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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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April 2014

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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, 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 some 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 represented 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.

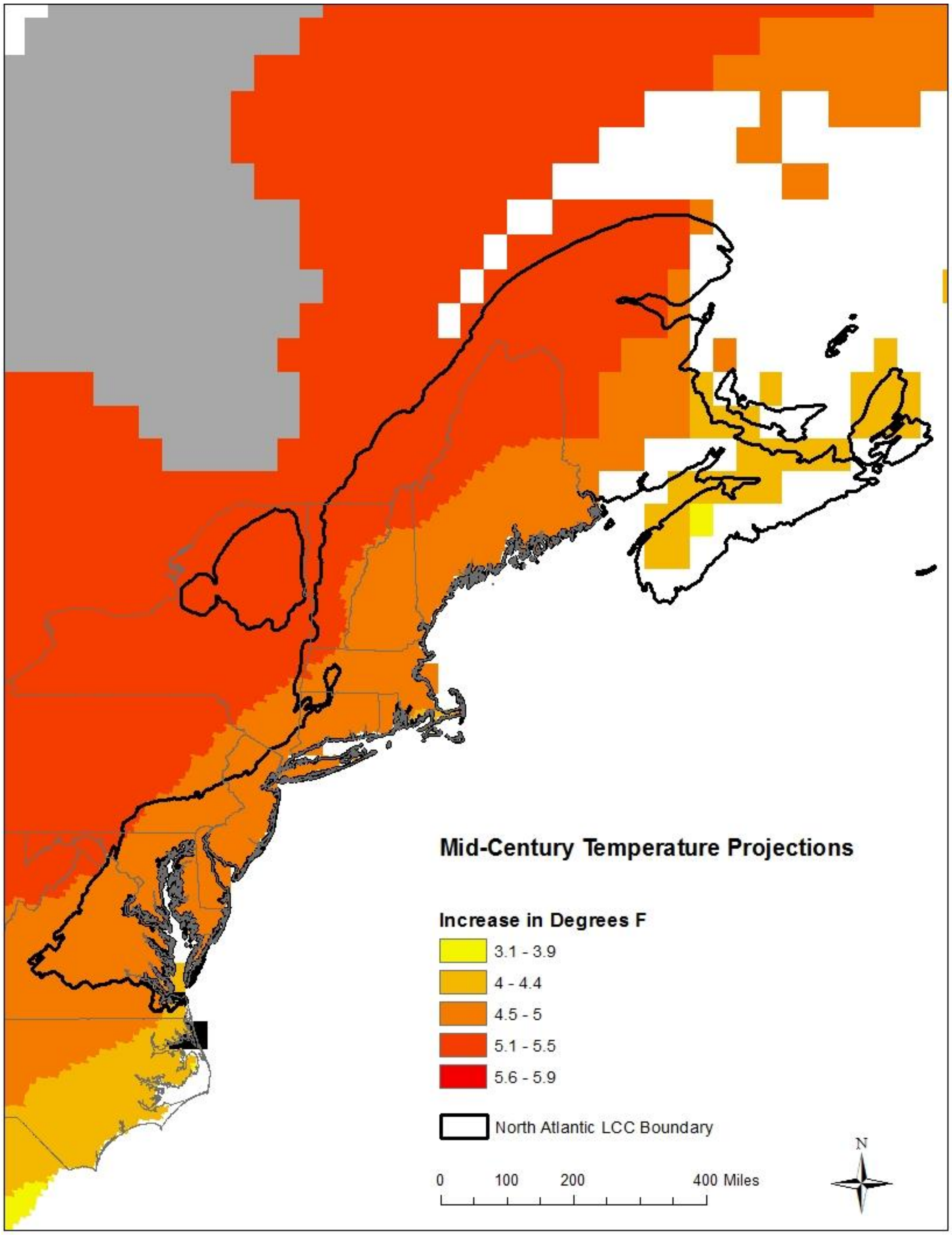

Figure 1. Projected mid-century temperature increases in the North Atlantic LCC based on IPCC Fourth Assessment, Medium A1B Emission Scenario, and ensemble average General Circulation Model.

