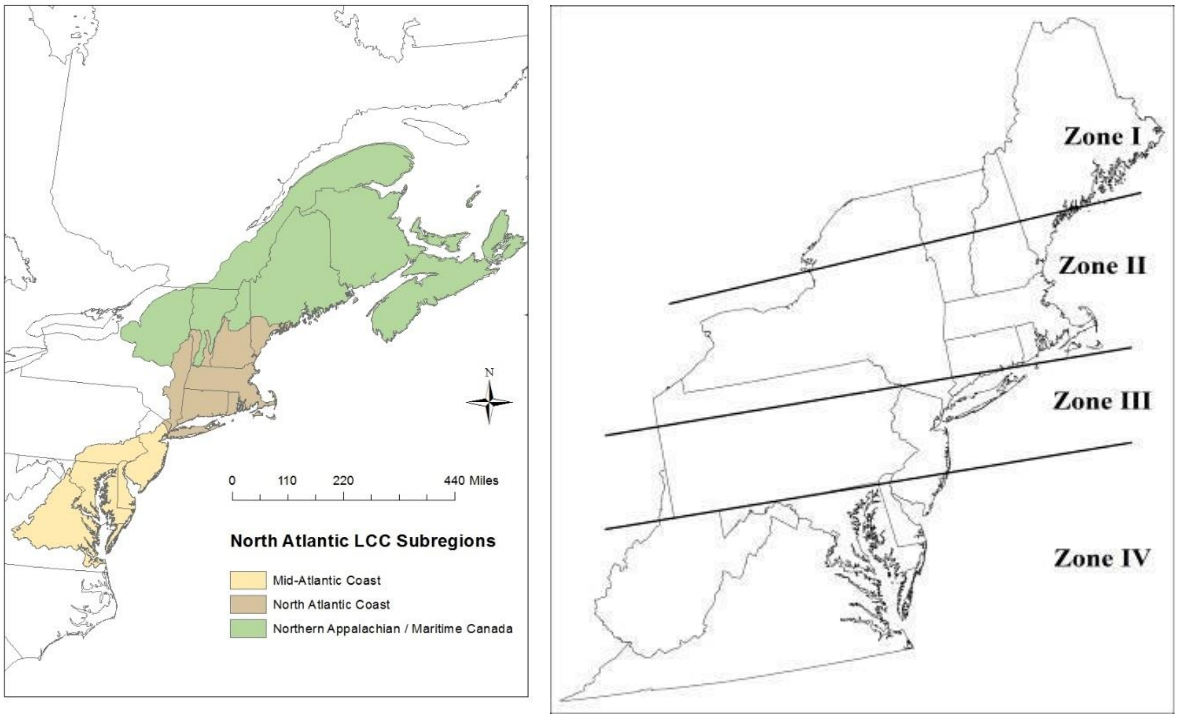

Table 6 illustrates the comparison of our species results for two habitats. Acadian – Appalachian Montane Spruce-Fir Forest was assessed to be Vulnerable or Highly Vulnerable by MCCS (2012a). Several species closely tied to this habitat were also found to be Moderately or Highly Vulnerable by the CCVI, as expected, including balsam fir, red spruce, Bicknell's thrush, and spruce grouse. However, two species (moose and blackpoll warbler) that are essentially limited to this habitat in the North Atlantic LCC region were assessed to be Presumed Stable or Increase Likely. In the Northern Appalachian/Maritime Canada subregion, the species assessment area extends farther north than did the habitat assessment. The greater area of projected cooler climate assessed for these species also likely influenced the results in that subregion. Also, both species are highly mobile and can likely move to more suitable areas as climate warms.

Northern Hardwood Forest was rated as Vulnerable in the North Atlantic Coast subregion, and Vulnerable / Highly Vulnerable in the Mid-Atlantic Coast by MCCS (2012a). We assessed a number of species associated with this habitat, only one of which resulted in Moderately Vulnerable rank (eastern hemlock) in these two subregions. The other species (sugar maple, small whorled pogonia, northern goshawk, ovenbird, and Jefferson salamander) were assessed as Presumed Stable or Increase Likely (ovenbird was assessed as Moderately Vulnerable in the Mid-Atlantic Coast subregion). Sugar maple and small whorled pogonia are not confined entirely to this habitat, and both are wind-dispersed, so these results are not necessarily contradictory. Northern goshawk and ovenbird are also good dispersers. Jefferson salamander, however, was assessed as Presumed Stable in our study, but as Highly Vulnerable by Furedi et al. (2011) in Pennsylvania. One factor that contributes to this discrepancy is the geography of the assessment areas. The interior of Pennsylvania is projected to experience relatively greater temperature increases than the coastal region, so exposure calculations are different. However, differing sensitivity scores, which presumably do not change within this geography, also contribute to the difference in the overall score. Several factors were scored Increase or Slightly Increase in vulnerability by Furedi et al. (2011) where they were scored Neutral in our study. These factors would not have significant impact individually, but in aggregate, and in combination with the exposure score, did produce two different results.

Table 6. Comparison of vulnerability ratings for individual species in this assessment to the vulnerability rating for their associated habitats. Also included are ratings from three state-level species assessments. Values in the rows for each species correspond to the CCVI rating (this product). Species not occurring in a subregion are indicated by "—". EV = Extremely Vulnerable; HV = Highly Vulnerable, MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

		Northern Appalachians and Maritime Canada (Zone 1)	North Atlantic Coast (Zone II)	Mid-Atlantic Coast (Zones III and IV)	PA[2]	NY[3]	VA[4]
Acadian-Appalachian Montane Spruce-Fir Forest[1]		**Vulnerable**	**Highly Vulnerable**	**N/A**			
Balsam fir	*Abies balsamea*	MV	HV	—	EV	—	—
Red spruce	*Picea rubens*	MV	MV	—	EV	—	—
Bicknell's thrush	*Catharus bicknelli*	MV	HV	—	—	MV	—
Blackpoll warbler	*Setophaga striata*	PS	PS	—	—	—	—
Spruce grouse	*Falcipennis canadensis*	MV	MV	—	—	—	—
Moose	*Alces americanus*	IL	PS	—	—	PS	—
Northern Hardwood Forest[1]		**Less Vulnerable**	**Vulnerable**	**Vulnerable /Highly Vulnerable**			
Sugar maple	*Acer saccharum*	IL	PS	PS	—	—	—
Eastern hemlock	*Tsuga canadensis*	PS	MV	MV	—	—	—
Small whorled pogonia	*Isotria medeoloides*	PS	PS	PS	—	—	—
Northern goshawk	*Accipiter gentilis*	IL	IL	PS	—	—	—
Ovenbird	*Seiurus aurocapilla*	PS	PS	MV	—	—	—
Jefferson salamander	*Ambystoma jeffersonianum*	PS	PS	PS	HV	—	—

[1]Manomet Center for Conservation Sciences and the National Wildlife Federation 2013a
[2]Furedi et al. 2011
[3]Schlesinger et al. 2011
[4]Virginia Division of Natural Heritage 2010

Our results for species associated with Mixed Oak – Pine Forest, Pine Barrens, and Coastal Plain Basin Peat Swamp are illustrated in Table 7. Our results between species assessments (white oak, white pine, and wood thrush) and MCCS (2012a) habitat assessment (Mixed Oak – Pine Forest) are in agreement. The tree species are wide-ranging, common, and have broad ecological tolerances, so their rating of Presumed Stable in this wide-ranging habitat is not surprising. Wood thrush is tied more strongly to this habitat, and its ranking of Moderately Vulnerable in the Mid-Atlantic Coast subregion is also consistent with the Vulnerable / Least Vulnerable result for this habitat in the same region.

Results for species associated with Pine Barrens (pitch pine, frosted elfin, northern pinesnake, and eastern red bat) were also consistent: all species were found to be Presumed Stable in all subregions where they occur, and the habitat was also found to be Least Vulnerable or Vulnerable/ Least Vulnerable across the northeast. White oak also occurs in this habitat in the North Atlantic and Mid-Atlantic, and white pine occurs in this habitat in the Northern Appalachian / Maritime Canada subregion, results that are also consistent.

We assessed four species associated with Coastal Plain Basin Peat Swamp: Atlantic white cedar, black gum, Hessel's hairstreak, and northern waterthrush. Note that MCCS (2012a) Latitudinal Zone I ranges slightly more northward and beyond the range of Atlantic white cedar, whereas our Northern Appalachian / Maritime Canada subregion includes the northern range limit of this species. MCCS (2012a) confined their assessment to Zones II-IV, where it resulted in ratings of Less Vulnerable. We achieved ratings of Presumed Stable for black gum in all three subregions, and for Atlantic white cedar and northern waterthrush in all but the Mid-Atlantic subregion, where we rated them as Moderately Vulnerable. The rating of Moderately Vulnerable for northern waterthrush in the Mid-Atlantic subregion is influenced by its modeled response, resulting in a score of Greatly Increased vulnerability in that subregion. The rating of Moderately Vulnerable for Atlantic white cedar in the Mid-Atlantic is based largely on potential exposure to increased drying, as scored by the Hamon moisture metric, and on historical hydrological niche. This may be a somewhat spurious result, as Atlantic white cedar is an extremely wide-ranging species, occurring as far south as Florida. We should not expect this degree of difference in tolerance to drying within the relatively small range of the North Atlantic LCC.

Hessel's hairstreak was rated Extremely Vulnerable in the Northern Appalachian / Maritime Canada subregion, and Highly Vulnerable in the other two subregions. The larval stage of this species feeds only on new growth of Atlantic white cedar, so its high dependency on a single species contributed to its vulnerability, as did the calculations of exposure to drying.

Table 7. Comparison of vulnerability ratings for individual species in this assessment to the vulnerability rating for their associated habitats. Also included are ratings from three state-level species assessments. Values in the rows for each species correspond to the CCVI rating (this product). Species not occurring in a subregion are indicated by "—". EV = Extremely Vulnerable; HV = Highly Vulnerable, MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

		Northern Appalachians and Maritime Canada (Zone 1)	North Atlantic Coast (Zone II)	Mid-Atlantic Coast (Zones III and IV)	PA[2]	NY[3]	VA[4]
Mixed Oak-Pine Forest[1]		**Least Vulnerable**	**Least Vulnerable**	**Vulnerable / Least Vulnerable**			
White oak	*Quercus alba*	PS	PS	PS	—	—	—
White pine	*Pinus strobus*	PS	PS	MV	—	—	—
Wood thrush	*Hylocichla mustelina*	PS	PS	PS	IL	—	—
Pine Barrens[1]		**Least Vulnerable**	**Least Vulnerable**	**Vulnerable / Least Vulnerable**			
Pitch pine	*Pinus rigida*	PS	PS	PS	—	—	—
Frosted elfin	*Callophrys irus*	PS	PS	PS	PS	EV	—
Northern pinesnake	*Pituophis melanoleucus melanoleucus*	—	PS	PS	—	—	—
Eastern red bat	*Lasiurus borealis*	PS	PS	PS	—	—	—
Coastal Plain Basin Peat Swamp[1]		**N/A**	**Less Vulnerable**	**Less Vulnerable**			
Atlantic white cedar	*Chamaecyparis thyoides*	PS	PS	MV	—	—	—
Black gum	*Nyssa sylvatica*	PS	PS	PS	—	—	—
Hessel's hairstreak	*Callophrys hesseli*	EV	HV	HV	—	—	—
Northern waterthrush	*Parkesia noveboracensis*	PS	PS	MV	—	—	—

[1]Manomet Center for Conservation Sciences and the National Wildlife Federation 2013a
[2]Furedi et al. 2011
[3]Schlesinger et al. 2011
[4]Virginia Division of Natural Heritage 2010

Table 8 illustrates comparisons of our species assessments with Boreal-Laurentian Bog and Acidic Fen, and to Cold-water Fish Habitat. We assessed six species associated with Boreal – Laurentian Bog and Acidic Fen, which was assessed as Highly Vulnerable by MCCS (2012a). In the North Atlantic subregion, our results were consistent for all five species that occur there. We rated black spruce, purple pitcher plant, leatherleaf, bog elfin, and northern white cedar as Moderately to Highly Vulnerable. Black spruce was rated as Highly Vulnerable and leatherleaf as Moderately Vulnerable in Pennsylvania by Furedi et al. (2011). We rated three species (bog elfin, leatherleaf, and incurvate emerald) as Presumed Stable in the Northern Appalachian / Maritime Canada subregion, although this was also rated as highly vulnerable habitat by MCCS (2012a).

Our ratings for brook trout were also consistent with associated Cold-water Fish Habitat (MCCS 2012b). We rated this species Presumed Stable in the northernmost subregion, and Moderately Vulnerable in the North Atlantic Coast subregion, compared to a rating of Vulnerable by MCCS. However, this species was rated as Highly Vulnerable by Schlesinger et al. 2011 in New York. A review of individual factor scores revealed a large difference in temperature exposure (80% of NY population exposed to the highest predicted temperature increases of 5.1 degrees, contrasted to our calculation of 11% of populations with this exposure), which reflects the ameliorating effects of coastal climates as opposed to the interior. Other factors included a Greatly Increased – Increased vulnerability in physiological thermal niche, as opposed to our score of Slightly Increased. MCCS (2012b) notes that recent studies by Trumbo (2010) suggest that the relationship of air temperature to water temperatures is more complex than initially assumed. They note that cold-water habitats may be better buffered by cooler ground-water inputs and shading than was previously thought.

Table 8. Comparison of vulnerability ratings for individual species in this assessment to the vulnerability rating for their associated habitats. Also included are ratings from three state-level species assessments. Values in the rows for each species correspond to the CCVI rating (this product). Species not occurring in a subregion are indicated by "—". EV = Extremely Vulnerable; HV = Highly Vulnerable, MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

		Northern Appalachians and Maritime Canada (Zone 1)	North Atlantic Coast (Zone II)	Mid-Atlantic Coast (Zones III and IV)	PA[3]	NY[4]	VA[5]
Boreal – Laurentian Bog and Acidic Fen[1]		**Highly Vulnerable**	**Highly Vulnerable**	**N/A**			
Black spruce	*Picea mariana*	MV	HV	—	HV	—	—
Purple pitcher plant	*Sarracenia purpurea*	MV	MV	—	—	—	—
Northern white cedar	*Thuja occidentalis*	MV	MV	—	—	—	—
Bog elfin	*Callophrys lanoraieensis*	PS	MV	—	—	—	—
Leatherleaf	*Chamaedaphne calyculata*	PS	MV	—	MV	—	—
Incurvate emerald	*Somatochlora incurvata*	PS	—	—	—	—	—
Cold-Water Fish Habitat[2]		**Vulnerable**	**Vulnerable**	**Vulnerable**			
Brook trout	*Salvelinus fontinalis*	PS	MV	—	—	HV	—

[1]Manomet Center for Conservation Sciences and the National Wildlife Federation 2013a
[1]Manomet Center for Conservation Sciences and the National Wildlife Federation 2014
[3]Furedi et al. 2011
[4]Schlesinger et al. 2011
[5]Virginia Division of Natural Heritage 2010

Comparison to other species studies

Our last comparisons are to species vulnerability assessments conducted in three states, all using the same method: NatureServe Climate Change Vulnerability Assessment (Table 9). Our results for saltmarsh sparrow, piping plover, eastern hellbender, cerulean warbler, American oystercatcher, diamondback terrapin, and Louisiana waterthrush were consistent with the results of those species assessed by Schlesinger et al. (2011) and Furedi et al. (2011). Our results for wood turtle were also consistent with those studies, but our result of Presumed Stable was somewhat at variance with the result of Moderately Vulnerable by Virginia Division of Natural Heritage (2010). The southern range limit of this species is Virginia, however, so this difference is not surprising. Our result of Presumed Stable for New England cottontail also differed for the rating of Moderately Vulnerable given by Schlesinger et al. (2011). Climate exposure calculations are not significant between the two studies, so the disparity is in assignment of sensitivity factors. The degree of variance among these was not substantial, but slight variations in interpretation led to a difference of one rating level.

Table 9. Comparison of selected species results to those of other state-level species vulnerability studies in the region. Species not occurring in a subregion are indicated by "—". EV = Extremely Vulnerable; HV = Highly Vulnerable, MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

Common name	Scientific name	Northern Appalachians and Maritime Canada	North Atlantic Coast	Mid-Atlantic Coast	PA[1]	NY[2]	VA[3]
Atlantic sturgeon	*Acipenser oxyrinchus*	PS	PS	PS	—	EV	—
Dwarf wedgemussel	*Alasmidonta heterodon*	PS	PS	PS	EV	EV	—
Brook Floater	*Alasmidonta varicosa*	PS	PS	PS	—	EV	—
American Shad	*Alosa sapidissima*	PS	PS	PS	—	MV	—
Saltmarsh sparrow	*Ammodramus caudacutus*	—	MV	HV	—	MV	—
Piping Plover	*Charadrius melodus*	MV	MV	MV	—	MV	—
Eastern Hellbender	*Cryptobranchus alleganiensis*	—	—	MV	EV	EV	—
Cerulean warbler	*Setophaga cerulea*	—	PS	IL	PS	—	—
Wood Turtle	*Glyptemys insculpta*	PS	PS	PS	PS	IL	MV
American oystercatcher	*Haematopus palliatus*	—	MV	MV	—	MV	—
Diamondback terrapin	*Malaclemys terrapin*	—	PS	MV	—	MV	—
Louisiana waterthrush	*Seiurus motacilla*	PS	PS	PS	IL	—	—
New England cottontail	*Sylvilagus transitionalis*	PS	PS	—	—	MV	—

[1]Furedi et al. 2011
[2]Schlesinger et al. 2011
[3]Virginia Division of Natural Heritage 2010

The greatest divergence in ratings between our study and those conducted in New York and Pennsylvania was in four aquatic species (Tables 10 and 11). Our results for Atlantic sturgeon, American shad, dwarf wedgemussel, and brook floater were Presumed Stable in all three subregions. Schlesinger et al. (2011) rated American shad as Moderately Vulnerable, and the other three species received ratings of Extremely Vulnerable. Furedi et al. (2011) assigned a rating of Highly Vulnerable to dwarf wedgemussel, and did not rate the brook floater.

Table 10. Comparison of scores of individual climate sensitivity factors for Dwarf Wedgemussel and Brook Floater from three vulnerability assessments. Abbreviations represent the factor's effect on vulnerability: "Inc" – Increase, "SI" – Slight Increase, "GI" – Greatly Increase; "D" – Decrease, "SD" – Slight Decrease, "N" – Neutral.

	Dwarf Wedgemussel			Brook Floater	
Factor	**PA[1]**	**NY[2]**	**NatureServe**	**NY[2]**	**NatureServe**
Natural barriers	SI	N	N	N	N
Anthropogenic barriers	N	Inc-SI	SI	Inc-SI	SI
Climate change mitigation impacts	N	SI	SI	SI	SI
Dispersal / movement	SI	GI-Inc	N	GI-Inc	N
Physiological thermal niche	N	N-SD	N	N-SD	N
Historical hydrological niche	GI	SD	SI*	SD	SI
Physiological hydrological niche	N	GI-Inc	N	GI-Inc	N
Habitat specificity	N	Inc	N	Inc	N
Dependence on other species for dispersal	SI	Inc	SI	Inc	SI

[1]Furedi et al. 2011
[2]Schlesinger et al. 2011
*Scored N in the Northern Appalachian / Maritime Canada subregion

Temperature exposure differences among assessment areas partially explain the differences in ranking for the two mussel species, but differences in interpretation of individual sensitivity factors also contributed significantly to the differences. Schlesinger et al. (2011) scored dwarf wedge mussel as having Greatly Increased vulnerability due to both physiological hydrological niche and dispersal ability, but Furedi et al. (2011) scored the former as Neutral, and the latter as Slightly Increased. Our scores for both factors for both species were Neutral. Our justification of Neutral scoring for dispersal ability is the ability of larval mussels to readily disperse via fish hosts; we assume that the conservative scoring by Schlesinger et al. (2011) was based on the adult phase, which is much less able to disperse.

Furedi et al. (2011) scored historical hydrological niche as Greatly Increased in Pennsylvania, and Schlesinger et al. (2011) scored this factor as Slightly Decreased in New York. This is a value calculated on mapped climate data by GIS and does not depend on individual interpretation, so is a reflection of presumed differences in available moisture historically.

Our individual sensitivity scores of American shad and Atlantic sturgeon also varied significantly from those of Schlesinger et al. (2011), and unlike the situation for the two mollusks, exposure scores were not substantially different for these two anadromous fish species. Schlesinger et al.

(2011) scored Atlantic sturgeon as having Greatly Increased vulnerability in physiological thermal niche, sea level rise, and both anthropogenic and natural barriers; our scores for the same factors were Neutral (Table 11).

Table 11. Comparison of scores of individual climate sensitivity factors for American shad and Atlantic sturgeon from two vulnerability assessments.

Factor	American Shad NY[1]	American Shad NatureServe	Atlantic Sturgeon NY[1]	Atlantic Sturgeon NatureServe
Sea level rise	SI	N	GI	N
Natural barriers	SI-Inc	SI	GI	N
Anthropogenic barriers	Inc-SI	SI	GI-Inc	N
Reliance on other species for dispersal	Dec	Dec	Dec	N
Physiological hydrological niche	GI	N	GI	N
Disturbance	Inc-SI	N	Inc-SI	N
Habitat specificity	Inc	N	Inc	N

[1]Schlesinger et al. 2011

Sources of uncertainty

Uncertainty is inherent in many of the outcomes of this study. The CCVI ratings themselves imply uncertainty; for example, "presumed stable" as opposed to "not vulnerable". The term "vulnerability" also implies that there is cause for concern, but it is not an absolute prediction.

