Climate Change and Biodiversity in Maine:

Vulnerability of Habitats and Priority Species

Manomet Center for Conservation Sciences

Andrew Whitman[1]
Andrew Cutko[2]
Phillip deMaynadier[3]
Steve Walker[4]
Barbara Vickery[5]
Sally Stockwell[6]
Robert Houston[7]

[1] Manomet Center for Conservation Sciences, Brunswick, ME
[2] Maine Department of Agriculture, Conservation and Forestry, Augusta, ME
[3] Maine Department of Inland Fisheries and Wildlife, Bangor, ME
[4] Maine Coast Heritage Trust, Topsham, ME
[5] The Nature Conservancy, Brunswick, ME
[6] Maine Audubon, Falmouth, ME
[7] U.S. Fish and Wildlife Service, Falmouth, ME

Recommended Citation: Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013. Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group) Report SEI-2013-03. 96 pp. Brunswick, Maine.

Contents

Tables

Figures

MANOMET Center for Conservation Sciences

Executive Summary

Climate change will affect Maine's ecosystems and biodiversity in many ways. This document summarizes a climate change vulnerability assessment of Maine's wildlife Species of Greatest Conservation Need (SGCN), state-listed Threatened or Endangered plant species, and Key Habitats of the Maine Comprehensive Wildlife Conservation Strategy (ME CWCS). The goals of this assessment were to (1) complete a vulnerability assessment of species and habitats, (2) highlight the relationship between species vulnerability and 21 ME CWCS Key Habitats, (3) provide information to Maine natural resource managers and policy makers that will help focus conservation action, and (4) facilitate incorporation of climate change information into an upcoming revision of the ME CWCS. The assessment involved over one-hundred biologists assessing the vulnerability of 442 species, and multiple habitat types. Each species and habitat type was ranked as high, medium, or low vulnerability to climate change. High-vulnerability species and habitats are predicted to experience greater negative impacts from climate change relative to species with medium or low vulnerability.

METHODS

Species vulnerability was assessed in a three-step, expert-opinion elicitation process involving more than one-hundred reviewers: (1) expert input through an online species assessment survey, (2) review and modification of online survey results by expert panels at a workshop, and (3) final expert review by key state agency biologists and others to fill in species review gaps. The vulnerability of habitats was assessed in a two-step, expert-opinion elicitation process: (1) results of the online assessment were used to assess the vulnerability of ME CWCS Key Habitats based on the vulnerability of their constituent SGCN and state-listed Threatened or Endangered plant species and (2) expert panels at a workshop assessed the vulnerability of ME CWCS Key Habitats. These results and those from a northeastern regional habitat vulnerability assessment were reviewed by the authors.

CLIMATE CHANGE VULNERABILITY OF SPECIES

- Climate change greatly increases the vulnerability of one-third of Maine's species of conservation concern. This assessment included 442 species, nearly twice the number of species assessed by any other state to date. One hundred and sixty-eight species (37%) were found to have high vulnerability to climate change and another 171 species (38%) had medium vulnerability scores.
- Fungi and lichen species had large proportions of medium- and high-vulnerability species because they include many species at the southern edge of their range, use habitats that are vulnerable to climate change, or have highly fragmented populations.
- The large proportion of medium- and high-vulnerability plant species was driven by the vulnerability of a few major habitat groups, mainly wetlands, alpine habitats and central and northern uplands. These species are vulnerable because they are at the southern edge of their range, have naturally fragmented habitats that limit dispersal, and have narrow habitat requirements. By contrast, barrens/disturbed ground and southern uplands, although often imperiled due to rarity, were considered less vulnerable to climate change.
- Major invertebrate groups varied in their assessed vulnerabilities. Terrestrial groups tended to have fewer species with high vulnerability. Many aquatic invertebrate SGCN in Maine are at the southern edge of their range and/or have fragmented distributions or other dispersal and migration limitations that make them more vulnerable to climate change.
- Fish had more medium-vulnerability species than low- or high-vulnerability species and included species particularly vulnerable to increased water temperatures.

- Overall, birds had large proportions of medium- and high-vulnerability species because Maine has many species that occur at the southern edge of their range or that use habitats vulnerable to climate change. However, major bird taxonomic groups varied in their assessed vulnerabilities. Seabird species have medium to high vulnerability because climate change may shift marine food webs and reduce prey availability and reproductive success. Most shorebird species also have medium to high vulnerability because the completion of their annual cycles relies upon a number of highly vulnerable marine habitats during migration and Arctic breeding habitats. Many waterbirds and waterfowl have medium to high vulnerability because climate change may reduce the availability of wetland breeding habitats and nesting success. Passerines comprise the bulk of bird species that have medium to high vulnerability because they include species associated with at-risk northern forest habitats or are migrants facing additive exposure to climatic risk at breeding areas, during migration, and on wintering areas. By contrast, raptors and owls may have low vulnerability to climate change.