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 cubtail	*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 CCVI tool. 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 uses exposure-weighted scoring of multiple factors that can potentially affect species' vulnerability to climate change (Young et al. 2012). 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.

Sensitivity

Sensitivity refers to how tightly species are linked to specific microclimates and ecological conditions that might be affected by climate change, as well as the capacity of the species to adapt to these changes. Sensitivity to climate change is assessed using up to 20 individual factors that are grouped into two categories: (1) indirect exposure to climate change, and (2) species-specific sensitivity pertaining to individual species' biology and natural history. Indirect climate exposure refers to the effects of climate change on the

[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.

landscape context of a species, as opposed to impacts on the species itself. Three indirect exposure factors are scored in the CCVI: sea level rise, distribution relative to barriers (both natural and anthropogenic), and predicted impact of land use changes resulting from human response to climate change. Examples of the third factor include wind farm placement, biofuel production, and tree planting for carbon sinks.

Other species-specific sensitivity factors include 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. Figure 2 illustrates the relationship of direct and indirect climate exposure and sensitivity factors in the CCVI.

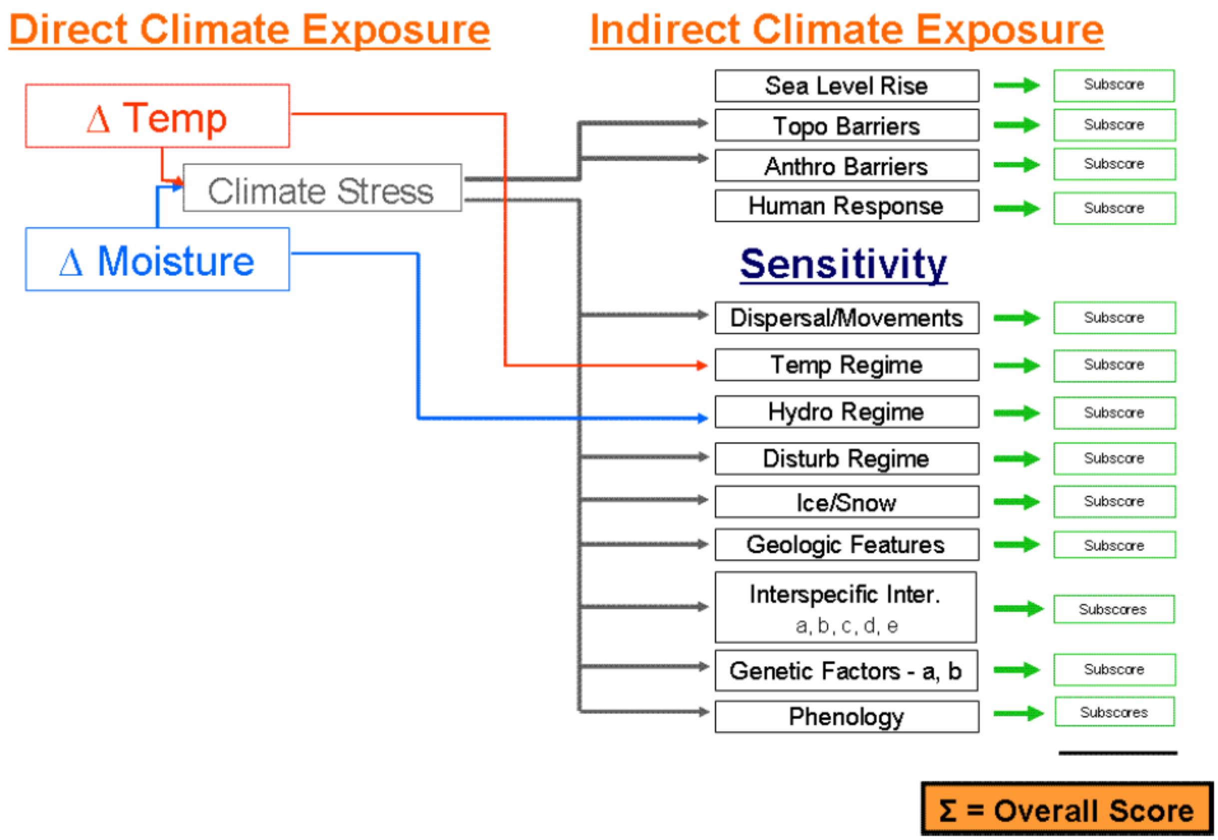

Figure 2. Relationship between exposure and sensitivity factors in the CCVI (from Young et al. 2012).

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.

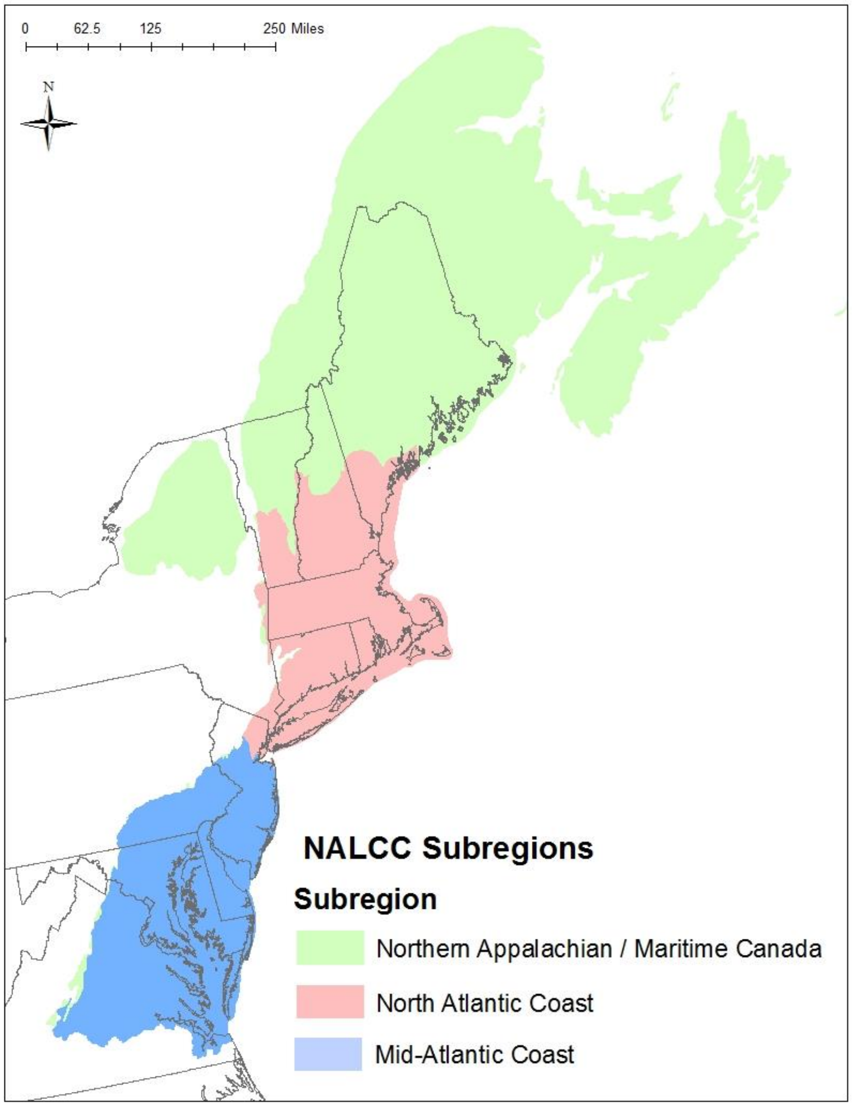

Figure 3. Subregions of the North Atlantic LCC used to conduct CCVI assessments.