Two factors unrelated to sensitivity and exposure can impact the results produced by the CCVI. A minimum number of data fields must be completed in order to generate a result, but the varying amounts of available data used in the index can also impact the result. This effect can be seen in comparing the results of Bicknell's thrush and Blackpoll warbler, two bird species with similarly restricted breeding habitat within the Northern Appalachian/Maritime Canada subregion. Addition of significant results in modeled response to climate change information for Bicknell's thrush yielded a result of Moderately Vulnerable in its breeding range, compared to Presumed Stable without this information. No modeled response data were available for Blackpoll warbler, yielding a Presumed Stable rating in its breeding range within the assessment area. Substituting the same information yields a Moderately Vulnerable rating for Blackpoll warbler. However, we cannot assume that the modeled results would have been the same for both species.

Another factor that can impact the results of the CCVI is the variation in interpretation of existing data among researchers, as illustrated by comparisons of our results of several aquatic species to those of Schlesinger et al. (2011). Differences in interpretation among researchers may in some cases reflect true differences among assessment areas, and in other cases it is the natural result of assigning categorical scores to variable data. However, the major cause is likely the reflection of the true complexity inherent in attempting to predict the impacts of climate change. Where there are substantial differences in opinion, we recommend a conservative course of action and assume greater vulnerability unless or until additional research suggests otherwise.

Some uncertainty is simply the result of an unprecedented degree and rapidity of climate change, and our past trend data are sometimes too coarse to model the extreme complexities of climate processes and how they play out in ecosystems. Other sources of uncertainty, however, are the result of current data that are at a coarse scale but could be refined substantially with the proper resources. The climate and species range data we used were readily available, as was a necessity for this project. Other more precise climate and species distribution modeling data are available, but require analysis that was beyond the scope of this work.

The species range maps we used are often crude interpolations of incomplete distributional data. Mapping inaccuracies and lack of precision have direct effects on exposure calculations in the CCVI. In dealing with generalist species that are wide-ranging, a high degree of mapping precision is usually unnecessary. However, imprecision of range data can have a substantial effect on exposure estimations for species with narrow ecological tolerances and limited dispersal capacity, such as many amphibians and plants. More precise climate data and species distribution modeling data are becoming more widely available and may provide more robust analyses.

Discrepancies in species range data were evident in the bird and tree atlas data (Matthews et al. 2011; Prasad et al. 2007–ongoing) in comparison with published range maps developed for trees (Little 1971; Little 1977), and other species (NatureServe Explorer 2013). Bird atlas data of Matthews et al. (2011) are based on breeding bird survey data, and the tree atlas data of Prasad et al. (2007) are based on Forest Inventory and Analysis data, both of which are likely to be under-representations of actual ranges. Calculated physiological thermal niche for two species with similar habitat requirements, red spruce and balsam fir, resulted in a rating of Greatly Increase for balsam fir and Increase for red spruce. This discrepancy is likely an artifact of imprecision in range maps rather than reflection of reality. More precision in species' ranges can be gained through species distribution modeling, using the environmental characteristics of known locations to predict the location of potential habitat using GIS analyses (Hernandez et al. 2008). These modeling efforts produce approximations of area of occupancy, a much more precise reflection of where species actually occur. Range maps, on the other hand, are much coarser representations in that they are usually polygons encompassing the outer limits of known occurrence.

In the US, downscaled climate data are now available at much greater resolution than that of earlier climate models. The US portion of the North Atlantic LCC has current climate data available at a resolution of 4 km, whereas data resolution for the projected future is only 12 km (Girvetz et al. 2009). However, resolution of the climate data in Canadian portion of the LCC is considerably coarser, at 50 km. An even greater source of uncertainty in the exposure data is the varying predictions of the different Global Circulation Models that are available. We used an ensemble average, but actual climate change may track one particular GCM better than the average. Also, future emissions of greenhouse gases are unknown, but recent trends suggest they may be greater than contemplated in the medium (A1B) scenario adopted for this study.

Recent studies of polar sea ice have revealed a greater than anticipated rate of melting. Thus, predictions of sea level rise have been amended in recent years, a revision upwards from the 10cm to 60 cm of earlier days to 60 cm to 160 cm (Jevrejeva et al. 2010), and others upwards of 190 cm (Vermeer et al. 2009) by 2100. SLAMM (Sea Level Affecting Marshes Model) has predicted a decrease in salt marsh habitat over all when using 1 m and 2 m scenarios, but salt marsh models are widely variable, depending on the site (Glick et al. 2009). Where marshes are predicted to increase, researchers usually assume that marsh accretion can keep pace with the rate of sea level rise. Morris et al. (2002) noted that, in the southeastern U.S., salt marshes experiencing high sediment loads and moderate tidal ranges could tolerate up to 1.2 cm/year rise in sea level. However, Donnelly and Bertness (2001) predicted that an increase of 0.6 cm/year is likely to result in drowning of salt marshes in the northeast, where sediment loads are lower.

Other factors to consider

Utility of the Climate Change Vulnerability Index

Some individual factors for species ranked "presumed stable" were noted to increase vulnerability. These species may still face threats from climate change, but the threats did not reach the calculated threshold that indicated vulnerability to climate change over all. Species that are limited, but not completely restricted in dispersal capability, or are experiencing greater than average temperature or hydrological fluctuations than they have historically, may still be ranked Presumed Stable. For example, aquatic species or species dependent on river habitats may have very good dispersal capability, but the general south-trending direction of riverine flow in the northeast may work against some aquatic species' reaching cooler climates to the north as a result of having to disperse against the current. Monitoring of a subset of species ranked initially as Presumed Stable would allow for detection of trends toward vulnerability.

One factor not explicitly addressed in the CCVI is shifts in phenology. Earlier spring arrival of migratory passerines can result in a phenological mismatches between the birds and the availability of food sources (for example, Ozelski 2015; Thomas et al. 2001). Four families of North American songbirds were found to be sensitive to shifting resource availability (Olsen et al. 2015)

Effects of Glaciation

Much of the North Atlantic LCC region was repeatedly glaciated during the Pleistocene Epoch. In at least 23 separate glacial cycles, all species currently north of the Pennsylvania border were completely removed, pushed southward to refugia, and migrated northward once again during the interglacial periods, each of which lasted an average of 20,000 years. One could say this is good evidence that all species of the glaciated region are effective dispersers. However, observed individual dispersal events of plants range from several hundred meters by those dispersed by wind or birds, to less than 5 cm, as in the case of purple pitcher plant. Given 20,000 years, it seems implausible that purple pitcher plant was ever able to reach so far north (central Canada) following glacial recession, in such a specialized habitat (bogs) isolated from each other by inhospitable habitat. And yet it is there, a reliable component of acidic peatlands. This seeming contradiction in apparent dispersal capability and the great distances that plants successfully achieved has been termed "Reid's paradox" after a nineteenth century British botanist's observations. This paradox certainly applies to non-motile animals as well. Ellison and Parker (2002) noted that rare long-distance dispersal events can likely account for the presence of purple pitcher plant in bogs of northern latitudes. We need better information on the role of long-distance dispersal by storms, wind, water, birds, and other animals, as well as how anthropogenic land use changes influence the likelihood of these events, to better plan for adaptation to climate change (Vitt and Havens 2009).

Adaptation and adaptive capacity

As a result of individual response to climate change, species are expected to assemble into new biological communities that have no historical analog (Urban et al. 2012). Our study focused on the potential vulnerability of species currently living in the northeast. We did not assess species that do not currently live in the North Atlantic LCC region but may disperse northward as the climate changes. It would be wise to consider how these new arrivals may interact with resident species, and how they adapt to their new environments. It is likely that we will be faced with new biological communities, but it is also possible that some species turnover will happen in a more predictable way as species find their way to similar habitats in the north that are dominated by, and presumably ameliorated by, long-lived canopy trees that are relatively more tolerant of climate change.

There is greatly increased interest by the scientific community in the adaptive capacity of plants and animals in light of climate change, both in the extent that phenotypic plasticity aids species in adapting to their environment, and in the potential for genetic response over time (Brautigam et al. 2013). A review of phenological adaptation in trees, insects, and birds suggests that both long-lived and short-lived species are responding to climate change by changing phenotype (Rutishauser et al. 2009; Menzel et al. 2006). It remains to be seen whether selection for fitness traits will be necessary for long-term survival. Better understanding of the potential for phenotypic response to temperature increase will allow us to determine when those limits are approached, and when to begin mitigation measures (Donnelly et al. 2012).

Conclusions and Recommendations

We are facing an unprecedented change in our climate in the coming years. The inherent complexity of climate processes, the complexity of biological response to climate, and the need to act quickly makes planning exceedingly difficult. Yet the cost of inaction to the natural world is likely to be dire, especially when so much of our biodiversity is already under threat on a number of fronts. It is important to note that the results of the CCVI present our assessment of a species' vulnerability to climate change, independent of other factors. The challenge is how to interpret and apply these results in the context of other threats that species already face. We must use the best available science to make educated predictions, to make decisions based on those predictions, to monitor efficiently, and to make course corrections as needed.

Conservation actions

Future conservation actions must account for climate change in addition to addressing existing stressors and threats. Our work here identified a number of species that are vulnerable to climate change, but their successful conservation will depend on taking an ecosystem approach to adaptation, as recommended by The National Fish, Wildlife and Plants Climate Adaptation Partnership (2012) and others:

- Focus conservation action on the habitats of fish, wildlife, and plant populations
- Support critical functions of ecosystems that support them
- Maintain or increase connectivity of habitat
- Reduce non-climate stressors – maintain or improve ecological integrity

A logical next critical step is to develop an implementation plan, and although this requires substantial resources and is beyond the scope of our project, we offer the following recommendations for building on current projects, as well as some new directions:

1. Integrate new information into North Atlantic LCC Conservation Planning Atlas: prioritize conservation by focusing first on habitats that support climate-vulnerable species throughout their range in the North Atlantic LCC. From our study, habitats and their most vulnerable species include coastal marshes (salt marsh sparrow, smooth cordgrass), coastal beaches and mudflats (American oystercatcher, piping plover, eastern beach tiger beetle, horseshoe crab), spruce-fir forests (Bicknell's thrush, balsam fir, spruce grouse), streams and rivers (eastern hellbender), swamps (northern white cedar, Hessel's hairstreak), and bogs (black spruce and purple pitcher plant). Focus next on second tier habitats that support species that are vulnerable in portions of the North Atlantic LCC region: northern hardwood – hemlock forests (eastern hemlock, ovenbird), freshwater tidal and non-tidal marshes (pickerelweed, American bittern), small streams and rivers (brook trout), and ponds and vernal pools (barbedbristle bulrush).
2. Identify high-quality examples (those with high ecological integrity, as well as those with high topographic and geological diversity) of these mapped habitats (Gawler 2008, Anderson et al. 2011; Donovan, T. 2011). The Conservation Planning Atlas of the LCC provides a number of data sets that can be used to identify high quality habitats, including Terrestrial Ecosystem Core Areas, Habitat Importance for Imperiled Species, Northeast US, and others.
3. Maintain or enhance ecological integrity of high quality examples of each habitat by first assessing ecological integrity for wetlands and further developing these protocols for upland habitats, then using these protocols to develop goals and target conditions for

restoration where appropriate. Faber-Langendoen et al. (2016) provides ranking protocol for assessing ecological integrity. An intact, or excellent example is defined as natural habitats in an unfragmented landscape, with few or no stressors; condition within the range of natural variation of vegetation structure and composition, lack of invasive species, and comprehensive set of key plant and animal indicators; and of a size larger than minimum dynamic area.

4. Consult the LCC's Conservation Planning Atlas and Climate Stress Metric map to identify climate refugia in the North Atlantic LCC region; conduct analyses of local climate data to detect more detailed trends in climate change spatially (Hamilton 2014; Loarie et al. 2009).
5. Improve connectivity within the LCC region (Anderson et al. 2011; Anderson et al. in progress) but also identify migration corridors to areas outside the North Atlantic LCC to facilitate establishment of species migrating from the south.

Additional monitoring and data needs

1. Conduct climate change vulnerability assessments of globally rare species not yet addressed in North Atlantic LCC conservation planning, especially plants and invertebrates. Many species selected as representative species are birds and other good dispersers that are not vulnerable to climate change. Assessment of more range-restricted and sensitive species would likely indicate early vulnerabilities to climate change that may not be indicated by mobile species.
2. Conduct distribution modeling of globally rare species and species of narrow ecological tolerances to improve our conservation planning capabilities.
3. Monitor salt marsh accretion rates to determine whether accretion remains stable or is being overtaken by sea level rise. This will improve our ability to identify potential habitat for new marshes to form, or to take mitigating action to buffer current marsh habitat.
4. Use updated and seasonal climate data, both current and future, especially for Canada. For example, USGS updated the National Climate Change Viewer in December 2016, replacing hydroclimate variables, adding spatially varying soil water holding capacities, and revising the potential evapotranspiration calculation (USGS Climate Research and Development Program 2016). In the face of species migration, these data will be important for identifying potential refugia.
5. Conduct meta-analyses of species vulnerability across boundaries of LCC's. Identify vulnerable species from south of the North Atlantic LCC that may find potential new habitat in this region, particularly in similar habitats currently dominated by long-lived foundation species that are not likely to be vulnerable to climate change.

6. Share information by partnering with other organizations such as the USA National Phenological Network, and contribute to the growing body of knowledge on phenological trends by using standard protocols (USA National Phenological Network 2012).
7. Monitor range expansions and contractions of species from each of the selection categories we used for this study: foundation, high regional concern, and representative, to better understand adaptive capacities, or lack thereof.
8. Capitalize on the interests of a growing citizen science community by directing a wide network of observers to collect these data.

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Appendix I

Appendix 1: Temperature and moisture exposure risk factors

Species	English Name	Subregion	Range Rel.	Temperature Scope				Hamon AET:PET Moisture Metric Scope			
				5.1F	4.5F	3.9F	<3.9F	-0.096	-0.073	-0.05	>-0.028
Abies balsamea	Balsam Fir	North Atlantic	Center	28	72	0	0	0	9	91	0
Abies balsamea	Balsam Fir	North Appalachian	Southern	47	24	23	6	0	0	83	17
Accipiter gentilis	Northern Goshawk	Mid Atlantic	Southern	2	91	7	0	0	53	47	0
Accipiter gentilis	Northern Goshawk	North Appalachian	East/West	54	37	7	2	0	0	31	69
Accipiter gentilis	Northern Goshawk	North Atlantic	East/West	11	83	6	0	0	1	96	3
Acer saccharinum	Silver Maple	North Atlantic	Northern	13	87	0	0	0	0	96	4
Acer saccharinum	Silver Maple	North Appalachian	Northern	2	46	2	50	20	28	50	2
Acer saccharum	Sugar maple	North Appalachian	East/West	54	37	7	2	0	0	30	70
Acer saccharum	Sugar maple	North Atlantic	East/West	11	87	2	0	0	0	96	4
Acer saccharum	Sugar maple	Mid Atlantic	Center	6	94	0	0	0	55	45	0
Acipenser oxyrinchus	Atlantic Sturgeon	Mid Atlantic	Center	1	99	0	0	0	41	59	0
Acipenser oxyrinchus	Atlantic Sturgeon	North Appalachian	Northern	50	35	12	3	0	0	13	87
Acipenser oxyrinchus	Atlantic Sturgeon	North Atlantic	Center	3	97	0	0	0	0	100	0
Alasmidonta heterodon	Dwarf Wedgemussel	Mid Atlantic	Center	2	98	0	0	0	63	37	0
Alasmidonta heterodon	Dwarf Wedgemussel	North Appalachian	Northern	39	59	2	0	0	0	7	93
Alasmidonta heterodon	Dwarf Wedgemussel	North Atlantic	Center	8	88	4	0	0	0	98	2
Alasmidonta varicosa	Brook Floater	Mid Atlantic	Center	4	96	0	0	0	59	41	0
Alasmidonta varicosa	Brook Floater	North Appalachian	Northern	27	57	13	3	0	0	32	68
Alasmidonta varicosa	Brook Floater	North Atlantic	Center	5	95	0	0	0	0	99	1
Alces americanus	Moose	North Appalachian	East/West	54	38	7	1	0	0	30	70
Alces americanus	Moose	North Atlantic	Southern	4	96	0	0	0	0	93	7
Alosa sapidissima	American Shad	Mid Atlantic	Center	1	98	1	0	0	58	42	0
Alosa sapidissima	American Shad	North Appalachian	Northern	46	42	10	2	0	0	23	77
Alosa sapidissima	American Shad	North Atlantic	Center	6	92	2	0	0	0	99	1
Ambystoma jeffersonianum	Jefferson Salamander	Mid-Atlantic	Southern	7	93	0	0	0	44	56	0
Ambystoma jeffersonianum	Jefferson Salamander	North Appalachian	Northern	82	18	0	0	0	0	56	44
Ambystoma jeffersonianum	Jefferson Salamander	North Atlantic	Center	10	90	0	0	0	0	98	2

Species	English Name	Subregion	Range Rel.	Temperature Scope 5.1F	4.5F	3.9F	<3.9F	Hamon AET:PET Moisture Metric Scope -0.096	-0.073	-0.05	>-0.028
Anas rubripes	American Black Duck	Mid Atlantic	East/West	2	90	8	0	0	58	42	0
Anas rubripes	American Black Duck	North Appalachian	East/West	54	37	7	2	0	0	31	69
Anas rubripes	American Black Duck	North Atlantic	East/West	11	83	6	0	0	1	96	3
Botaurus lentiginosus	American Bittern	Mid Atlantic	East/West	2	90	8	0	0	59	41	0
Botaurus lentiginosus	American Bittern	North Atlantic	East/West	11	83	6	0	0	1	96	3
Botaurus lentiginosus	American Bittern	North Appalachian	East/West	54	37	7	2	0	0	31	69
Buteo lineatus	Red-shouldered Hawk	Mid Atlantic	East/West	2	90	8	0	0	58	42	0
Buteo lineatus	Red-shouldered Hawk	North Appalachian	Northern	54	46	0	0	0	0	55	45
Buteo lineatus	Red-shouldered Hawk	North Atlantic	East/West	12	82	6	0	0	1	96	3
Callophrys hesseli	Hessel's Hairstreak	Mid Atlantic	Center	0	97	3	0	0	2	98	0
Callophrys hesseli	Hessel's Hairstreak	North Appalachian	Northern	0	100	0	0	0	0	100	0
Callophrys hesseli	Hessel's Hairstreak	North Atlantic	Northern	0	99	1	0	0	0	100	0
Callophrys irus	Frosted Elfin	Mid Atlantic	Center	2	98	0	0	0	33	67	0
Callophrys irus	Frosted Elfin	North Appalachian	Northern	100	0	0	0	0	1	68	31
Callophrys irus	Frosted Elfin	North Atlantic	Northern	10	89	1	0	0	0	98	2
Callophrys lanoraieensis	Bog Elfin	North Appalachian	Northern	58	26	13	3	0	0	3	97
Callophrys lanoraieensis	Bog Elfin	North Atlantic	Southern	0	100	0	0	0	0	100	0
Catharus bicknelli	Bicknell's Thrush	North Appalachian	Entire range	73	26	1	0	0	0	7	93
Catharus bicknelli	Bicknell's Thrush	North Atlantic	Southern	84	16	0	0	0	0	42	58
Chamaecyparis thyoides	Atlantic white cedar	North Atlantic	Northern	0	96	4	0	0	0	100	0
Chamaecyparis thyoides	Atlantic white cedar	North Appalachian	Northern	0	100	0	0	0	0	100	0
Chamaecyparis thyoides	Atlantic white cedar	Mid-Atlantic	Center	0	97	3	0	0	14	86	0
Chamaedaphne calyculata	Leatherleaf	North Appalachian	Center	54	37	7	2	0	0	30	70
Chamaedaphne calyculata	Leatherleaf	North Atlantic	Center	87	13	0	0	0	0	97	3
Chamaedaphne calyculata	Leatherleaf	Mid Atlantic	Southern	0	100	0	0	0	100	0	0
Charadrius melodus	Piping Plover	Mid Atlantic	Southern	0	84	16	0	0	0	69	31
Charadrius melodus	Piping Plover	North Appalachian	Northern	0	84	16	0	0	0	69	31
Charadrius melodus	Piping Plover	North Atlantic	Center	0	89	11	0	0	0	100	0

Species	English Name	Subregion	Range Rel.	Temperature Scope				Hamon AET:PET Moisture Metric Scope			
				5.1F	4.5F	3.9F	<3.9F	-0.096	-0.073	-0.05	>-0.028
Cicindela dorsalis	Eastern Beach Tiger Beetle	Mid Atlantic	Center	0	99	1	0	41	59	0	0
Cicindela dorsalis	Eastern Beach Tiger Beetle	North Atlantic	Northern	0	98	2	0	0	0	100	0
Cistothorus palustris	Marsh Wren	Mid Atlantic	Southern	2	90	8	0	0	58	42	0
Cistothorus palustris	Marsh Wren	North Appalachian	Northern	89	10	1	0	0	1	51	48
Cistothorus palustris	Marsh Wren	North Atlantic	East/West	11	82	7	0	0	1	97	2
Clemmys guttata	Spotted turtle	Mid Atlantic	East/West	2	98	0	0	0	53	47	0
Clemmys guttata	Spotted turtle	North Appalachian	Northern	95	5	0	0	0	0	12	88
Clemmys guttata	Spotted turtle	North Atlantic	East/West	8	90	2	0	0	0	98	2
Cryptobranchus alleganiensis	Hellbender	Mid Atlantic	East/West	12	88	0	0	0	79	21	0
Falcipennis canadensis	Spruce Grouse	North Appalachian	Southern	47	43	8	2	0	0	29	71
Falcipennis canadensis	Spruce Grouse	North Atlantic	Southern	0	100	0	0	0	0	97	3
Glyptemys insculpta	Wood Turtle	Mid Atlantic	Southern	5	95	0	0	0	51	49	0
Glyptemys insculpta	Wood Turtle	North Appalachian	Northern	51	40	7	2	0	0	30	70
Glyptemys insculpta	Wood Turtle	North Atlantic	Center	54	46	0	0	0	0	72	28
Haematopus palliatus	American Oystercatcher	Mid Atlantic	Center	0	76	24	0	0	43	57	0
Haematopus palliatus	American Oystercatcher	North Atlantic	Northern	0	97	3	0	0	0	100	0
Hylocichla mustelina	Wood Thrush	Mid Atlantic	East/West	2	90	8	0	0	58	42	0
Hylocichla mustelina	Wood Thrush	North Appalachian	East/West	56	39	3	2	0	0	35	65
Hylocichla mustelina	Wood Thrush	North Atlantic	East/West	11	83	6	0	0	1	96	3
Isotria medeoloides	small whorled pogonia	North Appalachian	Northern	27	73	0	0	0	0	64	36
Isotria medeoloides	small whorled pogonia	North Atlantic	Northern	0	100	0	0	0	0	100	0
Isotria medeoloides	small whorled pogonia	Mid Atlantic	Center	0	100	0	0	0	54	46	0
Ixobrychus exilis	Least Bittern	Mid Atlantic	East/West	0	89	11	0	0	54	46	0
Ixobrychus exilis	Least Bittern	North Appalachian	Northern	16	84	0	0	0	0	85	15
Ixobrychus exilis	Least Bittern	North Atlantic	East/West	3	88	9	0	0	1	99	0
Lanthus vernalis	Southern Pygmy Clubtail	Mid Atlantic	Center	10	90	0	0	0	36	64	0
Lanthus vernalis	Southern Pygmy Clubtail	North Appalachian	Northern	39	59	2	0	0	0	9	91
Lanthus vernalis	Southern Pygmy Clubtail	North Atlantic	Center	0	100	0	0	0	0	97	3