- Some amphibians and reptiles are vulnerable to climate change based on their dependence on vulnerable wetland habitats and expected changes in hydrology; others occur at the northern edge of their range in Maine and may further expand into the state as habitat conditions allow.

- Mammals are fairly mobile, yet species such as the Canada Lynx (Lynx canadensis) and American Marten (Martes americana) occur at the southern limits of their range in Maine and are highly dependent on boreal forest communities and snow conditions that are vulnerable to climate change. Climate change impacts to cave-hibernating bats are uncertain, but given current threats resulting from White-Nose Syndrome, any additional stress posed by climate change to these species is potentially significant.

- Twenty species were not listed species (i.e., not SGCN or state-listed Threatened or Endangered plant species) but were identified as having high vulnerability to climate change. Many more species may have high vulnerability to climate change than were identified in this report.

- The most important climate change vulnerability traits of species assessed as having medium or high vulnerability were related to species habitat specificity, mobility, range limits, and tolerance of physical changes. These ten traits included: high degree of habitat specialization (70% of species), highly fragmented distribution in Maine (49%), dispersal limitations posed by barriers (37%), dependence on stable hydrological regimes (35%), southern range limits in Maine (31%), occupied habitat likely to decline due to climate change (30%), habitat vulnerable to increasing invasive species (27%), low migration and dispersal distances (27%), dependence on environmental cues affected by climate change (24%), and use of habitat with special micro-climate features (23%).

CLIMATE CHANGE VULNERABILITY OF HABITATS AND NATURAL COMMUNITIES

- Three ecosystems had the highest percentage of high-vulnerability species: Alpine, Montane Forest, and Peatlands. More than 50% of the species in five early successional and other ecosystems greatly influenced by human activity (e.g., agriculture) had low vulnerability.

- The most vulnerable habitats and natural communities include alpine and montane systems, peatlands, northern rivershores, spruce flats, and cedar lowlands. While there is some uncertainty regarding processes such as tidal marsh accretion and ground water flows and temperatures, coastal and aquatic systems are considered at least moderately vulnerable by all assessments. Northern forest types also are moderately vulnerable, while oak-pine forests and barrens are likely to remain stable or expand.

EVALUATION OF EXPERT-OPINION ELICITATION PROCESS

- About 50% of the species were reviewed by three or more expert reviewers. Additional reviews of species vulnerability scores through workshop panels resulted on average in modest reductions in species vulnerability scores and no improvement in reviewers' confidence scores. However, additional reviews likely improved the credibility of the results.
- Ninety percent of the online survey reviewers were moderately or very confident in the survey as a means of assessing climate change vulnerability of species.

IMPLICATIONS FOR MANAGERS

- These results can be used to revise the list of target species considered high priorities for investing limited conservation resources. Some species currently uncommon but considered secure, for example American Marten (*Martes americana*), Mink Frog (*Lithobates septentrionalis*), and Cape May Warbler (*Dendroica tigrina*), may be re-ranked to a higher conservation status because their vulnerability to climate change is predicted to be high.
- The results also corroborate that many conventional habitat conservation practices are appropriate for conserving species and habitats in the long term. This should assure biologists and land managers that many existing conservation efforts that use these conventional practices are likely to succeed despite climate change.
- New adaptive strategies might be necessary to achieve site-specific conservation goals. For example, salt marsh migration, beach habitat erosion, and shrinkage of alpine habitat are emerging new stressors not considered by most land managers and biologists before recent projections of climate change. Connectivity and travel corridors between habitats, both aquatic and terrestrial, may become increasingly important so that both plants and animals can move in response to a shifting climate. Maine will likely lose some species and gain others. Prudent action may reduce the disruptive impacts of climate change to Maine's biodiversity.
- A potential climate change threat to Maine's future biodiversity exists if states to the south fail to maintain the connectivity necessary to allow southern species to disperse north. Overall, the prognosis for Maine and its current suite of species and habitats is potentially good (excepting endemics and similar specialist species) if landscape-scale corridors and large habitat blocks are maintained, assuming development includes local provisions for maintaining bodiversity.

Acknowledgements

Funding for producing this document was provided by the Maine Outdoor Heritage Fund, The Nature Conservancy, Manomet Center for Conservation Sciences, and an anonymous donor. The online survey was designed by Chase Saunders and Erik Mitchell at Maine Frameworks. This work was possible only with the contribution of the many reviewers who participated in the online survey and vulnerability assessment workshop. A complete list of reviewers can be found in Appendix E. Julie Beane and Ethel Wilkerson of Manomet made many improvements to this report.