Climate data

Direct exposure was measured using the downloaded future projected temperature and moisture 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), 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 ClimateWizard.

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 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. 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.

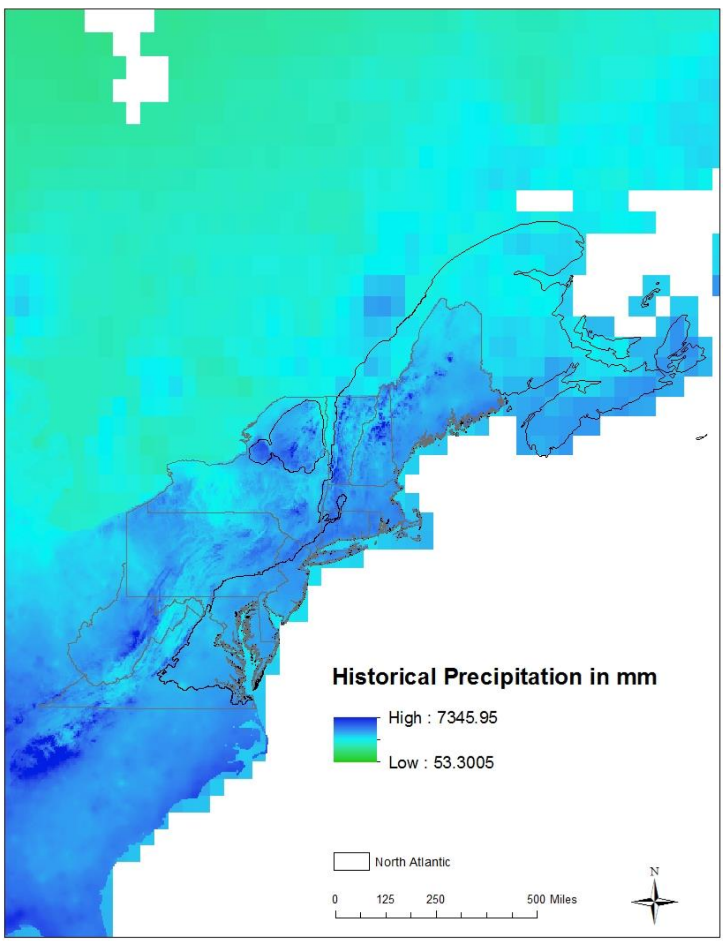

Figure 4. Precipitation in mm for last 50 years. Note resolution difference between US (4 km) and Canada (50 km).

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 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. 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

[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

[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 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 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 and red spruce 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, Atlantic white cedar [*Chamaecyparis thyoides*]), and eastern hemlock), 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 of 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.

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. Eastern hemlock has experienced significant loss 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 subregion, increasing temperatures will likely remove limits of woolly adelgid invasion in portions of this subregion (Paradis et al. 2008).

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 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.

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, white oak [*Quercus alba*], sugar maple, black gum [*Nyssa sylvatica*] and silver maple [*Acer saccharinum*]) and two herbaceous species (tapegrass 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 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, American oystercatcher, piping plover, least tern [*Serna antillarum*], Bicknell's thrush, spruce grouse), two invertebrates (Hessel's hairstreak 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 themselves 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 these largely impassable barriers.

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 and common tern), one fish (brook trout), 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 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. However, Lentz and Dunson (1999) found that ponds supporting this species 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. It was rated as Moderately Vulnerable in the Mid-Atlantic subregion and Presumably Stable in the other two subregions. 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, cerulean warbler [*Setophaga cerulea*], northern goshawk), 3 mammals (least weasel, New England cottontail and moose), 2 reptiles, (spotted turtle and wood turtle), 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.