Species	English Name	Subregion	Range Rel.	Temperature Scope 5.1F	4.5F	3.9F	<3.9F	Hamon AET:PET Moisture Metric Scope -0.096	-0.073	-0.05	>-0.028
Lasiurus borealis	Eastern Red Bat	Mid Atlantic	Center	1	98	1	0	0	56	44	0
Lasiurus borealis	Eastern Red Bat	North Appalachian	Northern	54	37	7	2	0	0	30	70
Lasiurus borealis	Eastern Red Bat	North Atlantic	Center	11	88	1	0	0	0	97	3
Limulus polyphemus	Horseshoe Crab	Mid Atlantic	Center	0	72	28	0	0	30	70	0
Limulus polyphemus	Horseshoe Crab	North Appalachian	Northern	0	100	0	0	0	0	100	0
Limulus polyphemus	Horseshoe Crab	North Atlantic	Northern	0	77	23	0	0	0	100	0
Lithobates sylvaticus	Wood Frog	Mid Atlantic	Northern	1	98	1	0	0	56	44	0
Lithobates sylvaticus	Wood Frog	North Appalachian	East/West	54	37	7	2	0	0	31	69
Lithobates sylvaticus	Wood Frog	North Atlantic	East/West	11	87	2	0	0	0	97	3
Malaclemys terrapin	Diamond-backed Terrapin	Mid Atlantic	Center	0	98	2	0	0	35	65	0
Malaclemys terrapin	Diamond-backed Terrapin	North Atlantic	Northern	0	91	9	0	0	0	100	0
Mustela nivalis	Least Weasel	Mid Atlantic	Southern	5	95	0	0	0	89	11	0
Mustela nivalis	Least Weasel	North Appalachian	Southern	0	0	0	100	14	86	0	0
Nyssa sylvatica	Blackgum	North Appalachian	Northern	51	49	0	0	0	32	58	10
Nyssa sylvatica	Blackgum	Mid Atlantic	Center	2	98	0	0	0	56	44	0
Nyssa sylvatica	Blackgum	North Atlantic	Center	5	93	2	0	0	26	73	1
Parkesia motacilla	Louisiana Waterthrush	Mid Atlantic	East/West	2	89	9	0	0	61	39	0
Parkesia motacilla	Louisiana Waterthrush	North Appalachian	Northern	82	18	0	0	0	1	55	44
Parkesia motacilla	Louisiana Waterthrush	North Atlantic	Northern	12	82	6	0	0	1	96	3
Parkesia noveboracensis	Northern Waterthrush	Mid Atlantic	Southern	2	90	8	0	0	58	42	0
Parkesia noveboracensis	Northern Waterthrush	North Appalachian	East/West	54	37	7	2	0	0	31	69
Parkesia noveboracensis	Northern Waterthrush	North Atlantic	Southern	11	83	6	0	0	1	96	3
Picea mariana	Black spruce	North Appalachian	Southern	54	37	7	2	0	0	31	69
Picea mariana	Black spruce	North Atlantic	Southern	12	88	0	0	0	0	96	4
Picea rubens	Red Spruce	North Appalachian	Northern	48	44	8	0	0	0	35	65
Picea rubens	Red Spruce	North Atlantic	Center	16	84	0	0	0	0	95	5
Pinus rigida	Pitch Pine	North Appalachian	Northern	31	69	0	0	0	0	82	18
Pinus rigida	Pitch Pine	North Atlantic	Center	8	90	2	0	0	0	98	2
Pinus rigida	Pitch Pine	Mid Atlantic	East/West	3	97	0	0	0	58	42	0

Species	English Name	Subregion	Range Rel.	Temperature Scope				Hamon AET:PET Moisture Metric Scope			
				5.1F	4.5F	3.9F	<3.9F	-0.096	-0.073	-0.05	>-0.028
Pinus strobus	White Pine	North Appalachian	Northern	53	38	7	2	0	0	31	69
Pinus strobus	White Pine	North Atlantic	Center	11	87	2	0	0	0	97	3
Pinus strobus	White Pine	Mid Atlantic	Center	3	97	0	0	0	55	45	0
Pituophis melanoleucus	Pinesnake	Mid Atlantic	Northern	0	100	0	0	0	2	98	0
Pituophis melanoleucus	Pinesnake	North Atlantic	Northern	0	100	0	0	0	0	100	0
Pontederia cordata	Pickerelweed	North Appalachian	Northern	47	42	9	2	0	0	37	63
Pontederia cordata	Pickerelweed	Mid Atlantic	Center	1	98	1	0	0	45	55	0
Pontederia cordata	Pickerelweed	North Atlantic	Center	11	87	2	0	0	0	65	35
Quercus alba	White Oak	North Appalachian	Northern	75	25	0	0	0	25	75	0
Quercus alba	White Oak	North Atlantic	Northern	0	100	0	0	0	0	100	0
Quercus alba	White Oak	North Atlantic	Northern	0	15	85	0	0	35	65	0
Salmo salar	Atlantic Salmon	North Appalachian	Center	52	39	7	2	0	0	30	70
Salmo salar	Atlantic Salmon	North Atlantic	Southern	13	87	0	0	0	0	95	5
Salvelinus fontinalis	Brook Trout	North Atlantic	East/West	11	87	2	0	0	0	97	3
Salvelinus fontinalis	Brook Trout	North Appalachian	East/West	54	37	7	2	0	0	31	69
Sarracenia purpurea	Purple pitcher plant	North Atlantic	Center	87	13	0	0	0	0	97	3
Sarracenia purpurea	Purple pitcher plant	North Appalachian	Center	54	37	7	2	0	0	30	70
Sarracenia purpurea	Purple pitcher plant	Mid Atlantic	Center	1	99	0	0	0	65	35	0
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Appalachian	Northern	53	47	0	0	0	0	93	7
Scirpus ancistrochaetus	Barbedbristle Bulrush	Mid Atlantic	Center	68	32	0	0	0	96	4	0
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Atlantic	Center	43	57	0	0	0	0	90	10
Scirpus cyperinus	Woolgrass	North Appalachian	Northern	54	37	7	2	0	0	30	70
Scirpus cyperinus	Woolgrass	North Atlantic	Center	87	13	0	0	0	0	97	3
Scirpus cyperinus	Woolgrass	Mid Atlantic	Center	1	98	1	0	0	55	45	0
Seiurus aurocapilla	Ovenbird	Mid Atlantic	East/West	2	90	8	0	0	58	42	0
Seiurus aurocapilla	Ovenbird	North Appalachian	Northern	54	37	7	2	0	0	31	69
Seiurus aurocapilla	Ovenbird	North Atlantic	East/West	11	83	6	0	0	1	96	3
Setophaga cerulea	Cerulean Warbler	Mid Atlantic	East/West	2	93	5	0	0	59	41	0
Setophaga cerulea	Cerulean Warbler	North Atlantic	Northern	3	97	0	0	0	0	100	0

Species	English Name	Subregion	Range Rel.	Temperature Scope 5.1F	4.5F	3.9F	<3.9F	Hamon AET:PET Moisture Metric Scope -0.096	-0.073	-0.05	>-0.028
Setophaga striata	Blackpoll Warbler	Mid Atlantic	East/West	2	90	8	0	0	58	42	0
Setophaga striata	Blackpoll Warbler	North Appalachian	Southern	57	34	7	2	0	0	32	68
Setophaga striata	Blackpoll Warbler	North Atlantic	East/West	11	83	6	0	0	1	96	3
Somatochlora incurvata	Incurvate Emerald	North Appalachian	Northern	60	25	12	3	0	0	3	97
Sorex palustris	American Water Shrew	Mid Atlantic	Southern	0	100	0	0	0	0	100	0
Sorex palustris	American Water Shrew	North Appalachian	East/West	54	37	7	2	0	0	30	70
Sorex palustris	American Water Shrew	North Atlantic	East/West	11	88	1	0	0	0	96	4
Spartina alterniflora	Saltwater cordgrass	North Atlantic	Center	0	93	7	0	0	0	100	0
Spartina alterniflora	Saltwater cordgrass	North Appalachian	Northern	28	31	34	7	0	0	13	87
Spartina alterniflora	Saltwater cordgrass	Mid Atlantic	Center	0	100	0	0	0	42	58	0
Sterna hirundo	Common Tern	Mid Atlantic	East/West	2	90	8	0	0	58	42	0
Sterna hirundo	Common Tern	North Appalachian	East/West	57	34	7	2	0	0	35	65
Sterna hirundo	Common Tern	North Atlantic	East/West	11	83	6	0	0	1	96	3
Sternula antillarum	Least Tern	North Atlantic	East/West	0	79	21	0	0	45	55	0
Sternula antillarum	Least Tern	North Atlantic	Northern	0	73	27	0	0	1	99	0
Sylvilagus transitionalis	New England cottontail	North Appalachian	Northern	54	46	0	0	0	0	63	37
Sylvilagus transitionalis	New England cottontail	North Atlantic	Southern	97	0	0	0	0	0	100	0
Thuja occidentalis	Northern white cedar	North Appalachian	Center	60	39	1	0	0	0	35	65
Thuja occidentalis	Northern white cedar	North Atlantic	Center	14	86	0	0	0	0	95	5
Thuja occidentalis	Northern white cedar	Mid Atlantic	Center	0	100	0	0	0	100	0	0
Tsuga canadensis	Eastern Hemlock	North Appalachian	Northern	47	43	8	2	0	0	36	64
Tsuga canadensis	Eastern Hemlock	Mid- Atlantic	East/West	6	94	0	0	0	39	61	0
Tsuga canadensis	Eastern Hemlock	North Atlantic	Center	10	88	2	0	0	0	96	4
Vallisneria americana	Tapegrass	North Appalachian	Center	50	8	0	0	0	0	41	59
Vallisneria americana	Tapegrass	North Atlantic	Northern	87	2	0	0	0	0	97	3
Vallisneria americana	Tapegrass	Mid Atlantic	Center	99	0	0	0	0	50	50	0

Appendix 2: Sensitivity risk factors

Species	English Name	Subregion	B1 Sea level	B2a Natl barriers	B2b Anth barriers	B3 CC mitigation	C1 Dispersal/ Movement	C2ai historical thermal niche	C2aii physiological thermal niche	C2bi historical hydrological niche
Abies balsamea	Balsam Fir	North Atlantic	N	Inc	N	N	SI	N	GI	N
Abies balsamea	Balsam Fir	North Appalachian	N	Inc	N	N	SI	N	Inc-SI	SD
Accipiter gentilis	Northern Goshawk	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Accipiter gentilis	Northern Goshawk	North Appalachian	N	N	N	N	Dec	N	N	N
Accipiter gentilis	Northern Goshawk	North Atlantic	N	N	N	N	Dec	N	N	N
Acer saccharinum	Silver Maple	North Atlantic	N	SI	N	N	SI	N	N	SI
Acer saccharinum	Silver Maple	North Appalachian	N	SI	N	N	SI	N-SD	N	SI-N
Acer saccharum	Sugar maple	North Appalachian	N	N	N	N	SI	N	N	SI
Acer saccharum	Sugar maple	North Atlantic	N	N	N	N	SI	N	N	SI
Acer saccharum	Sugar maple	Mid Atlantic	N	N	SI	N	SI	N	SI	SI
Acipenser oxyrinchus	Atlantic Sturgeon	Mid Atlantic	N	N	N	SI-N	N	N	N	SI
Acipenser oxyrinchus	Atlantic Sturgeon	North Appalachian	N	N	N	SI-N	N	N	N	N
Acipenser oxyrinchus	Atlantic Sturgeon	North Atlantic	N	N	N	SI-N	N	N	N	SI
Alasmidonta heterodon	Dwarf Wedgemussel	Mid Atlantic	N	N	N	SI	N	N	N	SI
Alasmidonta heterodon	Dwarf Wedgemussel	North Appalachian	N	N	N	SI	N	N	N	SI
Alasmidonta heterodon	Dwarf Wedgemussel	North Atlantic	N	N	N	SI	N	N	N	N
Alasmidonta varicosa	Brook Floater	Mid Atlantic	N	N	N	SI	N	N	N	SI
Alasmidonta varicosa	Brook Floater	North Appalachian	N	N	N	SI	N	N	N	SI
Alasmidonta varicosa	Brook Floater	North Atlantic	N	N	N	SI	N	N	N	SI
Alces americanus	Moose	North Appalachian	N	N	N	N	Dec	N	N	N
Alces americanus	Moose	North Atlantic	N	N	N	N	Dec	N	Inc-SI	N
Alosa sapidissima	American Shad	Mid Atlantic	N	SI	SI	SI	Dec	N	N	SI
Alosa sapidissima	American Shad	North Appalachian	N	SI	SI	SI	Dec	N	N	N
Alosa sapidissima	American Shad	North Atlantic	N	SI	SI	SI	Dec	N	N	SI

Species	English Name	Subregion	B1 Sea level	B2a Natl barriers	B2b Anth barriers	B3 CC mitigation	C1 Dispersal/ Movement	C2ai historical thermal niche	C2aii physiological thermal niche	C2bi historical hydrological niche
Ammodramus caudacutus	Saltmarsh Sparrow	Mid Atlantic	GI	N	N	Inc	Dec	N	N	Inc
Ammodramus caudacutus	Saltmarsh Sparrow	North Atlantic	GI	N	N	Inc	Dec	N	N	SI
Anas rubripes	American Black Duck	Mid Atlantic	Inc-SI	N	N	SI	Dec	N	N	SI
Anas rubripes	American Black Duck	North Appalachian	Inc-SI	N	N	SI	Dec	N	N	N
Anas rubripes	American Black Duck	North Atlantic	Inc-SI	N	N	SI	Dec	N	N	N
Botaurus lentiginosus	American Bittern	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Botaurus lentiginosus	American Bittern	North Atlantic	N	N	N	N	Dec	N	N	N
Botaurus lentiginosus	American Bittern	North Appalachian	N	N	N	N	Dec	N	N	N
Buteo lineatus	Red-shouldered Hawk	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Buteo lineatus	Red-shouldered Hawk	North Appalachian	N	N	N	N	Dec	N	N	N
Buteo lineatus	Red-shouldered Hawk	North Atlantic	N	N	N	N	Dec	N	N	N
Callophrys hesseli	Hessel's Hairstreak	Mid Atlantic	N	N	N	N	SI	N	N	Inc
Callophrys hesseli	Hessel's Hairstreak	North Appalachian	N	N	N	N	SI	N	N	GI
Callophrys hesseli	Hessel's Hairstreak	North Atlantic	N	N	N	N	SI	N	N	Inc
Callophrys irus	Frosted Elfin	Mid Atlantic	N	N	N	N	N-SD	N	SD	SI
Callophrys irus	Frosted Elfin	North Appalachian	N	N	N	N	N-SD	N	SD	Inc
Callophrys irus	Frosted Elfin	North Atlantic	N	N	N	N	N-SD	N	SD	SI
Callophrys lanoraieensis	Bog Elfin	North Appalachian	N	N	N	N	N	N	N	SI
Callophrys lanoraieensis	Bog Elfin	North Atlantic	N	N	N	N	N	N	N	Inc
Catharus bicknelli	Bicknell's Thrush	North Appalachian	N	N	N	SI	Dec	N	Inc	N
Catharus bicknelli	Bicknell's Thrush	North Atlantic	N	N	N	SI	Dec	N	GI	N
Chamaecyparis thyoides	Atlantic white cedar	North Atlantic	N	N	SI	N	N	N	N	SI
Chamaecyparis thyoides	Atlantic white cedar	North Appalachian	N	N	SI	N	N	N	N	Inc
Chamaecyparis thyoides	Atlantic white cedar	Mid-Atlantic	N	N	SI	N	N	SI	N	Inc
Chamaedaphne calyculata	Leatherleaf	North Appalachian	N	N	N	N	N	N	N	SI
Chamaedaphne calyculata	Leatherleaf	North Atlantic	N	SI	SI	N	N	N	N	SI
Chamaedaphne calyculata	Leatherleaf	Mid Atlantic	N	SI	SI	N	N	N	N	Inc

Species	English Name	Subregion	B1 Sea level	B2a Natl barriers	B2b Anth barriers	B3 CC mitigation	C1 Dispersal/ Movement	C2ai historical thermal niche	C2aii physiological thermal niche	C2bi historical hydrological niche
Charadrius melodus	*Piping Plover*	*Mid Atlantic*	GI	N	N	SI	Dec	N	N	SI
Charadrius melodus	*Piping Plover*	*North Appalachian*	GI	N	N	SI	Dec	N	N	SI
Charadrius melodus	*Piping Plover*	*North Atlantic*	GI	N	N	SI	Dec	N	N	Inc
Cicindela dorsalis	*Eastern Beach Tiger Beetle*	*Mid Atlantic*	GI	N	N	SI	SD	N	N	Inc
Cicindela dorsalis	*Eastern Beach Tiger Beetle*	*North Atlantic*	GI	GI	N	U	SD	N	N	Inc
Cistothorus palustris	*Marsh Wren*	*Mid Atlantic*	SI	N	N	N	Dec	N	N	SI
Cistothorus palustris	*Marsh Wren*	*North Appalachian*	SI	N	N	N	Dec	N	N	SI
Cistothorus palustris	*Marsh Wren*	*North Atlantic*	SI	N	N	N	Dec	N	N	N
Clemmys guttata	*Spotted turtle*	*Mid Atlantic*	N	N	N	N	N	N	N	SI
Clemmys guttata	*Spotted turtle*	*North Appalachian*	N	N	N	N	N	N	N	SI
Clemmys guttata	*Spotted turtle*	*North Atlantic*	N	N	N	N	N	N	N	SI
Cryptobranchus alleganiensis	*Hellbender*	*Mid Atlantic*	N	N	SI-N	SI	N	N	SI-N	SI
Falcipennis canadensis	*Spruce Grouse*	*North Appalachian*	N	SI	SI	N	N-SD	N	Inc	N
Falcipennis canadensis	*Spruce Grouse*	*North Atlantic*	N	N	N	N	N-SD	N	GI	N
Glyptemys insculpta	*Wood Turtle*	*Mid Atlantic*	N	N	N	SI	N-SD	N	SI-N	SI
Glyptemys insculpta	*Wood Turtle*	*North Appalachian*	N	N	N	SI	N-SD	N	N-SD	N
Glyptemys insculpta	*Wood Turtle*	*North Atlantic*	N	N	N	SI	N-SD	N	N-SD	SI
Haematopus palliatus	*American Oystercatcher*	*Mid Atlantic*	GI	N	N	SI	Dec	N	N	Inc
Haematopus palliatus	*American Oystercatcher*	*North Atlantic*	GI	N	N	SI	Dec	N	N	SI
Hylocichla mustelina	*Wood Thrush*	*Mid Atlantic*	N	N	N	N	Dec	N	N	SI
Hylocichla mustelina	*Wood Thrush*	*North Appalachian*	N	N	N	N	Dec	N	N	N
Hylocichla mustelina	*Wood Thrush*	*North Atlantic*	N	N	N	N	Dec	N	N	N
Isotria medeoloides	*small whorled pogonia*	*North Appalachian*	N	N	N	N	SI	N	N	N
Isotria medeoloides	*small whorled pogonia*	*North Atlantic*	N	N	N	N	N	N	N	Inc-SI
Isotria medeoloides	*small whorled pogonia*	*Mid Atlantic*	N	N	N	N	N	N	N	SI
Ixobrychus exilis	*Least Bittern*	*Mid Atlantic*	Inc-SI	N	N	N	SD-Dec	N	N	SI
Ixobrychus exilis	*Least Bittern*	*North Appalachian*	Inc-SI	N	N	N	SD-Dec	N	N	SI
Ixobrychus exilis	*Least Bittern*	*North Atlantic*	Inc-SI	N	N	N	SD-Dec	N	N	N