Introduction

Maine is the last stronghold for Wild Brook Trout (*Salvelinus fontinalis*) in the eastern United States. Wild Brook Trout require clean, cool, well-oxygenated water and prefer a narrow range of water temperatures between 12 and 19°C (Cherry et al. 1977). In some areas, climate change might raise water temperature above this range (Williams et al. 2007). This could lead to physiological stress and an increased susceptibility to predation and disease and has been shown to inhibit feeding, growth and reproduction (Giller and Malmqvist 1998). Drier summers could reduce groundwater and stream flows and cool-water refuges in streams, which could impact cold-water fish species, such as brook trout (Vasseur et al. 2008), and other cool water species of conservation concern (e.g., rare mayflies, dragonflies, freshwater mussels, salamanders).

Photograph by Eric Enbretson.

Maine's ecosystems and biodiversity will be affected by climate change in many ways (Jacobson et al. 2009, Whitman et al. 2013a, Frumhoff et al. 2007), and are projected to experience a larger temperature change than other regions in the U.S. outside of the Northeast (Gonzales et al. 2010). Maine can anticipate shifting species distributions, with an increasing number of novel species moving in from the south and many species with northern distributions moving north. Changes in seasonal rainfall patterns may exacerbate late summer dryness and increase levels and frequency of drought stress for plant communities and aquatic systems. Increasing temperatures may allow wildlife parasites such as Winter Moose Tick (*Dermacentor albipictus*) and forest pests such as Hemlock Wooly Adelgid (*Adelges tsugae*) to become more prevalent, stressing native wildlife populations and degrading their habitats. Because each species will respond individually to these threats, the composition of natural communities and wildlife habitats that we take for granted will change. While populations of some species and their habitats will increase, climate change could lead to extirpation of other species and significant changes to natural communities and wildlife habitats (Cahill et al. 2012).

Vulnerability to climate change refers to the degree to which a natural community or population size of a species is likely to be diminished by changes in climate (Schneider et al. 2007). It is a function of exposure and sensitivity to stresses and can be modified by the capacity to adapt to those stresses (Adger et al. 2007, Mertz et al. 2009). One means for building the knowledge of professionals about climate change impacts is to involve them in a climate change vulnerability assessment (Kelly and Adger 2000), an approach now recommended by national groups such as the Association of Fish and Wildlife Agencies (Association of Fish and Wildlife Agencies 2009). A vulnerability assessment can identify species, habitats, and natural communities most likely to be affected by climate changes (Glick et al. 2011). It also provides a tool for understanding the specific vulnerabilities of particular species or communities.

A vulnerability assessment informs conservation planning by identifying climate-related effects and resulting stresses, which then become part of a process for identifying and prioritizing conservation strategies (Staudinger et al. 2012). Identifying high-vulnerability species and understanding why they are vulnerable is critical to developing climate change adaptation strategies and reducing future biodiversity loss. When integrated into a conservation planning framework, adaptation does not replace current conservation strategies. Instead, it allows these strategies to take a coherent, long-term view in the context of a rapidly changing world.

Several vulnerability assessments have been conducted in the region. The Northeast Climate Impacts Assessment Team (Frumhoff et al. 2007) released "Confronting Climate Change in the U.S. Northeast," which summarized the current state of research and modeling for the region. New York (Schlesinger et al. 2011), Massachusetts (Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife 2010), Pennsylvania (Furedi et al. 2011), Illinois (Walk et al. 2011), and other states have now released vulnerability analyses of their wildlife species in the process of revising their state wildlife action plans (SWAPs). SWAPs are comprehensive state plans created by state wildlife agencies for conserving wildlife species and their habitats and are required by the U.S. Fish and Wildlife Service if state agencies are to be eligible for certain funding opportunities. States have begun to address climate change, in part, because the U.S. Fish and Wildlife Service is expected to require that states address climate change vulnerability of species and habitats in their 2015 SWAP revisions (Flaxman and Vargas-Moreno 2011). In Maine, the overarching conservation strategy is the Comprehensive Wildlife Conservation Strategy (CWCS), which is Maine's SWAP (Maine Department of Inland Fisheries and Wildlife 2005). Completed in 2005 by Maine Inland Fisheries and Wildlife (ME IF&W), it identifies conservation threats to Species of Greatest Conservation Need (SGCNs) and their habitats, and proposes actions to reduce those threats.