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. Horseshoe crab, 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 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 fourteen species include six birds (American black duck [*Anas rubripes*], marsh wren [*Cistothorus palustris*], wood thrush, Louisiana waterthrush [*Parkesia motacilla*], blackpoll warbler [*Setophaga striata*], and red-shouldered hawk [*Buteo lineatus*]), 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).

The fish (American shad), two invertebrate species (southern pygmy clubtail and incurvate emerald) and one mammal (eastern red bat [*Lasiurus borealis*]) ranked as Presumed Stable throughout the LCC region, mostly due to their dispersal capabilities. The remaining species, (American water shrew [*Sorex palustris*], northern pinesnake, and wood frog) were also 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, although 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 habitat 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. In general, birds are not found to be vulnerable to climate change due to their dispersal abilities, but 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. Barbed-bristle bulrush occurs in isolated, seasonally flooded basins, including some vernal pool habitats. Hessel's hairstreak is limited to subset of Atlantic white cedar swamps, so its range is considerably smaller than that of Atlantic white cedar.

Two vulnerability assessments conducted in areas partially overlapping the North Atlantic LCC were completed in 2011. In the New York analysis (Schlesinger et al. 2011), species were selected that either were thought to be susceptible to climate change, or that would be good indicators of the vulnerability of species in similar habitats. Species thought to be vulnerable to climate change were selected for the Pennsylvania analysis as well (Furedi et al. 2011), as were species of the state priority list. Of the species assessed, the two analyses yielded vulnerability (Extremely Vulnerable, Highly Vulnerable, Moderately Vulnerable) of 66% and 59%. It is interesting to note that of the species assessed in our study, 45% were found to be vulnerable, despite our selection of species irrespective of their potential vulnerability. Although hardly a rigorous analysis, it does at least suggest there are widespread implications of climate change in the LCC.

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 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, including 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[2] 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

[2] 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.

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 ORV 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 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[3]. 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.

[3] 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.

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 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).