Species	English Name	Subregion	Sea level B1	Natl barriers B2a	Anth barriers B2b	CC mitigation B3	Dispersal/ Movement C1	historical thermal niche C2ai	physiological thermal niche C2aii	historical hydrological niche C2bi
Lanthus vernalis	Southern Pygmy Clubtail	Mid Atlantic	N	N	N	SI-N	N-SD	N	SI-N	Inc
Lanthus vernalis	Southern Pygmy Clubtail	North Appalachian	N	N	N	SI-N	N-SD	N	SI-N	SI
Lanthus vernalis	Southern Pygmy Clubtail	North Atlantic	N	N	N	SI-N	N-SD	N	SI-N	Inc
Lasiurus borealis	Eastern Red Bat	Mid Atlantic	N	N	N	SI	Dec	N	N	SI
Lasiurus borealis	Eastern Red Bat	North Appalachian	N	N	N	SI	Dec	N	N	N
Lasiurus borealis	Eastern Red Bat	North Atlantic	N	N	N	SI	Dec	N	N	SI
Limulus polyphemus	Horseshoe Crab	Mid Atlantic	GI	N	N	SI-N	N-SD	SI	N	Inc
Limulus polyphemus	Horseshoe Crab	North Appalachian	GI	N	N	SI-N	N-SD	N	N	SI
Limulus polyphemus	Horseshoe Crab	North Atlantic	GI	N	N	SI-N	N-SD	N	N	SI
Lithobates sylvaticus	Wood Frog	Mid Atlantic	N	N	N	N	N	N	N	SI
Lithobates sylvaticus	Wood Frog	North Appalachian	N	N	N	N	N	N	N	N
Lithobates sylvaticus	Wood Frog	North Atlantic	N	N	N	N	N	N	N	SI
Malaclemys terrapin	Diamond-backed Terrapin	Mid Atlantic	GI	N	N	SI-N	N-SD	N	N-SD	Inc
Malaclemys terrapin	Diamond-backed Terrapin	North Atlantic	GI	N	N	SI-N	N-SD	N	N-SD	SI
Mustela nivalis	Least Weasel	Mid Atlantic	N	N	N	N	N	N	N	Inc-SI
Mustela nivalis	Least Weasel	North Appalachian	N	N	N	N	N	N	N	SI
Nyssa sylvatica	Blackgum	North Appalachian	N	SI	N	N	N	N	N	SI
Nyssa sylvatica	Blackgum	Mid Atlantic	N	SI	SI	N	N	N	N	SI
Nyssa sylvatica	Blackgum	North Atlantic	N	SI	SI	N	N	N	N	SI
Parkesia motacilla	Louisiana Waterthrush	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Parkesia motacilla	Louisiana Waterthrush	North Appalachian	N	N	N	N	Dec	N	N	N
Parkesia motacilla	Louisiana Waterthrush	North Atlantic	N	N	N	N	Dec	N	N	N
Parkesia noveboracensis	Northern Waterthrush	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Parkesia noveboracensis	Northern Waterthrush	North Appalachian	N	N	N	N	Dec	N	N	N
Parkesia noveboracensis	Northern Waterthrush	North Atlantic	N	N	N	N	Dec	N	N	N
Picea mariana	Black spruce	North Appalachian	N	N	N	N	N	N	Inc	N
Picea mariana	Black spruce	North Atlantic	N	SI	Inc	N	N	N	Inc	N

Species	English Name	Subregion	B1 Sea level	B2a Natl barriers	B2b Anth barriers	B3 CC mitigation	C1 Dispersal/ Movement	C2ai historical thermal niche	C2aii physiological thermal niche	C2bi historical hydrological niche
Picea rubens	Red Spruce	North Appalachian	N	N	N	U	SI	N	Inc	N
Picea rubens	Red Spruce	North Atlantic	N	Inc-SI	N	U	SI	N	Inc	SI
Pinus rigida	Pitch Pine	North Appalachian	N	N	N	U	SI	N	U	N
Pinus rigida	Pitch Pine	North Atlantic	N	N	N	U	SI	N	U	SI
Pinus rigida	Pitch Pine	Mid Atlantic	N	N	N	U	SI	N	U	SI
Pinus strobus	White Pine	North Appalachian	N	N	N	U	N	N	N	N
Pinus strobus	White Pine	North Atlantic	N	N	N	U	N	N	N	SI
Pinus strobus	White Pine	Mid Atlantic	N	SI-N	SI-N	U	N	N	N	SI
Pituophis melanoleucus	Pinesnake	Mid Atlantic	N	N	N	N	U	N	N-SD	Inc
Pituophis melanoleucus	Pinesnake	North Atlantic	N	N	N	N	U	N	N-SD	Inc
Pontederia cordata	Pickerelweed	North Appalachian	N	SI	N	N	N-SD	N	N	N
Pontederia cordata	Pickerelweed	Mid Atlantic	Inc	SI	SI	N	N-SD	N	N	Inc
Pontederia cordata	Pickerelweed	North Atlantic	SI	SI	SI	N	N-SD	N	N	SI
Quercus alba	White Oak	North Appalachian	N	N	N	N	SI	SD	N	SD
Quercus alba	White Oak	North Atlantic	N	N	N	N	SI	N	N	N
Quercus alba	White Oak	North Atlantic	N	N	N	N	SI	SD	N	SD
Salmo salar	Atlantic Salmon	North Appalachian	N	SI	SI	SI	Dec	N	SI	N
Salmo salar	Atlantic Salmon	North Atlantic	N	SI	SI	SI	Dec	N	SI	SI
Salvelinus fontinalis	Brook Trout	North Atlantic	N	SI	Inc-SI	SI	SD-Dec	N	SI	SI
Salvelinus fontinalis	Brook Trout	North Appalachian	N	SI	Inc-SI	SI	SD-Dec	N	SI	N
Sarracenia purpurea	Purple pitcher plant	North Atlantic	N	Inc	N	N	Inc	N	N	N
Sarracenia purpurea	Purple pitcher plant	North Appalachian	N	Inc	N	U	Inc	N	N	N
Sarracenia purpurea	Purple pitcher plant	Mid Atlantic	N	Inc	SI	N	U	N	N	Inc
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Appalachian	N	SI	N	N	N	N	N	SI
Scirpus ancistrochaetus	Barbedbristle Bulrush	Mid Atlantic	N	SI	SI	N	N	N	N	Inc
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Atlantic	N	SI	SI	N	U	N	N	N

Species	English Name	Subregion	B1 Sea level	B2a Natl barriers	B2b Anth barriers	B3 CC mitigation	C1 Dispersal/ Movement	C2ai historical thermal niche	C2aii physiological thermal niche	C2bi historical hydrological niche
Scirpus cyperinus	Woolgrass	North Appalachian	N	N	N	N	N	N	N	N
Scirpus cyperinus	Woolgrass	North Atlantic	N	N	N	N	U	N	N	SI
Scirpus cyperinus	Woolgrass	Mid Atlantic	N	N	N	N	U	N	N	Inc
Seiurus aurocapilla	Ovenbird	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Seiurus aurocapilla	Ovenbird	North Appalachian	N	N	N	N	Dec	N	N	N
Seiurus aurocapilla	Ovenbird	North Atlantic	N	N	N	N	Dec	N	N	N
Setophaga cerulea	Cerulean Warbler	Mid Atlantic	N	N	N	N	Dec	N	N	SI
Setophaga cerulea	Cerulean Warbler	North Atlantic	N	N	N	N	Dec	N	N	Inc
Setophaga striata	Blackpoll Warbler	Mid Atlantic	N	N	N	SI	Dec	N	N	SI
Setophaga striata	Blackpoll Warbler	North Appalachian	N	N	N	SI	N-SD	N	N	N
Setophaga striata	Blackpoll Warbler	North Atlantic	N	N	N	SI	Dec	N	N	N
Somatochlora incurvata	Incurvate Emerald	North Appalachian	N	N	N	SI-N	Dec	N	N	Inc
Sorex palustris	American Water Shrew	Mid Atlantic	N	N	N	N	N	N	N	Inc
Sorex palustris	American Water Shrew	North Appalachian	N	N	N	N	N	N	N	N
Sorex palustris	American Water Shrew	North Atlantic	N	N	N	N	N	N	N	SI
Spartina alterniflora	Saltwater cordgrass	North Atlantic	Inc-SI	N	Inc	N	N	N	N	Inc-SI
Spartina alterniflora	Saltwater cordgrass	North Appalachian	Inc	N	Inc-SI	N	N	N	N	SI
Spartina alterniflora	Saltwater cordgrass	Mid Atlantic	SI-N	N	Inc-SI	N	N	N	N	SI
Sterna hirundo	Common Tern	Mid Atlantic	GI	N	N	SI	Dec	N	N	SI
Sterna hirundo	Common Tern	North Appalachian	GI	N	N	SI	Dec	N	N	N
Sterna hirundo	Common Tern	North Atlantic	GI	N	N	SI	Dec	N	N	N
Sternula antillarum	Least Tern	North Atlantic	GI	N	N	SI	Dec	N	N	Inc
Sternula antillarum	Least Tern	North Atlantic	GI	N	N	SI	Dec	N	N	Inc
Sylvilagus transitionalis	New England cottontail	North Appalachian	N	SI	SI	N	N	N	N	N
Sylvilagus transitionalis	New England cottontail	North Atlantic	N	SI	SI	U	N	N	N	SI

Species	English Name	Subregion	B1 Sea level	B2a Natl barriers	B2b Anth barriers	B3 CC mitigation	C1 Dispersal/ Movement	C2ai historical thermal niche	C2aii physiological thermal niche	C2bi historical hydrological niche
Thuja occidentalis	Northern white cedar	North Appalachian	N	N	N	N	N	N	N	SI
Thuja occidentalis	Northern white cedar	North Atlantic	N	N	SI	N	N	N	N	SI
Thuja occidentalis	Northern white cedar	Mid Atlantic	N	Inc-N	SI	N	N	N	N	GI
Tsuga canadensis	Eastern Hemlock	North Appalachian	N	N	N	N	SI	N	SI	SI
Tsuga canadensis	Eastern Hemlock	Mid- Atlantic	N	N	SI-N	N	SI	N	SI	SI
Tsuga canadensis	Eastern Hemlock	North Atlantic	N	N	N	N	SI	N	SI	SI
Vallisneria americana	Tapegrass	North Appalachian	N	SI-N	SI-N	N	U	N	SD	SI
Vallisneria americana	Tapegrass	North Atlantic	N	SI-N	SI	U	U	N	SD	SI
Vallisneria americana	Tapegrass	Mid Atlantic	N	SI	Inc	U	U	N	SD	SI

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Abies balsamea	Balsam Fir	North Atlantic	N	N	N	N	N	N/A	N	N
Abies balsamea	Balsam Fir	North Appalachian	N	N	N	N	N	N/A	N	N
Accipiter gentilis	Northern Goshawk	Mid Atlantic	N	N	N	N	N	N	N/A	N
Accipiter gentilis	Northern Goshawk	North Appalachian	N	N	N	N	N	N	N/A	N
Accipiter gentilis	Northern Goshawk	North Atlantic	N	N	N	N	N	N	N/A	N
Acer saccharinum	Silver Maple	North Atlantic	N	SI	N	N	N	N/A	N	N
Acer saccharinum	Silver Maple	North Appalachian	Inc	SI	N	N	N	N/A	N	N
Acer saccharum	Sugar maple	North Appalachian	N	N	N	Dec	N	N/A	N	N
Acer saccharum	Sugar maple	North Atlantic	N	N	N	Dec	N	N/A	N	N
Acer saccharum	Sugar maple	Mid Atlantic	N	N	N	Dec	N	N/A	N	N
Acipenser oxyrinchus	Atlantic Sturgeon	Mid Atlantic	N	N	N	N	N	N	N/A	N
Acipenser oxyrinchus	Atlantic Sturgeon	North Appalachian	N	N	N	N	N	N	N/A	N
Acipenser oxyrinchus	Atlantic Sturgeon	North Atlantic	N	N	N	N	N	N	N/A	N
Alasmidonta heterodon	Dwarf Wedgemussel	Mid Atlantic	N	N	N	N	N	N	N/A	SI
Alasmidonta heterodon	Dwarf Wedgemussel	North Appalachian	N	N	N	N	N	N	N/A	SI
Alasmidonta heterodon	Dwarf Wedgemussel	North Atlantic	N	N	N	N	N	N	N/A	SI
Alasmidonta varicosa	Brook Floater	Mid Atlantic	N	N	N	N	N	N	N/A	SI
Alasmidonta varicosa	Brook Floater	North Appalachian	N	N	N	N	N	N	N/A	SI
Alasmidonta varicosa	Brook Floater	North Atlantic	N	N	N	N	N	N	N/A	SI
Alces americanus	Moose	North Appalachian	N	N	N	N	N	N	N/A	N
Alces americanus	Moose	North Atlantic	N	N	N	N	N	N	N/A	SI
Alosa sapidissima	American Shad	Mid Atlantic	N	N	N	N	N	N	N/A	N
Alosa sapidissima	American Shad	North Appalachian	N	N	N	N	N	N	N/A	N
Alosa sapidissima	American Shad	North Atlantic	N	N	N	N	N	N	N/A	N

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Ambystoma jeffersonianum	Jefferson Salamander	Mid-Atlantic	GI	N	N	N	N	N	N/A	N
Ambystoma jeffersonianum	Jefferson Salamander	North Appalachian	GI	N	N	N	N	N	N/A	N
Ambystoma jeffersonianum	Jefferson Salamander	North Atlantic	GI	N	N	N	N	N	N/A	N
Ammodramus caudacutus	Saltmarsh Sparrow	Mid Atlantic	N	SI	N	N	SI	N	N/A	N
Ammodramus caudacutus	Saltmarsh Sparrow	North Atlantic	N	SI	N	N	SI	N	N/A	N
Anas rubripes	American Black Duck	Mid Atlantic	SI	SI	N	N	N	SD	N/A	N
Anas rubripes	American Black Duck	North Appalachian	SI	SI	N	N	N	SD	N/A	N
Anas rubripes	American Black Duck	North Atlantic	SI	SI	N	N	N	SD	N/A	N
Botaurus lentiginosus	American Bittern	Mid Atlantic	SI	N	N	N	SI-N	N	N/A	N
Botaurus lentiginosus	American Bittern	North Atlantic	SI	N	N	N	SI-N	N	N/A	N
Botaurus lentiginosus	American Bittern	North Appalachian	SI	N	N	N	SI-N	N	N/A	N
Buteo lineatus	Red-shouldered Hawk	Mid Atlantic	N	SI-N	N	N	N	N	N/A	N
Buteo lineatus	Red-shouldered Hawk	North Appalachian	N	SI-N	N	N	N	N	N/A	N
Buteo lineatus	Red-shouldered Hawk	North Atlantic	N	SI-N	N	N	N	N	N/A	N
Callophrys hesseli	Hessel's Hairstreak	Mid Atlantic	Inc-SI	Inc-SI	N	N	GI-Inc	Inc	N/A	N
Callophrys hesseli	Hessel's Hairstreak	North Appalachian	Inc-SI	Inc-SI	N	N	GI-Inc	Inc	N/A	N
Callophrys hesseli	Hessel's Hairstreak	North Atlantic	Inc-SI	Inc-SI	N	N	GI-Inc	Inc	N/A	N
Callophrys irus	Frosted Elfin	Mid Atlantic	N	U	N	SI-N	N	Inc-SI	N/A	N
Callophrys irus	Frosted Elfin	North Appalachian	N	U	N	SI-N	N	Inc-SI	N/A	N
Callophrys irus	Frosted Elfin	North Atlantic	N	U	N	SI-N	N	Inc-SI	N/A	N
Callophrys lanoraieensis	Bog Elfin	North Appalachian	Inc-SI	N	N	N	N	Inc	N/A	N
Callophrys lanoraieensis	Bog Elfin	North Atlantic	Inc-SI	N	N	N	N	Inc	N/A	N
Catharus bicknelli	Bicknell's Thrush	North Appalachian	N	SD	N	N	SI	N	N/A	N
Catharus bicknelli	Bicknell's Thrush	North Atlantic	N	SD	N	N	SI	N	N/A	N
Chamaecyparis thyoides	Atlantic white cedar	North Atlantic	Inc-SI	N	N	N	N	N/A	N	N
Chamaecyparis thyoides	Atlantic white cedar	North Appalachian	SI	N	N	N	N	N/A	N	N
Chamaecyparis thyoides	Atlantic white cedar	Mid-Atlantic	SI	N	N	N	N	N/A	N	N

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Chamaedaphne calyculata	Leatherleaf	North Appalachian	SI	N	N	N	N	N/A	N	N
Chamaedaphne calyculata	Leatherleaf	North Atlantic	SI	N	N	N	N	N/A	N	N
Chamaedaphne calyculata	Leatherleaf	Mid Atlantic	SI	N	N	N	N	N/A	N	N
Charadrius melodus	Piping Plover	Mid Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Charadrius melodus	Piping Plover	North Appalachian	N	Inc-SI	N	N	N	N	N/A	N
Charadrius melodus	Piping Plover	North Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Cicindela dorsalis	Eastern Beach Tiger Beetle	Mid Atlantic	N	SI-N-SD	N	N	N	N	N/A	N
Cicindela dorsalis	Eastern Beach Tiger Beetle	North Atlantic	N	Inc	N	N	N	N	N/A	N
Cistothorus palustris	Marsh Wren	Mid Atlantic	SI	N	N	N	SI-N	N	N/A	N
Cistothorus palustris	Marsh Wren	North Appalachian	SI	N	N	N	SI-N	N	N/A	N
Cistothorus palustris	Marsh Wren	North Atlantic	SI	N	N	N	SI-N	N	N/A	N
Clemmys guttata	Spotted turtle	Mid Atlantic	SI	N	N	N	N	N	N/A	N
Clemmys guttata	Spotted turtle	North Appalachian	SI	N	N	N	N	N	N/A	N
Clemmys guttata	Spotted turtle	North Atlantic	SI	N	N	N	N	N	N/A	N
Cryptobranchus alleganiensis	Hellbender	Mid Atlantic	SI-N	N	N	SI-N	N	SI	N/A	N
Falcipennis canadensis	Spruce Grouse	North Appalachian	N	N	N	N	SI	Inc-SI	N/A	N
Falcipennis canadensis	Spruce Grouse	North Atlantic	N	N	N	N	SI	Inc-SI	N/A	N
Glyptemys insculpta	Wood Turtle	Mid Atlantic	SI-N	N	N	N	N	N	N/A	N
Glyptemys insculpta	Wood Turtle	North Appalachian	SI-N	N	N	N	N	N	N/A	N
Glyptemys insculpta	Wood Turtle	North Atlantic	SI-N	N	N	N	N	N	N/A	N
Haematopus palliatus	American Oystercatcher	Mid Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Haematopus palliatus	American Oystercatcher	North Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Hylocichla mustelina	Wood Thrush	Mid Atlantic	Inc-SI	SI	N	N	N	N	N/A	N
Hylocichla mustelina	Wood Thrush	North Appalachian	Inc-SI	SI	N	N	N	N	N/A	N
Hylocichla mustelina	Wood Thrush	North Atlantic	Inc-SI	SI	N	N	N	N	N/A	N

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Isotria medeoloides	small whorled pogonia	North Appalachian	N	N	N	N	N	N/A	N	N
Isotria medeoloides	small whorled pogonia	North Atlantic	N	N	N	N	N	N/A	N	N
Isotria medeoloides	small whorled pogonia	Mid Atlantic	N	N	N	N	N	N/A	SI-N	N
Ixobrychus exilis	Least Bittern	Mid Atlantic	SI	N	N	N	SI	N	N/A	N
Ixobrychus exilis	Least Bittern	North Appalachian	SI	N	N	N	SI	N	N/A	N
Ixobrychus exilis	Least Bittern	North Atlantic	SI	N	N	N	SI	N	N/A	N
Lanthus vernalis	Southern Pygmy Clubtail	Mid Atlantic	SI-N	N	N	N	N	N	N/A	N
Lanthus vernalis	Southern Pygmy Clubtail	North Appalachian	SI-N	N	N	N	N	N	N/A	N
Lanthus vernalis	Southern Pygmy Clubtail	North Atlantic	SI-N	N	N	N	N	N	N/A	N
Lasiurus borealis	Eastern Red Bat	Mid Atlantic	N	N	N	N	N	N	N/A	N
Lasiurus borealis	Eastern Red Bat	North Appalachian	N	N	N	N	N	N	N/A	N
Lasiurus borealis	Eastern Red Bat	North Atlantic	N	N	N	N	N	N	N/A	N
Limulus polyphemus	Horseshoe Crab	Mid Atlantic	N	SI	N	N	N	N	N/A	N
Limulus polyphemus	Horseshoe Crab	North Appalachian	N	SI	N	N	N	N	N/A	N
Limulus polyphemus	Horseshoe Crab	North Atlantic	N	SI	N	N	N	N	N/A	N
Lithobates sylvaticus	Wood Frog	Mid Atlantic	GI-Inc	N	N	N	N	N	N/A	N
Lithobates sylvaticus	Wood Frog	North Appalachian	GI-Inc	N	N	N	N	N	N/A	N
Lithobates sylvaticus	Wood Frog	North Atlantic	GI-Inc	N	N	N	N	N	N/A	N
Malaclemys terrapin	Diamond-backed Terrapin	Mid Atlantic	N	N	N	N	N	N	N/A	N
Malaclemys terrapin	Diamond-backed Terrapin	North Atlantic	N	N	N	N	N	N	N/A	N
Mustela nivalis	Least Weasel	Mid Atlantic	N	N	N	N	N	N	N/A	N
Mustela nivalis	Least Weasel	North Appalachian	N	N	N	N	N	N	N/A	N
Nyssa sylvatica	Blackgum	North Appalachian	SI	N	N	N	N	N/A	U	N
Nyssa sylvatica	Blackgum	Mid Atlantic	N	N	N	N	N	N/A	N	N
Nyssa sylvatica	Blackgum	North Atlantic	SI	N	N	N	N	N/A	U	N

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Parkesia motacilla	Louisiana Waterthrush	Mid Atlantic	Inc-SI	N	N	N	N	N	N/A	N
Parkesia motacilla	Louisiana Waterthrush	North Appalachian	Inc-SI	N	N	N	N	N	N/A	N
Parkesia motacilla	Louisiana Waterthrush	North Atlantic	Inc-SI	N	N	N	N	N	N/A	N
Parkesia noveboracensis	Northern Waterthrush	Mid Atlantic	Inc-SI	N	N	N	N	N	N/A	N
Parkesia noveboracensis	Northern Waterthrush	North Appalachian	Inc-SI	N	N	N	N	N	N/A	N
Parkesia noveboracensis	Northern Waterthrush	North Atlantic	Inc-SI	N	N	N	N	N	N/A	N
Picea mariana	Black spruce	North Appalachian	SI	N	N	N	N	N/A	N	N
Picea mariana	Black spruce	North Atlantic	N	SI-N	N	N	N	N/A	N	N
Picea rubens	Red Spruce	North Appalachian	N	N	N	N	N	N/A	N	N
Picea rubens	Red Spruce	North Atlantic	N	N	N	N	N	N/A	N	N
Pinus rigida	Pitch Pine	North Appalachian	SD	SD	N	N	N	N/A	N	N
Pinus rigida	Pitch Pine	North Atlantic	SD	SD	N	N	N	N/A	N	N
Pinus rigida	Pitch Pine	Mid Atlantic	SD	SD	N	N	N	N/A	N	N
Pinus strobus	White Pine	North Appalachian	N	N	N	N	N	N/A	N	N
Pinus strobus	White Pine	North Atlantic	N	N	N	N	N	N/A	N	N
Pinus strobus	White Pine	Mid Atlantic	N	N	N	N	N	N/A	N	N
Pituophis melanoleucus	Pinesnake	Mid Atlantic	N	SI-N-SD	N	N	N	N	N/A	N
Pituophis melanoleucus	Pinesnake	North Atlantic	N	SI-N-SD	N	N	N	N	N/A	N
Pontederia cordata	Pickerelweed	North Appalachian	SI	N	N	N	N	N/A	N	N
Pontederia cordata	Pickerelweed	Mid Atlantic	SI	N	N	N	N	N/A	N	N
Pontederia cordata	Pickerelweed	North Atlantic	SI	N	N	N	N	N/A	N	N
Quercus alba	White Oak	North Appalachian	N	N	N	Dec	N	N/A	N	SI
Quercus alba	White Oak	North Atlantic	SD	N	N	Dec	N	N/A	N	SI
Quercus alba	White Oak	North Atlantic	N	N	N	Dec	N	N/A	N	SI
Salmo salar	Atlantic Salmon	North Appalachian	SI	N	N	N	N	N	N/A	N
Salmo salar	Atlantic Salmon	North Atlantic	SI	N	N	N	N	N	N/A	N

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Salvelinus fontinalis	Brook Trout	North Atlantic	SI	N	N	N	N	N	N/A	N
Salvelinus fontinalis	Brook Trout	North Appalachian	SI	N	N	N	N	N	N/A	N
Sarracenia purpurea	Purple pitcher plant	North Atlantic	SI	N	N	N	N	N/A	N	N
Sarracenia purpurea	Purple pitcher plant	North Appalachian	SI	N	N	N	N	N/A	N	N
Sarracenia purpurea	Purple pitcher plant	Mid Atlantic	SI	N	N	N	N	N/A	N	N
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Appalachian	Inc	N	N	N	N	N/A	N	N
Scirpus ancistrochaetus	Barbedbristle Bulrush	Mid Atlantic	Inc	N	N	N	N	N/A	N	N
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Atlantic	Inc	N	N	N	N	N/A	N	N
Scirpus cyperinus	Woolgrass	North Appalachian	N	N	N	N	N	N/A	N	N
Scirpus cyperinus	Woolgrass	North Atlantic	SI	N	N	N	N	N/A	N	N
Scirpus cyperinus	Woolgrass	Mid Atlantic	SI	N	N	N	N	N/A	N	N
Seiurus aurocapilla	Ovenbird	Mid Atlantic	Inc-SI	SI	N	N	N	N	N/A	N
Seiurus aurocapilla	Ovenbird	North Appalachian	Inc-SI	N	N	N	N	N	N/A	N
Seiurus aurocapilla	Ovenbird	North Atlantic	Inc-SI	N	N	N	N	N	N/A	N
Setophaga cerulea	Cerulean Warbler	Mid Atlantic	SI-N	SI	N	U	N	N	N/A	N
Setophaga cerulea	Cerulean Warbler	North Atlantic	SI-N	SI	N	U	N	N	N/A	N
Setophaga striata	Blackpoll Warbler	Mid Atlantic	N	N	N	N	N	N	N/A	N
Setophaga striata	Blackpoll Warbler	North Appalachian	SI	N	N	N	SI	N	N/A	N
Setophaga striata	Blackpoll Warbler	North Atlantic	N	N	N	N	N	N	N/A	N
Somatochlora incurvata	Incurvate Emerald	North Appalachian	SI	N	N	N	N	N	N/A	N
Sorex palustris	American Water Shrew	Mid Atlantic	SI-N	N	N	N	N	N	N/A	N
Sorex palustris	American Water Shrew	North Appalachian	SI-N	N	N	N	N	N	N/A	N
Sorex palustris	American Water Shrew	North Atlantic	SI-N	N	N	N	N	N	N/A	N
Spartina alterniflora	Saltwater cordgrass	North Atlantic	SI	Inc	N	N	N	N/A	N	N
Spartina alterniflora	Saltwater cordgrass	North Appalachian	Inc	Inc	N	SI	N	N/A	N	N
Spartina alterniflora	Saltwater cordgrass	Mid Atlantic	Inc	Inc	N	N	N	N/A	N	N

Species	English Name	Subregion	C2bii physiological hydrological niche	C2c Disturbance	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp
Sterna hirundo	Common Tern	Mid Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Sterna hirundo	Common Tern	North Appalachian	N	Inc-SI	N	N	N	N	N/A	N
Sterna hirundo	Common Tern	North Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Sternula antillarum	Least Tern	North Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Sternula antillarum	Least Tern	North Atlantic	N	Inc-SI	N	N	N	N	N/A	N
Sylvilagus transitionalis	New England cottontail	North Appalachian	N	N-SD	N	N	N	N	N/A	N
Sylvilagus transitionalis	New England cottontail	North Atlantic	N	N-SD	N	N	N	N	N/A	N
Thuja occidentalis	Northern white cedar	North Appalachian	SI	N	N	SI	N	N/A	N	N
Thuja occidentalis	Northern white cedar	North Atlantic	SI	N	N	SI	N	N/A	N	N
Thuja occidentalis	Northern white cedar	Mid Atlantic	SI	N	N	SI	N	N/A	N	N
Tsuga canadensis	Eastern Hemlock	North Appalachian	U	N	N	N	N	N/A	N	N
Tsuga canadensis	Eastern Hemlock	Mid- Atlantic	N	N	N	N	N	N/A	N	N
Tsuga canadensis	Eastern Hemlock	North Atlantic	N	N	N	N	N	N/A	N	N
Vallisneria americana	Tapegrass	North Appalachian	N	N	N	N	N	N/A	N	N
Vallisneria americana	Tapegrass	North Atlantic	N	N	N	N	N	N/A	N	N
Vallisneria americana	Tapegrass	Mid Atlantic	N	U	N	N	N	N/A	N	N

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Abies balsamea	*Balsam Fir*	*North Atlantic*	N	SI	N/A	SI	U	Inc	SI	N
Abies balsamea	*Balsam Fir*	*North Appalachian*	N	N	N/A	N	U	SI	SI	N
Accipiter gentilis	*Northern Goshawk*	*Mid Atlantic*	N	U	N	U	U	U	U	U
Accipiter gentilis	*Northern Goshawk*	*North Appalachian*	N	U	N	U	U	U	U	U
Accipiter gentilis	*Northern Goshawk*	*North Atlantic*	N	U	N	U	U	U	U	U
Acer saccharinum	*Silver Maple*	*North Atlantic*	N	N	N/A	U	U	SD	N	U
Acer saccharinum	*Silver Maple*	*North Appalachian*	N	N	N/A	U	U	Dec	N	U
Acer saccharum	*Sugar maple*	*North Appalachian*	U	N	N/A	SD	SD	SD	U	U
Acer saccharum	*Sugar maple*	*North Atlantic*	U	N	N/A	SD	U	N	N	U
Acer saccharum	*Sugar maple*	*Mid Atlantic*	U	N	N/A	SD	U	N	N	U
Acipenser oxyrinchus	*Atlantic Sturgeon*	*Mid Atlantic*	N	U	U	U	U	U	U	U
Acipenser oxyrinchus	*Atlantic Sturgeon*	*North Appalachian*	N	U	U	U	U	U	U	U
Acipenser oxyrinchus	*Atlantic Sturgeon*	*North Atlantic*	N	U	U	U	U	U	U	U
Alasmidonta heterodon	*Dwarf Wedgemussel*	*Mid Atlantic*	U	U	U	U	U	U	U	U
Alasmidonta heterodon	*Dwarf Wedgemussel*	*North Appalachian*	U	U	U	U	U	U	U	U
Alasmidonta heterodon	*Dwarf Wedgemussel*	*North Atlantic*	U	U	U	U	U	U	U	U
Alasmidonta varicosa	*Brook Floater*	*Mid Atlantic*	N	U	U	U	U	U	U	U
Alasmidonta varicosa	*Brook Floater*	*North Appalachian*	N	U	U	U	U	U	U	U
Alasmidonta varicosa	*Brook Floater*	*North Atlantic*	N	U	U	U	U	U	U	U
Alces americanus	*Moose*	*North Appalachian*	N	U	N	U	U	U	U	U
Alces americanus	*Moose*	*North Atlantic*	Inc-SI	U	N	U	U	U	U	U
Alosa sapidissima	*American Shad*	*Mid Atlantic*	N	U	N	U	U	U	U	U
Alosa sapidissima	*American Shad*	*North Appalachian*	N	U	N	U	U	U	U	U
Alosa sapidissima	*American Shad*	*North Atlantic*	N	U	N	U	U	U	U	U
Ambystoma jeffersonianum	*Jefferson Salamander*	*Mid-Atlantic*	N	U	U	U	U	U	U	U
Ambystoma jeffersonianum	*Jefferson Salamander*	*North Appalachian*	N	U	N	U	U	U	U	U
Ambystoma jeffersonianum	*Jefferson Salamander*	*North Atlantic*	N	U	N	U	U	U	U	U

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Ammodramus caudacutus	Saltmarsh Sparrow	Mid Atlantic	N	U	N	U	U	U	U	U
Ammodramus caudacutus	Saltmarsh Sparrow	North Atlantic	N	U	N	U	U	U	U	U
Anas rubripes	American Black Duck	Mid Atlantic	N	U	N	U	U	U	U	U
Anas rubripes	American Black Duck	North Appalachian	N	U	N	U	U	U	U	U
Anas rubripes	American Black Duck	North Atlantic	N	U	N	U	U	U	U	U
Botaurus lentiginosus	American Bittern	Mid Atlantic	N	U	N	U	U	U	U	U
Botaurus lentiginosus	American Bittern	North Atlantic	N	U	N	U	U	U	U	U
Botaurus lentiginosus	American Bittern	North Appalachian	N	U	N	U	U	Inc	U	U
Buteo lineatus	Red-shouldered Hawk	Mid Atlantic	N	U	N	U	U	SD-Dec	U	U
Buteo lineatus	Red-shouldered Hawk	North Appalachian	N	U	N	U	U	SD-Dec	U	U
Buteo lineatus	Red-shouldered Hawk	North Atlantic	N	U	N	U	U	SD-Dec	U	U
Callophrys hesseli	Hessel's Hairstreak	Mid Atlantic	N	U	N	U	U	U	U	U
Callophrys hesseli	Hessel's Hairstreak	North Appalachian	N	U	N	U	U	U	U	U
Callophrys hesseli	Hessel's Hairstreak	North Atlantic	N	U	N	U	U	U	U	U
Callophrys irus	Frosted Elfin	Mid Atlantic	N	U	U	U	U	U	U	U
Callophrys irus	Frosted Elfin	North Appalachian	N	U	U	U	U	U	U	U
Callophrys irus	Frosted Elfin	North Atlantic	N	U	U	U	U	U	U	U
Callophrys lanoraieensis	Bog Elfin	North Appalachian	N	U	U	U	U	U	U	U
Callophrys lanoraieensis	Bog Elfin	North Atlantic	N	U	U	U	U	U	U	U
Catharus bicknelli	Bicknell's Thrush	North Appalachian	SI	U	U	U	SI	GI-Inc	U	U
Catharus bicknelli	Bicknell's Thrush	North Atlantic	SI	U	U	U	Inc-SI	GI-Inc	U	U
Chamaecyparis thyoides	Atlantic white cedar	North Atlantic	U	N	N/A	U	U	N	N	U
Chamaecyparis thyoides	Atlantic white cedar	North Appalachian	U	N	N/A	U	U	N	N	U
Chamaecyparis thyoides	Atlantic white cedar	Mid-Atlantic	U	N	N/A	U	U	N	N	U
Chamaedaphne calyculata	Leatherleaf	North Appalachian	U	SI	N/A	U	U	U	U	U
Chamaedaphne calyculata	Leatherleaf	North Atlantic	U	SI	N/A	N	U	U	U	U
Chamaedaphne calyculata	Leatherleaf	Mid Atlantic	U	SI	N/A	N	U	U	U	U

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Charadrius melodus	Piping Plover	Mid Atlantic	N	U	N	U	U	U	U	U
Charadrius melodus	Piping Plover	North Appalachian	N	U	N	U	U	U	U	U
Charadrius melodus	Piping Plover	North Atlantic	N	U	N	U	U	U	U	U
Cicindela dorsalis	Eastern Beach Tiger Beetle	Mid Atlantic	N	U	U	U	U	U	U	U
Cicindela dorsalis	Eastern Beach Tiger Beetle	North Atlantic	N	U	U	U	U	U	U	U
Cistothorus palustris	Marsh Wren	Mid Atlantic	N	U	N	U	U	U	U	U
Cistothorus palustris	Marsh Wren	North Appalachian	N	U	N	U	U	U	U	U
Cistothorus palustris	Marsh Wren	North Atlantic	N	U	N	U	U	U	U	U
Clemmys guttata	Spotted turtle	Mid Atlantic	N	U	N	U	U	U	U	U
Clemmys guttata	Spotted turtle	North Appalachian	N	U	N	U	U	U	U	U
Clemmys guttata	Spotted turtle	North Atlantic	N	U	N	U	U	U	U	U
Cryptobranchus alleganiensis	Hellbender	Mid Atlantic	N	U	U	U	U	U	U	U
Falcipennis canadensis	Spruce Grouse	North Appalachian	N	U	N	U	U	U	U	U
Falcipennis canadensis	Spruce Grouse	North Atlantic	N	U	N	U	U	U	U	U
Glyptemys insculpta	Wood Turtle	Mid Atlantic	N	U	U	U	U	U	U	U
Glyptemys insculpta	Wood Turtle	North Appalachian	N	U	U	U	U	U	U	U
Glyptemys insculpta	Wood Turtle	North Atlantic	N	U	U	U	U	U	U	U
Haematopus palliatus	American Oystercatcher	Mid Atlantic	N	U	N	U	U	U	U	U
Haematopus palliatus	American Oystercatcher	North Atlantic	N	U	N	U	U	U	U	U
Hylocichla mustelina	Wood Thrush	Mid Atlantic	N	U	N	Inc-SI	U	Inc-SI	U	U
Hylocichla mustelina	Wood Thrush	North Appalachian	N	U	N	Inc-SI	U	N-SD	U	U
Hylocichla mustelina	Wood Thrush	North Atlantic	N	U	N	Inc-SI	U	SI	U	U
Isotria medeoloides	small whorled pogonia	North Appalachian	N	SI	N/A	U	U	U	U	U
Isotria medeoloides	small whorled pogonia	North Atlantic	N	SI	N/A	U	U	U	U	U
Isotria medeoloides	small whorled pogonia	Mid Atlantic	N	SI	N/A	U	U	U	U	U
Ixobrychus exilis	Least Bittern	Mid Atlantic	N	U	U	U	U	U	U	U
Ixobrychus exilis	Least Bittern	North Appalachian	N	U	U	U	U	U	U	U

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Ixobrychus exilis	Least Bittern	North Atlantic	N	U	U	U	U	U	U	U
Lanthus vernalis	Southern Pygmy Clubtail	Mid Atlantic	N	U	U	U	U	U	U	U
Lanthus vernalis	Southern Pygmy Clubtail	North Appalachian	N	U	U	U	U	U	U	U
Lanthus vernalis	Southern Pygmy Clubtail	North Atlantic	N	U	U	U	U	U	U	U
Lasiurus borealis	Eastern Red Bat	Mid Atlantic	N	U	U	U	U	U	U	U
Lasiurus borealis	Eastern Red Bat	North Appalachian	N	U	U	U	U	U	U	U
Lasiurus borealis	Eastern Red Bat	North Atlantic	N	U	U	U	U	U	U	U
Limulus polyphemus	Horseshoe Crab	Mid Atlantic	N	U	N	U	U	U	U	U
Limulus polyphemus	Horseshoe Crab	North Appalachian	N	U	N	U	U	U	U	U
Limulus polyphemus	Horseshoe Crab	North Atlantic	N	U	N	U	U	U	U	U
Lithobates sylvaticus	Wood Frog	Mid Atlantic	N	U	N	U	U	U	U	U
Lithobates sylvaticus	Wood Frog	North Appalachian	N	U	N	U	U	U	U	U
Lithobates sylvaticus	Wood Frog	North Atlantic	N	U	N	U	U	U	U	U
Malaclemys terrapin	Diamond-backed Terrapin	Mid Atlantic	N	U	SI-N	U	U	U	U	U
Malaclemys terrapin	Diamond-backed Terrapin	North Atlantic	N	U	SI-N	U	U	U	U	U
Mustela nivalis	Least Weasel	Mid Atlantic	N	U	N	U	U	U	U	U
Mustela nivalis	Least Weasel	North Appalachian	N	U	N	U	U	U	U	U
Nyssa sylvatica	Blackgum	North Appalachian	U	U	U	U	U	SD	N	U
Nyssa sylvatica	Blackgum	Mid Atlantic	U	U	U	U	U	SI	N	U
Nyssa sylvatica	Blackgum	North Atlantic	U	U	U	U	U	SI	N	U
Parkesia motacilla	Louisiana Waterthrush	Mid Atlantic	N	U	N	U	U	U	U	U
Parkesia motacilla	Louisiana Waterthrush	North Appalachian	N	U	N	U	U	U	U	U
Parkesia motacilla	Louisiana Waterthrush	North Atlantic	N	U	N	U	U	U	U	U
Parkesia noveboracensis	Northern Waterthrush	Mid Atlantic	N	U	N	U	U	GI	U	U
Parkesia noveboracensis	Northern Waterthrush	North Appalachian	N	U	N	U	U	SI	U	U
Parkesia noveboracensis	Northern Waterthrush	North Atlantic	N	U	N	U	U	SI	U	U
Picea mariana	Black spruce	North Appalachian	U	U	U	U	U	Inc	Inc	U

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Picea mariana	Black spruce	North Atlantic	U	U	U	U	U	GI	GI	U
Picea rubens	Red Spruce	North Appalachian	U	SI	N/A	U	U	SI	N	U
Picea rubens	Red Spruce	North Atlantic	U	SI	N/A	U	U	SI	N	U
Pinus rigida	Pitch Pine	North Appalachian	U	SD	N/A	U	U	N	N	U
Pinus rigida	Pitch Pine	North Atlantic	U	SD	N/A	U	U	N	N	U
Pinus rigida	Pitch Pine	Mid Atlantic	U	SD	N/A	U	U	U	U	U
Pinus strobus	White Pine	North Appalachian	U	N	N/A	U	U	SD	U	U
Pinus strobus	White Pine	North Atlantic	U	N	N/A	U	U	SI	U	U
Pinus strobus	White Pine	Mid Atlantic	U	N	N/A	U	U	GI	U	U
Pituophis melanoleucus	Pinesnake	Mid Atlantic	N	U	N	U	U	U	U	U
Pituophis melanoleucus	Pinesnake	North Atlantic	N	U	N	U	U	U	U	U
Pontederia cordata	Pickerelweed	North Appalachian	U	U	U	U	U	U	U	U
Pontederia cordata	Pickerelweed	Mid Atlantic	U	U	U	U	U	SI	U	U
Pontederia cordata	Pickerelweed	North Atlantic	U	U	U	U	U	U	U	U
Quercus alba	White Oak	North Appalachian	N	SI-N	N/A	U	U	SD	N	N
Quercus alba	White Oak	North Atlantic	N	SI-N	N/A	U	U	SD	N	N
Quercus alba	White Oak	North Atlantic	N	SI-N	N/A	U	U	SD	N	N
Salmo salar	Atlantic Salmon	North Appalachian	N	U	U	U	U	U	U	U
Salmo salar	Atlantic Salmon	North Atlantic	N	U	U	U	U	U	U	U
Salvelinus fontinalis	Brook Trout	North Atlantic	N	U	N	U	U	U	U	U
Salvelinus fontinalis	Brook Trout	North Appalachian	N	U	N	U	U	U	U	U
Sarracenia purpurea	Purple pitcher plant	North Atlantic	U	N-SD	N/A	U	U	U	U	U
Sarracenia purpurea	Purple pitcher plant	North Appalachian	U	N-SD	N/A	U	U	U	U	U
Sarracenia purpurea	Purple pitcher plant	Mid Atlantic	U	N-SD	N/A	U	U	U	U	U
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Appalachian	U	N	N/A	U	U	U	U	U
Scirpus ancistrochaetus	Barbedbristle Bulrush	Mid Atlantic	U	N	N/A	U	U	U	U	U
Scirpus ancistrochaetus	Barbedbristle Bulrush	North Atlantic	U	N	N/A	U	U	U	U	U