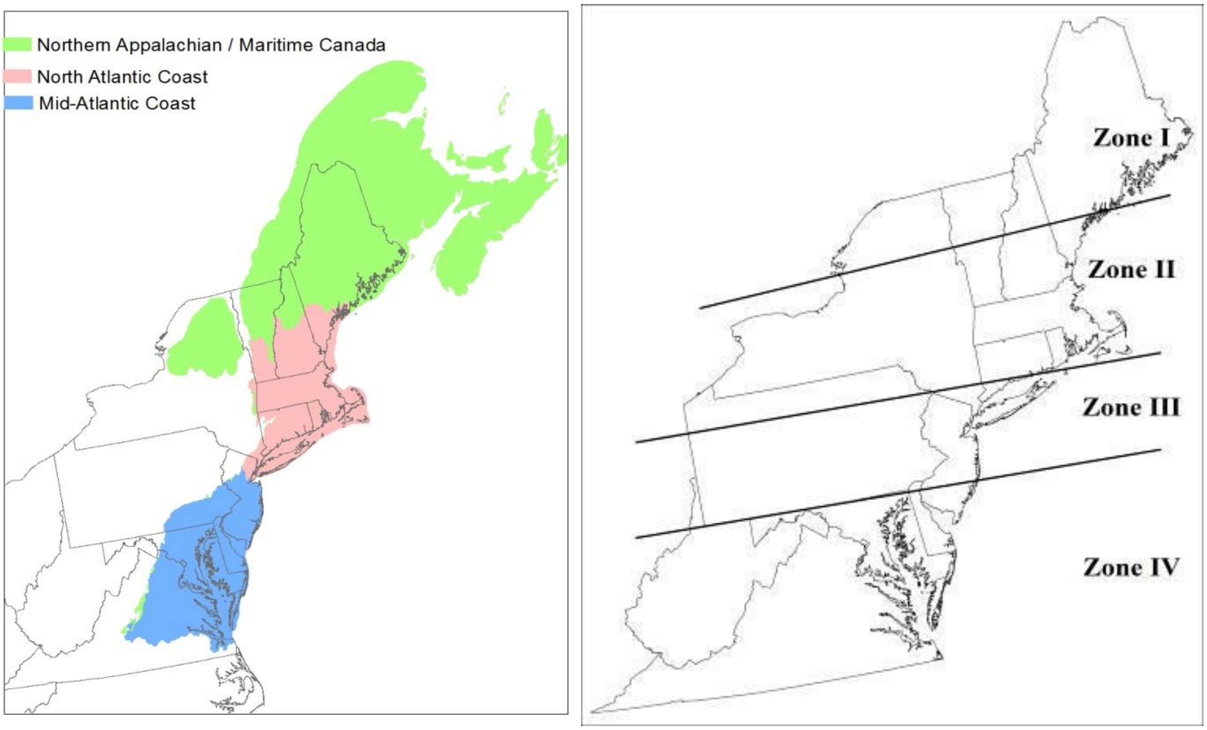

Table 6 illustrates the comparison of our species results for two habitats. Acadian – Appalachian Montane Spruce-Fir Forest was assessed to be Vulnerable or Highly Vulnerable by MCCS (2012a). Several species closely tied to this habitat were also found to be Moderately or Highly Vulnerable by the CCVI, 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 inflluenced the results in that subregion. Also, both species are highly mobile and can likely move to more suitable areas as climate warms.

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 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.

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 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 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, which is consistent with the rating of Vulnerable (likely to be relatively unaffected) 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 – Increase 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	North Atlantic Coast	Mid-Atlantic Coast	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	*Dendroica 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.

	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		Atlantic Sturgeon	
	NY[1]	NatureServe	NY[1]	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.

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.

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 when recent studies of polar sea ice have revealed a greater than anticipated rate of melting. 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 salt marshes in the southeastern U.S. 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 an increase of 0.6 cm/year, which 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.

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 warms. 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 ongoing conservation planning (McGarigal et al., in progress): 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 of these mapped habitats (Gawler 2008, Anderson et al. 2011; Donovan, T. 2011).

3. Maintain or enhance ecological integrity of high quality examples of each habitat by first assessing ecological integrity (Faber-Langendoen et al. 2011) for wetlands and further developing these protocols for upland habitats, then using these protocols to develop goals and target conditions for restoration where appropriate.
4. Develop a climate stress index and 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. Obtain more precise climate data, both current and future, especially for Canada. In the face of species migration northward, 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. 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.
7. 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 5.1F	4.5F	3.9F	<3.9F	Hamon AET:PET Moisture Metric Scope -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				Hamon AET:PET Moisture Metric Scope			
				5.1F	4.5F	3.9F	<3.9F	-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

				Temperature Scope				Hamon AET:PET Moisture Metric Scope			
Species	**English Name**	**Subregion**	**Range Rel.**	**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

				Temperature Scope				Hamon AET:PET Moisture Metric Scope			
Species	**English Name**	**Subregion**	**Range Rel.**	**5.1F**	**4.5F**	**3.9F**	**<3.9F**	**-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

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
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
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

				Temperature Scope				Hamon AET:PET Moisture Metric Scope			
Species	**English Name**	**Subregion**	**Range Rel.**	**5.1F**	**4.5F**	**3.9F**	**<3.9F**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**
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
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	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
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

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
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
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

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
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
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

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
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
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**	**physiological hydrological niche C2bii**	**Disturbance C2c**	**Ice/snow C2d**	**Phys habitat C3**	**Other spp for hab C4a**	**Diet C4b**	**Pollinators C4c**	**Other spp disp C4d**
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	physiological hydrological niche C2bii	Disturbance C2c	Ice/snow C2d	Phys habitat C3	Other spp for hab C4a	Diet C4b	Pollinators C4c	Other spp disp C4d
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

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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
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

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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
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

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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