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Scirpus cyperinus	Woolgrass	North Appalachian	U	U	U	U	U	U	U	U
Scirpus cyperinus	Woolgrass	North Atlantic	U	U	U	U	U	U	U	U
Scirpus cyperinus	Woolgrass	Mid Atlantic	U	U	U	U	U	U	U	U
Seiurus aurocapilla	Ovenbird	Mid Atlantic	N	U	N	U	U	GI	U	U
Seiurus aurocapilla	Ovenbird	North Appalachian	N	U	N	U	U	SI	U	U
Seiurus aurocapilla	Ovenbird	North Atlantic	N	U	N	U	U	Inc-SI	U	U
Setophaga cerulea	Cerulean Warbler	Mid Atlantic	N	U	N	U	U	SI	U	U
Setophaga cerulea	Cerulean Warbler	North Atlantic	N	U	N	U	U	SD-Dec	U	U
Setophaga striata	Blackpoll Warbler	Mid Atlantic	N	U	N	U	U	U	U	U
Setophaga striata	Blackpoll Warbler	North Appalachian	N	U	N	U	U	U	U	U
Setophaga striata	Blackpoll Warbler	North Atlantic	N	U	N	U	U	U	U	U
Somatochlora incurvata	Incurvate Emerald	North Appalachian	N	U	N	U	U	U	U	U
Sorex palustris	American Water Shrew	Mid Atlantic	N	U	N	U	U	U	U	U
Sorex palustris	American Water Shrew	North Appalachian	N	U	N	U	U	U	U	U
Sorex palustris	American Water Shrew	North Atlantic	N	U	N	U	U	U	U	U
Spartina alterniflora	Saltwater cordgrass	North Atlantic	U	N-SD	N/A	U	Inc	N	U	U
Spartina alterniflora	Saltwater cordgrass	North Appalachian	U	N-SD	N/A	U	N	N	U	U
Spartina alterniflora	Saltwater cordgrass	Mid Atlantic	U	N-SD	N/A	U	N-SD	N-SD	U	U
Sterna hirundo	Common Tern	Mid Atlantic	N	U	U	U	U	U	U	U
Sterna hirundo	Common Tern	North Appalachian	N	U	U	U	U	U	U	U
Sterna hirundo	Common Tern	North Atlantic	N	U	U	U	U	U	U	U
Sternula antillarum	Least Tern	North Atlantic	N	U	N	U	U	U	U	U
Sternula antillarum	Least Tern	North Atlantic	N	U	N	U	U	U	U	U
Sylvilagus transitionalis	New England cottontail	North Appalachian	U	N-SD	N/A	U	U	U	U	U
Sylvilagus transitionalis	New England cottontail	North Atlantic	U	N-SD	N/A	U	U	U	U	U

Species	English Name	Subregion	C4e Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas
Thuja occidentalis	Northern white cedar	North Appalachian	U	SI	N/A	U	U	Inc	N	U
Thuja occidentalis	Northern white cedar	North Atlantic	U	SI	N/A	U	U	Inc	N	U
Thuja occidentalis	Northern white cedar	Mid Atlantic	U	SI	N/A	U	U	GI	N	U
Tsuga canadensis	Eastern Hemlock	North Appalachian	U	N	N/A	U	U	N-SD	N	U
Tsuga canadensis	Eastern Hemlock	Mid- Atlantic	U	N	N/A	U	U	N-SD	N	U
Tsuga canadensis	Eastern Hemlock	North Atlantic	U	N	N/A	U	U	N-SD	N	U
Vallisneria americana	Tapegrass	North Appalachian	U	U	U	U	U	U	U	U
Vallisneria americana	Tapegrass	North Atlantic	U	N	N/A	U	U	U	U	U
Vallisneria americana	Tapegrass	Mid Atlantic	U	N	N/A	U	U	U	U	U

Appendix 3 Notes and References for Scoring Species

Factor	Reference	Details / Justification
Abies balsamea		
B.2.A. distribution relative to natural barriers	Systems map and ELU's	Using mapped systems and high elevation areas as estimate of range is considerably narrower than the Little range map. In North Atlantic, occurrences of spruce - fir upland and terrestrial systems are largely confined to one subsection, on non-contiguous areas of suitable habitat. Where they occur on montane habitats, they are on the summits with nowhere to go.
B.2.B. distribution relative to anthropogenic barriers	Systems map	In North Atlantic, some areas of highly developed areas are within the assessment area but generally south of occurrences of Abies.
C.1. sensitivity, dispersal	Asselin et al. 2001; USFS Sylvics vol 1	Mean dispersal distance of Abies balsamea measured as 25-60 m in boreal forest of Quebec (Asselin et al. 2001)
C.2.a.i. Historical Thermal niche	climate wizard	North Atlantic and Mid-Atlantic assessment areas are fully within one category; Northern Appalachian / Maritime Canada spans 2 categories.
	Thompson et al. 1999	48 degrees C extrapolated from USGS atlas
C.2.a.ii. Physiological thermal niche	Sylvics vol. 1, R.M. Frank	Mean annual temp within range is 25-45 degrees F; essentially confined to cool climates
C.2.b.i Historical hydrological niche	climate wizard	1654mm - 881mm = 773mm
C.2.b.i Physiological hydrological niche	Sylvics vol. 1, R.M. Frank	Most of range is characterized by "abundant moisture"
C.5.a. measured genetic variation	Sylvics vol. 1, R.M. Frank	Balsam fir seedlings grown from seed collected along an elevational gradient in New Hampshire showed a clinal pattern of carbon dioxide uptake with respect to the elevational gradient. This suggests an adaption to temperature through natural selection.
	Shea and Furnier 2002	low genetic variability in isolated populations; conifers in general higher than average variability but Abies less by comparison

C4e. Sensitivity to pathogens or natural enemies	Belyea 1952; Gray 2008	balsam fir mortality was noted to be near complete following 8 years of spruce budworm infestation in Ontario (Belyea 1952); increase of 6 years in infestation duration projected by late century (Gray 2008)
C.6. Phenological response	Sylvics vol. 1, R.M. Frank	photoperiod influences flowering time; I infer that Abies would be less likely to respond to temperature changes in phenology
D.2. Modeled future change in range	Prasad et al. 2007	Range contraction to 12% of North Atlantic range by 2100 (from 25,000 to 3000 sq. km); range contraction of <50% in US portion of range (102,300 to 47,000 sq km); Canadian portion not mapped but likely to be less severe.
D.3. Modeled overlap in future and current range	Prasad et al. 2007	<30% range overlap in North Atlantic, and >60% range overlap in Northern Appalachian, and by extrapolation, in maritime Canada
D.3. Occurrence of protected areas	Prasad et al. 2007	There is a concentration of Gap status 2 protected areas in the remaining portion of the range in North Atlantic; large protected areas in Maine, New Hampshire, and New York in remaining range of Northern Appalachian (US portion)

Accipiter gentilis		
C2c. Dependence on a specific disturbance regime		Climate change may result in an increase in the frequency or intensity of forest fires, but probably not to the extent that the overall distribution or abundance of the species in assessment area would be significantly affected.
C4a. Dependence on other species to generate habitat		Breeding habitat may include any of several different tree species.
C4b. Dietary versatility (animals only)		Diet readily changes with prey availability.

Acer saccharinum		
B.2.A. distribution relative to natural barriers		Although large and medium rivers provide more or less uninterrupted potential habitat, the north-to-south flow orientation of these rivers works against need for migration northwards with climate change. (overlaid NEAHCS medium and large rivers on assessment area)

B.2.B. distribution relative to anthropogenic barriers		This species is restricted to river fronts, and as such usually has little in the way of anthropogenic barriers to dispersal
C.1. sensitivity, dispersal	http://na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/acer/saccharinum.htm	Seedlings of silver maple require 2,000 to 2,500 hours of chilling to break dormancy
	Greene and Johnson 1992	Winged fruits and seeds travel approximately twice as far as predicted by micrometeorological models of seed dispersal by the wind. We hypothesize that seeds preferentially abscise at higher velocities because the motive force for abscission is drag (proportional to the square of the wind velocity). A 3-year study of fruit abscission in *Acer saccharinum* L., supplemented by experimental studies, demonstrates that for this species (*i*) separation layers develop rapidly when relative humidity is low (the early afternoon in a typical diurnal relative humidity cycle), and (*ii*) the exponents in power law equations relating abscission rate to wind speed are somewhat higher than the expected value of 2.0.
	Horn et al. 2001	Increased wind turbulence and velocities can foster long-distance seed dispersal. By inference, with an increase in extreme climate events, Acer saccharinum would be at an advantage for long-distance dispersal.
	Vittoz and Engler_2007	Pterometeorochory (anemochory)(winged seeds) for trees: dispersal distance 4m - 150m
C.2.a.i. Historical Thermal niche	Thompson et al. 1999	from January temp and July temp, approx 44 degrees C difference
C.2.a.ii. Physiological thermal niche		
C.2.b.i Historical hydrological niche	Thompson et al. 1999	from January precip and July precip approx 500mm difference
C.2.b.i Physiological hydrological niche		
C.2.c. Dependence on specific disturbance regime	http://na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/acer/saccharinum.htm	Requires moist, mineral soils with considerable organic matter, I infer that this is brought about by flooding regime that may be altered by drying.

C.5.a. measured genetic variation	Saeki et al. 2011	Comparison between A. rubrum showed A. saccharinum had lower haplotype diversity and weaker phylogeographic structure. Authors infer that the pattern in A. saccharinum may have resulted from bottlenecks due to ecological and historical factors. A. saccharinum "displays markedly less morphological variation" - overall genetic variability difficult to interpret
	Hamrick et al 1976	Relative genetic variability of trees, outcrossers, high fecundity, wind-dispersed, late-successional, mesic is higher than herbaceous, selfed, low-fecundity, animal-dispersed, early successional xeric species
Acer saccharum		
B.2.A. distribution relative to natural barriers		
B.2.B. distribution relative to anthropogenic barriers		
C.1. sensitivity, dispersal	Vittoz and Engler_2007	Pterometeorochory (anemochory)(winged seeds) for trees: dispersal distance 4m - 150m
C.5.a. measured genetic variation	Hamrick et al 1976	Relative genetic variability of trees, outcrossers, high fecundity, wind-dispersed, late-successional, mesic is higher than herbaceous, selfed, low-fecundity, animal-dispersed, early successional xeric species
C.6. Phenological response	Norby et al 2003	Experimental warming correlated with earlier bud burst over four years in Acer saccharum

Acipenser oxyrinchus		
B1. Exposure to sea level rise		All populations migrate through areas subject to sea level rise, but it seems unlikely that changing sea level will have a significant positive or negative impact on the species.
B2a. Distribution relative to natural barriers	Atlantic Sturgeon Status Review Team (ASSRT). 2007	Natural barriers (e.g., waterfalls) generally mark the upstream limit of historical spawning habitat (ASSRT 2007). Potentially they could affect the ability of this species to shift its range with climate change, but in reality probably will not cause a climate-change-related loss or reduction in habitat or area of occupancy within the assessment areas.
B2b. Distribution relative to anthropogenic barriers	Atlantic Sturgeon Status Review Team (ASSRT). 2007	Anthropogenic barriers (e.g., dams) generally (but not always) coincide with natural falls and the upstream limit of historical spawning habitat (ASSRT 2007). In some rivers, anthropogenic barriers could affect the ability of this species to shift its range with climate change, but climate-change-related loss or reduction in habitat or area of occupancy within the assessment areas probably will be minor.
B3. Predicted impact of land use changes	Atlantic Sturgeon Status Review Team (ASSRT). 2007	Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain (ASSRT 2007). Construction of new major dams in response to climate change probably will not significantly affect this species in the assessment areas.
C1. Dispersal and movements	NSX; King et al. 2001	High degree of fidelity to natal habitat (philopatry) and low rate of colonization of vacant habitat may be offset by high mobility in ocean and within rivers, such that viable populations in some areas would be a source for eventual colonization of currently vacant rivers that might become suitable as a result of climate change. However, the time frame for this is uncertain.
C2aii. Physiological thermal niche	NSX	Wide range of spawning temperatures.

Alasmidonta heterodon		
B1. Exposure to sea level rise		
B2a. Distribution relative to natural barriers		Barriers are not likely to contribute to a climate-change-related loss or reduction in habitat or area of occupancy within the assessment area.
B2b. Distribution relative to anthropogenic barriers		
B3. Predicted impact of land use changes		Construction of dams/impoundments in response to climate drying might negatively affect this species is some areas. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.
C1. Dispersal and movements		Fish hosts provide the primary means of dispersal, and not uncommonly these hosts likely disperse mussels at least 100-1,000 meters.
C4d. Dependence on other species for propagule dispersal	NSX	Relies on not more than a few species of fish hosts
C5b. Occurrence of bottlenecks in recent evolutionary history	NSX	Area of occupancy has undergone a substantial decline, but the population has not rebounded and so does not qualify for the Increase Vulnerability/Somewhat Increase Vulnerability categories.

Alasmidonta varicosa		
B2a. Distribution relative to natural barriers		Barriers are not likely to contribute to a climate-change-related loss or reduction in habitat or area of occupancy within the assessment area.
B2b. Distribution relative to anthropogenic barriers		Construction of dams/impoundments in response to climate drying might negatively affect this species is some areas. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.

C1. Dispersal and movements		Fish hosts provide the primary means of dispersal, and not uncommonly these hosts likely disperse mussels at least 100-1,000 meters.
C4d. Dependence on other species for propagule dispersal	NSX	Likely relies on not more than a few species of fish hosts
C5b. Occurrence of bottlenecks in recent evolutionary history	NSX	Area of occupancy has undergone a substantial decline, but the population has not rebounded and so does not qualify for the Increase Vulnerability/Somewhat Increase Vulnerability categories.

Alces americanus		
B2a. Distribution relative to natural barriers		Natural barriers are not likely to contribute to a climate-change-related loss or reduction in habitat or area of occupancy within the assessment area.
B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers exist in all assessment areas, but these are not likely to result in a significant reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.
C2bi. Physiological hydrological niche		Moose recently have expanded their range southward into relatively warm and dry areas in New England and the Rocky Mountains, so it seems unlikely that projected climate change in the northern portion of the North Atlantic LCC will negatively affect moose with respect to hydrological or thermal niche. It may be reasonable to assume that climate change in the southernmost part of the North Atlantic LCC will negatively affect this relatively cool-climate-adapted species with respect to thermal niche.
C2c. Dependence on a specific disturbance regime		Moose do thrive on second growth but are fairly flexible with respect to habitat and are not very dependent on a specific disturbance regime that is likely to be changed significantly in a predictable way as a result of climate change.

Alosa sapidissima		
B1. Exposure to sea level rise		All populations migrate through areas subject to sea level rise, but it seems unlikely that changing sea level will have a significant positive or negative impact on the species.
B2a. Distribution relative to natural barriers		Natural barriers (e.g., high waterfalls) exist in some areas, and these might in some cases result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change. There are no natural barriers to north-south range shifts.
B2b. Distribution relative to anthropogenic barriers		Locally, dams might negatively affect the ability of this species to shift its range and thereby result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with climate change.
B3. Predicted impact of land use changes		Construction of dams/impoundments in response to climate drying might negatively affect this species is some areas. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.
C1. Dispersal and movements		The rapid range expansion of this species after it was introduced in California in 1871 suggests that dispersal ability would not limit the species' ability to shift its range with climate change.
C2aii. Physiological thermal niche		Tolerates wide range of thermal conditions.
C3. Restriction to uncommon geological features or derivatives	NSX	Uses diverse and widely available spawning substrates.

Ambystoma jeffersonianum		
B2a. Distribution relative to natural barriers		Natural barriers are not likely to contribute to a climate-change-related loss or reduction in habitat or area of occupancy within the assessment area.
B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers exist in all assessment areas, but these are not likely to result in a significant reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.
C2aii. Physiological thermal niche		Niche is here regarded as primarily hydrological rather than thermal, but the role of temperature in the distribution of this species is uncertain.
C2bi. Physiological hydrological niche		Reduction in vernal pool habitat is assumed not to be offset by increases in habitat that might result from a change of certain permanent ponds into ephemeral pools.
C4b. Dietary versatility (animals only)	NSX	This species feeds opportunistically on a wide array of small invertebrates.

Ammodramus caudacutus (salt marsh sparrow)		
B1. Exposure to sea level rise		All of range is subject to sea level rise.
B3. Predicted impact of land use changes		This species is vulnerable to habitat loss/degradation resulting from land use changes (e.g., sea wall construction) that may be undertaken is response to climate-change related increase in sea level.
C1. Dispersal and movements		Despite some degree of natal philopatry and fidelity to breeding sites, this species has movement capabilities that should enable it readily to shift its range with climate change.
C2c. Dependence on a specific disturbance regime		Climate-change related increases in severe weather events (e.g., hurricanes) could cause reductions in the extent of available breeding habitat and also could reduce populations through increased incidence of reproductive failure (e.g., when habitat is flooded).

C4a. Dependence on other species to generate habitat		Habitat is dominated by only a few plant species.

Anas rubripes		
B1. Exposure to sea level rise		Only a small part of the nesting range is subject to sea level rise, but a much greater area of winter habitat is vulnerable to sea level rise.
B3. Predicted impact of land use changes		This species is vulnerable to winter habitat loss/degradation resulting from land use changes (e.g., sea wall construction) that may be undertaken is response to climate-change related increase in sea level.
C2bi. Physiological hydrological niche		Some wetland habitat could be lost as a result of climate change.
C2c. Dependence on a specific disturbance regime		Some winter habitat could be lost or degraded as a result of climate-change related increases in severe weather events.
C4f. Sensitivity to competition from native or non-native species	Conroy et al. 2002	Interbreeding with and competition with mallards in winter habitat is one of four continental-scale factors in decline

Botaurus lentiginosus		
B1. Exposure to sea level rise		Only a very small portion of the range is vulnerable to sea level rise.
B3. Predicted impact of land use changes		Some wetland habitats could be lost or reduced (flooded) as a result of dams constructed in response to climate change, but the scope of this threat is likely to be quite small. Also, such loss might be offset by increases in habitat that might result from dam construction that results in wetland increase.
C1. Dispersal and movements		Dispersal and movement capability are such that this species should be able to shift its range as needed to accommodate climate-change-related alterations in the distribution of suitable habitat.

C2bi. Physiological hydrological niche		Some marginal wetland habitat could be lost or rendered less suitable as a result of climate change. On the other hand, some currently open water areas might become suitable habitat. Here I assume that the overall effect would be a net decrease in available habitat.
C4a. Dependence on other species to generate habitat		The number of emergent wetland plant species that provide suitable habitat is relatively small but often more than a few.
C4b. Dietary versatility (animals only)		Diet is very flexible.

Buteo lineatus (red-shouldered hawk)		
C1. Dispersal and movements		This species should be able to make substantial range shifts as necessary with climate change.
C2c. Dependence on a specific disturbance regime		Fire frequency/intensity might increase with climate change, and this could reduce the amount of suitable habitat, but the degree of the effect probably would be relatively small.
C4f. Sensitivity to competition from native or non-native species	Jacobs and Jacobs 2002	this species is susceptible to competition by red-tailed hawk where forest cover is decreasing due to agriculture or development
D2. Modeled future (2050) change in population or range size	http://www.nrs.fs.fed.us/atlas/bird/fut_incid_3390.html	Modeled climate-based future range/abundance indicates increases in all assessment areas.

Callophrys hesseli (Hessel's hairstreak)		
B1. Exposure to sea level rise	NSX	On a global scale, some populations are vulnerable to sea level rise, but it appears that this factor would affect less than 10 percent of the range in all three assessment areas of the North Atlantic LCC. The extent to which sea level rise could allow suitable habitat to develop in areas now lacking it is unknown.
C1. Dispersal and movements	NSX	These butterflies readily disperse within their swamp habitat but rarely disperse across other habitats.
C2bi. Physiological hydrological niche	NSX	Climate drying likely will reduce the extent and quality of the species' wetland habitat.

C2c. Dependence on a specific disturbance regime	NSX	Fire frequency could increase with climate drying. Although fires can stimulate habitat regeneration, in today's landscape, with numerous deer, regeneration after fire is unlikely.

Callophrys irus (frosted elfin)		
C1. Dispersal and movements	NSX	Dispersal beyond 1 km seems not to be rare across open habitats but tends to be more limited across forested areas.
C2bi. Physiological hydrological niche	NSX	Favors relatively warm dry sites.
C3. Restriction to uncommon geological features or derivatives	NSX	Populations generally are associated with xeric sands, which are at least somewhat patchy in distribution, but Baptisia feeders may also occur on rocky outcrops and glacial till.
C4b. Dietary versatility (animals only)	NSX	Primary food plants are Lupinus and Baptisia.

Callophrys lanoraieensis (bog elfin)		
B2b. Distribution relative to anthropogenic barriers		Beaches that are heavily used by humans generally are not barriers but rather unsuitable habitat.
C1. Dispersal and movements		Dispersal characteristics are unknown, but dispersal beyond 2 km likely is rare.
C2bi. Physiological hydrological niche		Some populations likely occur in habitats that may be lost or reduced as a result of climate change, whereas others occur in wetter habitats that presumably would remain suitable.
C4a. Dependence on other species to generate habitat		Restriction to black spruce habitats is scored under factor C4b (dietary versatility).

Catharus bicknelli (Bicknell's thrush)		
B3. Predicted impact of land use changes		The overall impact of wind farms is uncertain but probably negative. Establishment of wind farms is likely to destroy and fragment some habitat, but wind farm establishment and maintenance may also create some habitat (regenerating forest). Some mortality resulting from collisions with wind turbines is likely to occur on an ongoing basis, but the severity of this threat is uncertain.
C1. Dispersal and movements	Rimmer et al. 2001	This species should be able to make substantial range shifts as necessary with climate change.
C2aii. Physiological thermal niche	Rodenhouse et al. 2008	In a major portion of the Northern Appalachian range, this is a high-elevation/mountain-top species that is currently undergoing a climate-change-related decline that is likely to continue to a very large degree as habitat shrinks. In the North Atlantic assessment area, habitat might completely disappear.
C2c. Dependence on a specific disturbance regime		This species responds positively to various kinds of habitat disturbances such as fires, insect outbreaks, wind throw, and ice and snow damage. Score assumes that these disturbances will become more frequent, extensive, or severe with climate change,
C4a. Dependence on other species to generate habitat		Essential habitat structure in many areas is provided by just a few plant species (e.g., balsam fir; red spruce)
C4f. Sensitivity to competition from native or non-native species	Lambert and McFarland 2004	Degree of effects of competition with Swainson's thrush needs further study
C4g. Other interspecific interactions	http://www.fws.gov/northeast/climatechange/stories/bicknellsthrush.html	Climate-change-related increases in red squirrel populations could increase nest predation on the thrush and reduce thrush populations.
C6. Phenological response to changing seasonal temp/precip dynamics	http://www.fws.gov/news/blog/index.cfm/2011/5/23/Vermont-Climate-Change-Poses-Challenges-for-the-Bicknells-Thrush--Shrinking-Habitat-Nestinvadin	A mismatch between the arrival time in spring of Bicknell's thrush, which is regulated by day length, and the abundance of insect prey, linked to temperature, might occur as a result of climate change, but the timing, scope, and severity of this potential threat are unknown.

D1. Documented response to recent climate change	Rodenhouse et al. 2008	
D2. Modeled future (2050) change in population or range size	http://www.slideshare.net/catharus/climate-change-and-bicknells-thrush	

Chamaecyparis thyoides (Atlantic white cedar)		
C1. Dispersal and movements	Kuzer et al 1997	Lack of correlation between geographic and genetic distances among pops suggest that cedar did not advance northward up the coast post-glaciation. Wind-dispersed seeds can travel 1.6 km from a tall tree in windy conditions but it would have taken >50,000 years to reach Maine. They postulate that long-distance dispersal, by birds, water, and snowpack.
C5a. Measured genetic variation	Kuzer et al 1997	heterozygosity was found to be higher in this species than that of Thuja occidentalis or Thuja plicata

Chamaedaphne calyculata (leatherleaf)		
C1. Dispersal and movements	Redington 1994	fruits eaten by ruffed grouse
C4c. Pollinator versatility (plants only)	Wroblewska 2012	insect-pollinated
C5a. Measured genetic variation	Wroblewska 2012	notes low genetic diversity of this species throughout its range

Charadrius melodus (piping plover)		
B1. Exposure to sea level rise	Seavey et al. 2011	This species is 100% exposed to sea level rise, and the percentage of the range that would be eliminated by projected sea level rise is probably high in some areas. In some places, the sandy beach nesting habitat of this species might simply shift to a higher level in the current topography, but in other areas development precludes such shifting. This factor is intertwined with B3 (land use changes related to climate change) and C2c (disturbance from climate storminess).

B3. Predicted impact of land use changes	Burger et al. 2011	In some areas, this species might be negatively affected by habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to address climate-change-related rise in sea level. Wind turbines on the outer Atlantic continental shelf are unlikely to impact populations; flight is generally closer to shore and below the average blade level (Burger et al. 2011)
C1. Dispersal and movements		There appears to be no reason to suspect that the movement capabilities of this species would prevent it from shifting its range as necessary with projected climate change. In fact, this species evolved with a very dynamic breeding habitat that requires shifts on a multi-year scale.
C2c. Dependence on a specific disturbance regime	Seavey et al. 2011	This species could be affected by an increase in the frequency, extent, and/or intensity of severe storms (e.g., hurricanes) in the assessment area. In the pre-settlement era, severe storms likely functioned in both destroying and creating habitat, with the net impact varying over time and location. Today, rising sea level and development near the plover's habitat could result in an overall tendency toward habitat loss with increased disturbance from storms, but the level of uncertainty appears to be relatively high. Also, increased storminess likely will result in an increase in flooding during the nesting season, increased reproductive failure, and possible reduction in plover distribution and abundance.
C3. Restriction to uncommon geological features or derivatives		Habitat (coastal beach sands) is widespread.
C4e. Sensitivity to pathogens or natural enemies	Lauro and Tanacredi 2002	predation by gulls and crows led to loss of eggs and chicks in NY

Cicindela dorsalis (eastern beach tiger beetle)		
B1. Exposure to sea level rise		This species is 100% exposed to sea level rise, but the percentage of the range that would be eliminated by projected sea level rise is unknown. It could be high, but in some areas the sandy beach habitat of this species might simply shift to a higher level in the current topography.

B2a. Distribution relative to natural barriers		Current range within the North Atlantic assessment area in MA, RI, CT, NY, and NJ is on an island completely surrounded by a large extent of open water, which here is regarded as a barrier, though probably it is not an absolute barrier. In the mid-Atlantic assessment area (NJ, DE, MD, VA), natural barriers that would prevent range shifts are here believed to be minimal.
B2b. Distribution relative to anthropogenic barriers		Development landward of existing occupied beaches is likely to be a barrier in some areas. This factor is scored as neutral because the same phenomenon is already accounted for in factor B1 (exposure to sea level rise) and because anthropogenic barriers to along-shore movement are not expected to contribute to a loss or reduction in habitat or area of occupancy with projected climate change in the assessment areas.
B3. Predicted impact of land use changes		In some portion of the Middle Atlantic assessment area, this species might be negatively affected by habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to combat climate-change-related rise in sea level.
C1. Dispersal and movements		These beetles are thought to have relatively good dispersal capability and sometimes move 10s of kilometers.
C2aii. Physiological thermal niche		Projected temperature increase likely will not render habitat unsuitable for this species.
C2bi. Physiological hydrological niche		Projected change in moisture availability likely will not render habitat unsuitable for this species.
C2c. Dependence on a specific disturbance regime		Assuming an increase in the frequency and/or intensity of severe storms (especially hurricanes) in the assessment area, this species probably will experience a strong negative impact in the North Atlantic assessment area (MA, RI, CT, NY, NJ), given its current extreme scarcity (one site). In the pre-settlement era, when this species was more widespread and had a viable metapopulation structure, severe storms likely functioned in both destroying and creating habitat. In the mid-Atlantic assessment area (NJ, DE, MD, VA), multiple metapopulations of this species still exist, and severe storms may not have such a negative impact and theoretically might create more habitat than is destroyed.

C3. Restriction to uncommon geological features or derivatives		Habitat (coastal beach sands) is widespread.
C5b. Occurrence of bottlenecks in recent evolutionary history		Population in the assessment area has undergone a severe decline to a very small size. However, it has not rebounded so does not qualify for other than the Neutral category.

Cistothorus palustris (marsh wren)		
B1. Exposure to sea level rise	Veloz et al. 2011	A relatively small proportion of the range is vulnerable to sea level rise, and these areas may experience a decline in marsh wren habitat and populations with sea level rise. For example, in the San Francisco Bay Area, California, sea level rise is expected to result in a decline in marsh wren habitat and populations under most scenarios (Veloz et al. 2001).
B3. Predicted impact of land use changes		Some wetland habitats could be lost or reduced (flooded) as a result of dams constructed in response to climate change, but the scope of this threat is likely to be quite small. Also, such loss might be offset by increases in habitat that might result from dam construction that results in wetland increase.
C1. Dispersal and movements	Federation of Alberta Naturalists. 2007	This species readily colonizes newly available habitats and has very good dispersal ability. In Canada, for example, Breeding Bird Survey data suggest that the marsh wrens may be shifting spatially with climate change without changing population size (Federation of Alberta Naturalists 2007:408).
C2bi. Physiological hydrological niche		Some marginal wetland habitat could be lost or rendered less suitable as a result of climate change. On the other hand, some currently open water areas might become suitable habitat. Here I assume that the overall effect would be a net decrease in available habitat.
C4a. Dependence on other species to generate habitat		The number of emergent wetland plant species that provide suitable habitat is relatively small but often more than a few.

Clemmys guttata (spotted turtle)		
B2a. Distribution relative to natural barriers		Natural barriers exist in some areas but are not likely to cause a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change.

B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers exist in all assessment areas, but these are not likely to result in a significant reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.
C1. Dispersal and movements	NSX	These turtles readily move hundreds of meters through various upland habitats.
C2bi. Physiological hydrological niche		Some habitat may be lost or degraded as a result of reduced hydroperiod of vernal pools.

Cryptobranchus alleganiensis (hellbender)		
B2a. Distribution relative to natural barriers		Natural barriers exist in some areas but are not likely to cause a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change.
B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers (especially dams) exist, and presumably these could contribute to a small reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.
B3. Predicted impact of land use changes		Construction of dams/impoundments in response to climate drying might negatively affect this species is some areas. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.
C1. Dispersal and movements	NSX	Hellbenders tend to be sedentary but are capable of moving 100s of meters or more.
C2aii. Physiological thermal niche		Species needs cool water, but the degree to which projected climate change would eliminate or reduce habitat in the assessment area is uncertain but probably not very high.
C2bi. Physiological hydrological niche	NSX	Habitat includes only permanent rivers; climate drying probably will not eliminate or greatly reduce this habitat in the assessment area, but presumably it could have an effect in marginal habitat.

C3. Restriction to uncommon geological features or derivatives		Species occurs primarily where river substrate includes large slab rocks. This microhabitat is not rare but is not always present in cool rivers in the assessment area.
C4b. Dietary versatility (animals only)	NSX	A few crayfish species generally dominate the diet.

Falcipennis canadensis (spruce grouse)		
B2a. Distribution relative to natural barriers		Large bodies of water along the northern edge of some parts of the range may act as barriers.
B2b. Distribution relative to anthropogenic barriers		Extensive areas of urban and agricultural development may act as barriers in some places. The extent to which spruce grouse may fly over these areas is uncertain but is here presumed to be rare.
C1. Dispersal and movements	Boag et al. 1992	Known dispersal distances are small, often less than 10 km and sometimes less than 1 km (see Boag and Schroeder 1992).
C2aii. Physiological thermal niche	New Hampshire Fish and Game Department 2005; Ross et al. 2011	In much of the Northern Appalachian assessment areas, this species is associated with cool environments that are vulnerable to loss or reduction with climate change. In the Middle Atlantic assessment area, the cool environments used by this species are vulnerable to complete loss.
C2c. Dependence on a specific disturbance regime		Spruce grouse can be affected positively and negatively by forest fires, which could increase in extent, frequency, or severity with climate change. Fires could eliminate small isolated grouse populations. On the other hand, in portions of the Northern Appalachian assessment area, ongoing forest maturation probably is a threat to spruce grouse, and an increase in fires likely would be beneficial over the long term. However, fire suppression probably would limit the extent of fires. This assessment assumes that climate-change-related changes in fires will not have a strong affect one way or the other. Insect infestations are another disturbance factor with possible relevance to spruce grouse, but how these might change and affect spruce grouse in the assessment areas is unknown.
C4a. Dependence on other species to generate habitat	Boag et al. 1992	Suitable habitat in the assessment areas generally comprises just a few dominant tree species.

C4b. Dietary versatility (animals only)		Winter diet is essentially restricted to the needles of not more than a few (and sometimes primarily one) conifer species.

Glyptemys insculpta (wood turtle)		
B2a. Distribution relative to natural barriers		Natural barriers exist in some areas but are not likely to cause a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change.
B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers exist in all assessment areas, but these are not likely to result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change.
B3. Predicted impact of land use changes		Construction of dams/impoundments in response to climate drying might negatively affect this species is some areas. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.
C1. Dispersal and movements	NSX	Wood turtles readily move up to a kilometer or more.
C2aii. Physiological thermal niche		Climate warming likely would result in changes that are somewhat more favorable for wood turtles in northern assessment areas. At the southern end of the range in the Mid-Atlantic region, climate warming might result in changes that are less favorable for wood turtles, presuming that the southern edge of the species' range is at least in part influenced by thermal factors.
C2bi. Physiological hydrological niche		Projected climate drying theoretically could result in loss or reduction of stream habitat that is at present marginally suitable for wood turtles.

Haematopus palliatus (American oystercatcher)		
B1. Exposure to sea level rise		This species is 100% exposed to sea level rise, and the percentage of the range that would be eliminated by projected sea level rise is probably high in some areas. In some places, the sandy beach nesting habitat of this species might simply shift to a higher level in the current topography, but in other areas development precludes such shifting. This factor is intertwined with B3 (land use changes related to climate change) and C2c (disturbance from climate storminess).
B3. Predicted impact of land use changes		In some portion of the Middle Atlantic assessment area, this species might be negatively affected by habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to address climate-change-related rise in sea level.
C1. Dispersal and movements		There appears to be no reason to suspect that the movement capabilities of this species would prevent it from shifting its range as necessary with projected climate change.
C2c. Dependence on a specific disturbance regime		This species could be affected by an increase in the frequency, extent, and/or intensity of severe storms e.g., hurricanes) in the assessment area. In the pre-settlement era, severe storms likely functioned in both destroying and creating habitat, with the net impact varying over time and location. Today, rising sea level and development near the plover's habitat could result in an overall tendency toward habitat loss with increased disturbance from storms, but the level of uncertainty appears to be relatively high. Also, increased storminess likely will result in an increase in flooding during the nesting season, increased reproductive failure, and possible reduction in oystercatcher distribution and abundance.
C3. Restriction to uncommon geological features or derivatives		Habitat is widespread.

Hylocichla mustelina (wood thrush)		
C1. Dispersal and movements		This species exhibits a fairly high degree of breeding site fidelity, but it also readily colonizes reforested areas as they mature and become more suitable, suggesting that dispersal capability is quite good and that this species should be capable of shifting its range as needed with climate change.
C2bi. Physiological hydrological niche	http://www.birdpop.org/downloaddocuments/SMA_WOTH_justified.pdf	A trend toward drier conditions might render some forests less suitable for wood thrushes, for which mesic forests are most suitable. Also, decreases in wet season precipitation across much of the winter range will likely lead to changes in the forest type and structure that may affect winter survival, body condition, and subsequent reproductive success.
C2c. Dependence on a specific disturbance regime		Climate change may result in drier forest conditions and increased fire extent, frequency, or severity, which in turn may reduce understory vegetation and reduce habitat suitability for wood thrushes.
C4e. Sensitivity to pathogens or natural enemies	Schmidt and Whelan 1998	Differential predation by raccoons occurred (higher in wood thrush than in American robin) with increasing nest density
C6. Phenological response to changing seasonal temp/precip dynamics	Stanley et al. 2012	Migration schedule of individuals appears to be relatively consistent from year to year, suggesting that environmental changes resulting from climate change could result in some temporal decoupling of important thrush ecological relationships.
D2. Modeled future (2050) change in population or range size	http://www.nrs.fs.fed.us/atlas/bird/fut_incid_7550.html	Modeled climate-based future range/abundance indicates notable decline in Mid-Atlantic assessment area, modest decline in North Atlantic assessment area, and perhaps little change or a small increase in the Northern Appalachian assessment area.

Isotria medeoloides (small whorled pogonia)		
C1. Dispersal and movements	Stone 2012	I. medeoloides generates tiny wind-dispersed seeds that usually land close to the parent, but can also travel several km in rare long-distance dispersal events.
C4c. Pollinator versatility (plants only)	Mehrhoff 1983	Self-pollination results in greatly increased maturation of capsules compared to its congener I. verticillata, although when compared to other orchid species is considered low to moderate. I.medeoloides had 4 times the number of pollinated flowers compared to I. verticillata on a flower by flower basis, but on a genet by genet basis, the numbers are reversed.
C5a. Measured genetic variation	Stone 2012	Genetic diversity was found to be low over all, but less so at the northern range limit. Isotria medeoloides self-pollinates, and there is low within-population variation.

Ixobrychus exilis (least bittern)		
B1. Exposure to sea level rise		An uncertain percentage of the range is subject to sea level rise.
C1. Dispersal and movements		Dispersal and site fidelity characteristics are unknown, but there appears to be no reason to suspect that this species would not be capable of shifting its range as necessary with climate change.
C2bi. Physiological hydrological niche		Some marginal wetland habitat could be lost or rendered less suitable as a result of climate change. On the other hand, some currently open water areas might become suitable habitat. Here I assume that the overall effect would be a net decrease in available habitat.
C4a. Dependence on other species to generate habitat		Habitat is dominated by not more than a few species of tall emergent plants.

Lanthus vernalis (southern pygmy clubtail)		
B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers may exist, but these are not likely to result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change.
B3. Predicted impact of land use changes		Species would be negatively affected by dam/reservoir construction that might occur in response to climate drying.
C1. Dispersal and movements	NSX	Adults have good movement capability. Dispersal distances probably sometimes exceed 1 km.
C2aii. Physiological thermal niche		Species prefers shaded and thus relatively cool streams, but climate warming in the assessment area is projected to be modest.
C2bi. Physiological hydrological niche		Climate drying theoretically might cause some marginal habitats to become unsuitable as a result of flow reduction.

Lasiurus borealis (eastern red bat)		
B3. Predicted impact of land use changes		Presumably this species will be negatively affected to some degree by the increasing number of "wind farms" along its migration routes. These arrays of wind turbines are known to kill many eastern red bats.

Limulus polyphemus (horseshoe crab)		
B1. Exposure to sea level rise		Spawning habitat is completely exposed to sea level rise. The degree to which sea level rise will alter habitat availability in the assessment area is uncertain, but it is likely that a significant reduction will occur, given existing natural and anthropogenic conditions in areas landward of existing spawning beaches.

B2a. Distribution relative to natural barriers		Steep topography or other natural features landward of existing spawning beaches are likely to be barriers in some areas. This factor is scored as neutral because the same phenomenon is already accounted for in factor B1 (exposure to sea level rise) and because there are no significant natural barriers to along-shore movement.
B2b. Distribution relative to anthropogenic barriers		Development landward of existing spawning beaches is likely to be a barrier in some areas. This factor is scored as neutral because the same phenomenon is already accounted for in factor B1 (exposure to sea level rise) and because there are no significant anthropogenic barriers to along-shore movement.
B3. Predicted impact of land use changes		In some areas, this species could be negatively affected by spawning habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to combat climate-change-related rise in sea level.
C1. Dispersal and movements	Botton and Loveland 2003; King et al. 2005; Swan 2005; Moore and Perrin 2007; James-Pirri 2010	Adults are capable of long movements, though in New England they exhibit a substantial degree of site fidelity or at least a strong tendency to remain within a particular estuary. Larvae stay close to shore and appear to have limited capacity for long-range dispersal. However, despite these tendencies, genetic data indicate differentiation at the broad regional level (not within an estuary), and it seems unlikely that range shifts with climate change would be significantly limited by dispersal capability.
C2c. Dependence on a specific disturbance regime		Spawning habitat availability could be affected by increased frequency and/or intensity of severe storms (especially hurricanes) that may accompany climate change, but whether this would increase or decrease available habitat is uncertain and undoubtedly depends on local circumstances. Here I assume that the overall effect would be negative.
C3. Restriction to uncommon geological features or derivatives		Spawning habitat is fairly specific with respect to surf exposure, substrate, and salinity, but suitable conditions are extensive.

Lithobates sylvaticus (wood frog)		
C1. Dispersal and movements	NSX	These frogs readily move distances of several hundred kilometers. Breeders exhibit a high level of site fidelity but nevertheless readily colonize newly available nearby habitat. Dispersal ability should not inhibit range shifts with climate change.
C2bi. Physiological hydrological niche		Most productive breeding sites are in ephemeral waters that are vulnerable to loss as a result of climate drying. Reduction in vernal pool habitat is assumed not to be offset by increases in habitat that might result from a change of certain permanent ponds into ephemeral pools.
C2c. Dependence on a specific disturbance regime	NSX	Nesting habitat availability could be affected by increased frequency and/or intensity of severe storms (especially hurricanes) that may accompany climate change, but whether this would increase or decrease available habitat is uncertain and undoubtedly depends on local circumstances. Here I assume that the overall effect would be negative.

Malaclemys terrapin (diamond-backed terrapin)		
B1. Exposure to sea level rise		Foraging habitat is 100 percent exposed to sea level rise, and some nesting habitat is vulnerable as well. The degree to which sea level rise will alter habitat availability in the assessment area is uncertain, but it is likely that a significant reduction will occur, given existing natural and anthropogenic conditions in areas landward of existing habitat.
B2a. Distribution relative to natural barriers		Some natural features (e.g., rocky outcrops) landward of existing habitat are likely to be barriers in some areas. This factor is scored as neutral because the same phenomenon is already accounted for in factor B1 (exposure to sea level rise) and because there are no significant natural barriers to along-shore movement.

B2b. Distribution relative to anthropogenic barriers		Development landward of existing habitat is likely to be a barrier in some areas. This factor is scored as neutral because the same phenomenon is already accounted for in factor B1 (exposure to sea level rise) and because there are no significant anthropogenic barriers to along-shore movement.
B3. Predicted impact of land use changes		In some areas, this species could be negatively affected by spawning habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to combat climate-change-related rise in sea level.
C1. Dispersal and movements	NSX	These turtles readily move hundreds of meters and sometimes move much farther than 1 km within a single season. Dispersal and movement capability should not inhibit range shifts with climate change.
C2c. Dependence on a specific disturbance regime		Nesting habitat availability could be affected by increased frequency and/or intensity of severe storms (especially hurricanes) that may accompany climate change, but whether this would increase or decrease available habitat is uncertain and undoubtedly depends on local circumstances. Here I assume that the overall effect would be neutral, given the flexibility of these turtles in selecting nesting sites.
C3. Restriction to uncommon geological features or derivatives		Habitat is fairly specific with respect to surf exposure, substrate, and salinity, but suitable conditions are extensive.
C4a. Dependence on other species to generate habitat		Coastal marsh habitat is dominated by several plant species; habitat generation does not involve specific-specific processes.
C5b. Occurrence of bottlenecks in recent evolutionary history	NSX	Abundance declined substantially in the late 1800s and early 1900s (primarily as a result of heavy commercial harvest), then increased.

Mustela nivalis (least weasel)		
C1. Dispersal and movements	NSX	Dispersal and movement capability should not inhibit range shifts with climate change.
C2bi. Physiological hydrological niche		Climate drying might render marginal habitats unsuitable, but probably this effect would not be extensive.

Nyssa sylvatica (black gum)		
C1. Dispersal and movements	Styles 1980	Nyssa is consumed and dispersed by birds. Fruit retention in general in digestive tract is 12-45 min so transport is relatively short distance

Parkesia motacilla (Louisiana waterthrush)		
B3. Predicted impact of land use changes		This species might be affected by increased mortality resulting from collisions with wind turbines, but this probably would have a negligible impact on the population.
C2bi. Physiological hydrological niche		Climate change likely will render marginal breeding and winter habitats unsuitable, but the scope and severity of this are uncertain.

Parkesia noveboracensis (northern waterthrush)		
B3. Predicted impact of land use changes		This species might be affected by increased mortality resulting from collisions with wind turbines, but this probably would have a negligible impact on the population.
C2bi. Physiological hydrological niche		Climate change likely will render marginal habitats unsuitable, but the scope and severity of this are uncertain.
D2. Modeled future (2050) change in population or range size	Matthews et al. 2007	Projected climate-change-based northward shift in breeding distribution may eliminate this species from the Mid-Atlantic assessment area and reduce the distribution/abundance in the North Atlantic and Northern Appalachian assessment areas.

Picea mariana (black spruce)		
C2aii. Physiological thermal niche		shady, cool ravines and swamps
C5a. Measured genetic variation	Stearns and Olson 1958	Experimental seed germination response varied among widely separated populations ranging from TN to QU, suggesting genetic variability

D2. Modeled future (2050) change in population or range size	Prasad et al. 2007.	Climate change tree atlas does not show Picea mariana to be present in the currently mapped range; tree atlas is based on FIA plot data. Given that this species is modelled to be absent from the northern app portion of its range, it stands to reason that it is also presumed to be absent from the North Atlantic portion of the range.

Picea rubens (red spruce)		
C1. Dispersal and movements	Prasad 2007	Winged seeds are dispersed by wind, usually less than 100m from parent tree.
C5a. Measured genetic variation	Rajora et al. 2000 (abstract only)	Measurement of remnant populations at the northern end of the range: Ontario populations "have maintained their genetic diversity and integrity". 29% of loci polymorphic
	Hawley and deHayes 1994	Red spruce is less genetically variable than most other north-temperate woody species.
D2. Modeled future (2050) change in population or range size		Too little information to see results of model in mid-Atlantic

Pinus rigida (pitch pine)		
C1. Dispersal and movements	Prasad 2007	Winged seeds are dispersed by wind, usually less than 90m from parent tree.
C5a. Measured genetic variation	Guries and Ledig 1982	Authors note "appreciable" amount of genetic diversity. Measuring multiple loci.

Pinus strobus (white pine)		
C1. Dispersal and movements	Wendel and Smith in Burns and Honkala 1990	Seeds are dispersed by wind, reaching up to 700 feet from parent tree in open landscapes.
C5a. Measured genetic variation	Rajora et al. 1998 (abstract only)	6 small isolated pops were studied, 20 allozyme loci; 48% polymorphic. 8000 years of isolation following deglaciation had little to no detectable effect on genetic diversity
	Mehes et al. 2009	Genetic diversity noted to be moderate to high.

Pontederia cordata (pickerelweed)		
C1. Dispersal and movements	Redington 1994	Seeds eaten by muskrat, deer, black duck, mallard
C2aii. Physiological thermal niche	Whigham and Simpson 1982	Pontederia seeds require cold storage before they will germinate
C4c. Pollinator versatility (plants only)	Harder and Barrett 1993	noted pollinator visitation by four insect species
	Wolfe and Barrett 1988	18 insect species observed pollinating Pontederia cordata in Ontario
D2. Modeled future (2050) change in population or range size	Glick et al. 2008	36% loss of freshwater tidal marshes in Chesapeake Bay region by 2100 with 1-m increase in SLR

Quercus alba (white oak)		
C.1. sensitivity, dispersal	Steele 2004	Red oaks have greater dispersal advantage over white oaks; predicted that red oaks establish in wider range of micro-environments, at greater distances from parent trees, and with greater spacing. White oaks would be limited to est. closer to parents.
	Moore and Swihart 2006	Jays disperse many species of oaks and are important where landscape is fragmented.
	Clark 1998	Plants can migrate at rates far exceeding predicted dispersal patterns, seen in the fossil record. It is likely that rare but long-distance dispersal events account for this. Among the oaks, white oak (Quercus alba) reigned supreme (Abrams 1992, Whitney 1994). It has the largest range of all the eastern oaks, including every state east of the central Plains (Burns and Honkala 1990). Early botanists claimed, perhaps embellishing somewhat, that vast areas of the eastern forest were nine-tenths white oak (Whitney 1994).

	Rogers in Walters and Yawney 2004.	The major site factors influencing white oak growth are latitude, aspect, and topography (9, 18). White oak has the ability to grow on all upland aspects and slope positions within its range except extremely dry, shallow-soil ridges; poorly drained flats; and wet bottom land. It grows best on north and east-facing lower slopes and coves and grows well on moderately dry slopes and ridges with shallow soils. White oak is more abundant although smaller in size on the drier west- and south-facing slopes than on the more mesophytic sites.
C.2.a. historical thermal niche	Abrams 2003	White oak is significantly less abundant in the northeast than historically, according to witness tree data. Q. rubra and Q. rubra show the reverse. During the late 19th and early 20th centuries, much of the eastern forest was decimated by land clearing, extensive clear-cutting, catastrophic fires, chestnut blight, and then fire suppression and intensive deer browsing. These activities had the greatest negative impact on the highly valued white oak, while promoting the expansion of red oak and chestnut oak. More recently, however, recruitment of all the dominant upland oaks has been limited on all but the most xeric sites.
	Rogers in USFS Sylvics 2004	White oak grows under a wide variety of climatic conditions. Mean annual temperature ranges from 7° C (45° F) along the northern edge of the growing area to nearly 21° C (70° F) in east Texas and north Florida. The extreme low temperature ranges from -460 C (-50° F) in Wisconsin and Minnesota to -18° C (0° F) in north Florida. Annual precipitation ranges from 2030 mm (80 in) in the southern Appalachians to 760 mm (30 in) in southern Minnesota. Snowfall averages 178 cm (70 in) in southern Maine and less than 3 cm (1 in) in northern Florida. The average noon July relative humidity is less than 50 percent in the western part of the range and more than 65 percent on the Atlantic Coast. The frost-free season is 5 months in the north and 9 months in the extreme southern part of the range

C.5.a. Measured genetic variation	Gram and Sork 2001	From abstract: We measured the correlation between multivariate genotypes and forest structure variables, (Quercus alba, Carya tomentosa, and Sassafras albidum) in Missouri Ozark and assessed the influence of physical landscape on multivariate genotypes. For all three species, we found significant relationships between genetic variation and environmental heterogeneity. We discovered that populations in local habitat patches with different forest structures also differed in combinations of multivariate genotypes. In contrast, we did not detect significant differences in multivariate genotypes among soil-type/aspect classes in any of the three study species, suggesting that genotypic differentiation is operating on a finer scale than soil or aspect differences. We conclude that natural selection, possibly interacting with founder events, has influenced the population differentiation of these three long-lived plant species. Such microgeographic variation in response to environmental heterogeneity is expected for a broad range of species, even when extensive gene flow is present.
D2. modeled future change	Prasad et al. 2007; Solomon 1986; Iverson and Prasad 2001	average of 3 GCM's High: most of Adirondacks is within range; Low: small portion of Adirondacks is within range; predicted increase of oak-hickory and oak-pine in northeast at expense of spruce-fir and northern hardwoods

Salmo salar (Atlantic salmon)		
B1. Exposure to sea level rise		All populations migrate through areas subject to sea level rise, but it seems unlikely that changing sea level will have a significant positive or negative impact on the species.
B2a. Distribution relative to natural barriers		Natural barriers (e.g., high waterfalls) exist in some areas, and these might in some cases result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change. There are no natural barriers to north-south range shifts.

B2b. Distribution relative to anthropogenic barriers		Locally, dams might negatively affect the ability of this species to shift its range and thereby result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with climate change.
B3. Predicted impact of land use changes		Species could be negatively affected by habitat loss and fragmentation from dam/reservoir construction that might occur to increase hydropower production or in response to climate drying. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.
C1. Dispersal and movements		Species exhibits fidelity to spawning streams, but dispersal and movement capability should be sufficient to allow range shifts with climate change.
C2aii. Physiological thermal niche		Cool-water spawning habitat might be reduced by climate warming.
C2bi. Physiological hydrological niche		Climate drying might reduce stream flows such that marginal suitable habitats become unsuitable.
C3. Restriction to uncommon geological features or derivatives		Species depends on gravelly substrate for spawning, but this substrate type is not uncommon.

Salvelinus fontinalis (brook trout)		
B1. Exposure to sea level rise		Some populations are exposed to sea level rise, but this is unlikely to have a significant detrimental effect on the overall distribution and abundance of the species in the assessment area.
B2a. Distribution relative to natural barriers		Natural barriers (e.g., high waterfalls) exist in some areas, and these might in some cases result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with projected climate change.
B2b. Distribution relative to anthropogenic barriers		Locally, dams might negatively affect the ability of this species to shift its range and thereby result in a significant reduction or loss of the species' habitat or area of occupancy in the assessment area with climate change.

B3. Predicted impact of land use changes		Species could be negatively affected by habitat loss and fragmentation from dam/reservoir construction that might occur to increase hydropower production or in response to climate drying. Increased withdrawals of water from rivers in response to climate drying potentially could degrade riverine habitat, but the degree to which this species may be affected by this is uncertain.
C1. Dispersal and movements	NSX	Dispersal and movement capability are substantial and should not inhibit range shifts with climate change.
C2aii. Physiological thermal niche	NSX	Presumably climate warming will render unsuitable at least some habitats that are at present marginally cool enough for this species.
C2bi. Physiological hydrological niche		Climate drying might reduce stream flows such that marginal suitable habitats become unsuitable.
C3. Restriction to uncommon geological features or derivatives		Species depends on gravelly substrate for spawning, but this substrate type is not uncommon.

Sarracenia purpurea (purple pitcher-plant)		
C1. Dispersal and movements	Ellison and Parker_2002	seed dispersal averages 5 cm from parent plant, limiting long-distance dispersal
C5b. Occurrence of bottlenecks in recent evolutionary history	Karberg and Gale 2005	genetic variation in populations in Lake Superior Basin was moderate
	Godt and Hamrick 1998	significant genetic divergence was noted among infraspecific taxa

Scirpus ancistrochaetus (barbed-bristle bulrush)		
C5a. Measured genetic variation	Cippolini et al. no date; http://www.centerforplantconservation.org/collection/cpc_viewprofile.asp?CPCNum=3878#Distribution	"Genetic variation was found" but insufficient data to determine how variable; one site noted to be genetically distinct.

Seiurus aurocapillus (ovenbird)		
B3. Predicted impact of land use changes		This species might be affected by increased mortality resulting from collisions with wind turbines, but this probably would have a negligible impact on the population.
C1. Dispersal and movements		Ovenbirds exhibit a moderate degree of breeding area fidelity but nevertheless readily colonize deforested areas once suitable forest conditions develop, so they should be capable of range shifts in response to climate change.
C2bi. Physiological hydrological niche	http://people.eku.edu/browndav/past%20research.htm	Climate change, particularly drying, may negatively affect ovenbirds through reduced food availability, reduced body condition, and subsequent reduced survival and reproductive success. This effect may apply to the breeding and nonbreeding portions of the range. The degree of impact is uncertain.
C4a. Dependence on other species to generate habitat		Habitat generally comprises more than a few tree species. Forest structure appears to be more critical than tree species composition.
D2. Modeled future (2050) change in population or range size	Matthews et al. 2007	Climate change may result in a significant reduction in abundance in all three assessment areas. The species may disappear from most of the Mid-Atlantic assessment area.

Setophaga cerulea (cerulean warbler)		
C2bi. Physiological hydrological niche		A drying trend might at least somewhat reduce habitat quality for this mesic-forest-associated bird, but this is uncertain.
C2c. Dependence on a specific disturbance regime		Increased extent, frequency, or severity of strong storms could open forest canopies, reduce habitat quality, and result in reduced warbler distribution and/or abundance.
D2. Modeled future (2050) change in population or range size	Matthews et al. 2007	Distribution/abundance was projected to decline in the Mid-Atlantic assessment area but increase in the North Atlantic assessment area.

Setophaga striata (blackpoll warbler)		
B3. Predicted impact of land use changes	NSX	This species might be negatively affected by collisions with increasing number of wind turbines.
C1. Dispersal and movements	Hunt and Eliason 1999	Available information indicates that this species exhibits a relatively high level of nesting area fidelity, which theoretically might reduce its ability to shift its range with climate change in the Northern Appalachian assessment, but this is uncertain. In the migration range (Mid- and North Atlantic assessment areas, dispersal/movement capability should not be limiting with climate change.
C2bi. Physiological hydrological niche		In the Northern Appalachian assessment area (breeding range), a drying trend might at least somewhat reduce habitat quality for this mesic-habitat-associated bird. This probably does not apply in the other assessment areas where this species uses a wide range of habitats as a strict migrant.
C4a. Dependence on other species to generate habitat		In some areas, habitat is dominated by one (spruce) or few species. This does not apply to the Mid-Atlantic and North Atlantic assessment areas where this species is strictly a migrant.
C4e. Other interspecific interactions	Hunt and Eliason 1999	No clear relationship exists with spruce budworm outbreaks.

Somatochlora incurvata (incurvate emerald)		
B2a. Distribution relative to natural barriers	NSX	Natural barriers are very limited or absent; regardless, none are likely to have a significant effect on the ability of this species to shift its range with climate change.
B2b. Distribution relative to anthropogenic barriers	NSX	Anthropogenic barriers are very limited or absent; regardless, none are likely to have a significant effect on the ability of this species to shift its range with climate change.
B3. Predicted impact of land use changes		In some areas, habitat could be lost as a result of construction of dams in response to climate drying, but probably this would be of limited scope.

C1. Dispersal and movements	NSX	Dispersal and movement capability are substantial and should not inhibit range shifts with climate change.
C2bi. Physiological hydrological niche		Larvae can withstand dry conditions for several months (White et al. 2010), but marginally suitable bogs presumably could become unsuitable with climate drying.
C4a. Dependence on other species to generate habitat		Habitat generally includes sphagnum and sedges but comprises more than a few plant species.

Sorex palustris (American water shrew)		
B2a. Distribution relative to natural barriers		Natural barriers exist in some areas but are not likely to cause a significant reduction or loss of the species' habitat or area of occupancy in the assessment areas with projected climate change.
B2b. Distribution relative to anthropogenic barriers		Anthropogenic barriers exist in some areas but are not likely to cause a significant reduction or loss of the species' habitat or area of occupancy in the assessment areas with projected climate change.
C1. Dispersal and movements		Dispersal and movement capability should not inhibit range shifts with climate change.

Spartina alterniflora (saltwater cordgrass)		
B1. Exposure to sea level rise	Warren and Neiring 1993	Even in 1993, the authors document change in low salt marsh by increasing sea level; marsh elevations are significantly lower for areas that have changed, due to change in accretion of peat
C5a. Measured genetic variation	Seliskar et al 2002	S. alterniflora transplanted from 3 different locations retained characteristics of their original site, suggesting genetic control.
D2. Modeled future (2050) change in population or range size	Kirwan et al 2009	Latitudinal gradient in productivity indicates productivity increases with increased temp; authors predict increasing productivity of marshes as a result of climate change….

	Bertness and Ewanchuk 2002	Plant interactions noted to be different with latitude, and hence climate. Suggests that climate warming may change from competitive to facilitative, but warn against predicting climate warming on community structure and function.

Sterna hirundo (common tern)		
B1. Exposure to sea level rise		This species is 100% exposed to sea level rise, and the percentage of the range that would be eliminated by projected sea level rise is probably high in some areas. In some places, the sandy beach nesting habitat of this species might simply shift to a higher level in the current topography, but in other areas development precludes such shifting. This factor is intertwined with B3 (land use changes related to climate change) and C2c (disturbance from climate storminess). See Seavey et al. (2011) for information on piping plover, with which least terns share nesting areas in many locations.
B3. Predicted impact of land use changes		In some areas, this species might be negatively affected by habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to address climate-change-related rise in sea level.
C1. Dispersal and movements		There appears to be no reason to suspect that the movement capabilities of this species would prevent it from shifting its range as necessary with projected climate change.
C2c. Dependence on a specific disturbance regime		This species could be affected by an increase in the frequency, extent, and/or intensity of severe storms (e.g., hurricanes) in the assessment area. In the pre-settlement era, severe storms likely functioned in both destroying and creating habitat, with the net impact varying over time and location. Today, rising sea level and development near the tern's habitat could result in an overall tendency toward habitat loss with increased disturbance from storms, but the level of uncertainty appears to be relatively high. Also, increased storminess likely will result in an increase in flooding during the nesting season, increased reproductive failure, and possible reduction in tern distribution and abundance.

Sternula antillarum (least tern)		
B1. Exposure to sea level rise	Seavey et al. 2011	This species is 100% exposed to sea level rise, and the percentage of the range that would be eliminated by projected sea level rise is probably high in some areas. In some places, the sandy beach nesting habitat of this species might simply shift to a higher level in the current topography, but in other areas development precludes such shifting. This factor is intertwined with B3 (land use changes related to climate change) and C2c (disturbance from climate storminess).
B3. Predicted impact of land use changes		In some areas, this species might be negatively affected by habitat loss or degradation resulting from construction of sea walls or other structures that may be established in efforts to address climate-change-related rise in sea level.
C1. Dispersal and movements		There appears to be no reason to suspect that the movement capabilities of this species would prevent it from shifting its range as necessary with projected climate change. In fact, this species evolved with a very dynamic breeding habitat that requires shifts on a multi-year scale.
C2c. Dependence on a specific disturbance regime		This species could be affected by an increase in the frequency, extent, and/or intensity of severe storms (e.g., hurricanes) in the assessment area. In the pre-settlement era, severe storms likely functioned in both destroying and creating habitat, with the net impact varying over time and location. Today, rising sea level and development near the tern's habitat could result in an overall tendency toward habitat loss with increased disturbance from storms, but the level of uncertainty appears to be relatively high. Also, increased storminess likely will result in an increase in flooding during the nesting season, increased reproductive failure, and possible reduction in tern distribution and abundance. See Seavey et al. (2011) for information on piping plover, with which least terns share nesting areas in many locations.
C3. Restriction to uncommon geological features or derivatives		Habitat (coastal beach sands) is widespread.

Sylvilagus transitionalis (New England cottontail)		
C1. Dispersal and movements	Litvaitis and Villafuerte 1996	Populations are organized in metapopulations that are generally no more than 3 km apart
C5a. Measured genetic variation	Litvaitis et al 1997	Mitochondrial DNA analysis suggested the splitting of this species into two. Although this did not happen, there is genetic variation between northern and southern populations

Thuja occidentalis (northern white cedar)		
C1. Dispersal and movements	Curtis 1946	Seeds are winged and transported by wind, generally dispersed 45-60 m from the parent tree.
C3. Restriction to uncommon geological features or derivatives	Curtis 1946	Thuja is commonly found on calcareous habitats, although is not restricted to them.
C4e. Other interspecific interactions	DeBlois and Bouchard 1999; Cornett et al. 2001	In Quebec, Thuja was noted to establish easily on mesic sites and persist as dense populations that resisted invasion by other trees. Cornett et al, though, demonstrated that seed bed conditions regulated establishment of Thuja, which showed limited regeneration under Betula papyrifera canopy.
C5a. Measured genetic variation	Perry and Knowles 1990 abstract only; Matthes-Sears et al. 1991	Low outcrossing rates noted in Thuja in Ontario; Matthes-Sears et al. noted overall genetic variability as "extremely small" in swamp and cliff sites of Thuja in Ontario.
D2. Modeled future (2050) change in population or range size	Prasad et al 2007	Seeds are winged and transported by wind, but few seeds are dispersed beyond 80m of the stand, but can be transported farther by strong winds.

Tsuga canadensis (eastern hemlock)		
C1. Dispersal and movements	Prasad et al 2007	Winged seeds are wind-dispersed, up to 100m from parent tree.
C5a. Measured genetic variation	Kessell 1979	Tsuga canadensis was found to have bimodal ecotypes, occurring in both mesic sites and xeric sites, but rarely in between. Both ecotypes occur in mesic sites; phenotypic plasticity is thought to confer competitive advantage.

	Potter et al. 2012	Moderate inbreeding found across geographic range; greater genetic diversity at southern range (beyond glacial maximum), as expected.
D2. Modeled future (2050) change in population or range size	Prasad	Importance values and range expansion are both predicted to increase in this portion of the LCC.

Vallisneria americana (tapegrass)		
C1. Dispersal and movements	Lokker et al 1994; Korschgen and green 1988	Both seeds and tubers are dispersed by water; seeds may also be dispersed by waterfowl.
C2aii. Physiological thermal niche	Best and Boyd 2001	Vallisneria can be a nuisance plant in warm climates, but usually in shallow water only
C4c. Pollinator versatility (plants only)	Lokker et al 1994	Pollen limitation not important factor in regulating seed production, but floral induction in female ramets may be more significant factor.
C5a. Measured genetic variation	Lokker et al 1994	Study found Vallisneria to have high small-scale genetic diversity