MANOMET Center for Conservation Sciences

In 2009, Maine's Beginning with Habitat (BwH) Program, a ME IF&W-led partnership of state and federal agencies with conservation organizations, initiated a vulnerability assessment in preparation for the 2015 ME CWCS revision. It tasked a subcommittee[1] with conducting a vulnerability assessment of Maine's SGCN, state-listed Threatened or Endangered plant species, ME CWCS Key Habitats, and natural communities. Although the key objective was a vulnerability assessment, the subcommittee also recognized the importance of increasing the capacity of wildlife managers to understand and manage for climate change. Hence, the goals of this vulnerability assessment were to (1) complete a vulnerability assessment of species, habitats, and natural communities; (2) highlight the relationship between species vulnerability and 21 ME CWCS Key Habitats listed in the ME CWCS; (3) provide information to Maine natural resource managers and conservationists that will help to appropriately focus conservation action in light of climate change impacts on Maine's species and habitats; and (4) provide information to support a revision of the ME CWCS. This document reviews a climate change vulnerability assessment of Maine's terrestrial and aquatic wildlife SGCN, state-listed Threatened or Endangered plant species, CWCS Key Habitats (sec. Maine Department of Inland Fisheries and Wildlife 2005), and natural communities (sec. Gawler and Cutko 2010).

Methods

The vulnerability of Maine's wildlife and plant species, ME CWCS key habitats, and natural communities was assessed using an expert-opinion elicitation process (Martin et al. 2012) that included input from over 100 experts from Maine, other northeastern states, and the Maritime Provinces of Canada. We selected this approach because it is a powerful assessment approach when data availability is limited (Kuhnert et al. 2010). We also incorporated the Delphi approach, a structured method for helping experts to better understand a question or topic (e.g., climate change) and then eliciting their opinions (MacMillan and Marshall 2006). This ensures that their responses can adequately address the key questions of a survey. It starts with independent elicitation of estimates from each expert, in this case by means of an online survey. Subsequently, the results are collated and reviewed by experts a second time where experts reconsider their estimates without knowing the names of contributors. In this project, species vulnerability was assessed in a three-step process described in detail below: (1) an expert elicitation through an online species assessment survey, (2) expert review and modification of online survey results and habitat assessments by expert panels at a workshop, and (3) a final expert review by key state agency biologists and other biologists to fill in data gaps. This process focused on SGCN identified in the 2005 ME CWCS and state-listed Threatened or Endangered plant species, CWCS Key Habitats, and groupings of natural communities (sec Gawler and Cutko 2010). However, participants were permitted to add species they thought likely to be significantly negatively affected by climate change.

The Small Round-leaved Orchid (*Amerorchis rotundifolia*) is a rare and delicate wildflower of northern white cedar swamps in Aroostook County. As a state-listed Threatened species, its persistence is limited by its small, isolated populations, limited dispersal, and specific habitat requirements. This orchid is found only at sites with shaded, undisturbed cedar with very specific levels of soil moisture. Even subtle changes in forest microclimate or groundwater flow could alter the habitat enough to eliminate this species in Maine. **Photo by Maine Natural Areas Program.**

Step 1: Online Assessment

The first step was to use an anonymous online survey so that reviewers could provide an expert opinion regarding the vulnerability score of Maine's SGCN and state-listed Threatened or Endangered plant species. The online survey was developed to allow a large number of taxonomic experts to review the climate change vulnerability of wildlife and plant species. An anonymous approach was selected so that reviewers would provide independent assessments of species vulnerability and avoid being influenced by other experts (Martin et al. 2012).

1 This subcommittee was composed of Steve Walker (ME IF&W), Andy Cutko (Maine Natural Areas Program), Phillip deMaynadier (ME IF&W), Robert Houston (U.S. Fish and Wildlife Service), Sally Stockwell (Maine Audubon), Barbara Vickery (Maine Chapter of The Nature Conservancy), and Andrew Whitman (Manomet Center for Conservation Sciences).

The target reviewers were field biologists with extensive regional field and/or research experience with animal and plant groups native to Maine. A list of invitees was drawn up by the steering committee based on their extensive professional contacts in many agencies and organizations. Invitees were selected because of their strong taxonomic expertise and willingness to participate. Invitees were emailed an invitation and received follow-up email reminders. The invitation and reminders also requested that invitees forward the invitation to qualified contacts. Sixty reviewers participated in the online survey. Before taking the survey, reviewers were asked to review a document describing climate change projections for 21 Key Habitat types (listed in the ME CWCS, Maine Inland Fisheries and Wildlife 2005) and major plant and animal species groups (Whitman et al. 2009)[2]. This document was created to summarize predicted climate changes to which species and wildlife habitats would be exposed in Maine and help standardize the knowledge base of each participant and starting assumptions for the survey.

The survey included (1) SGCN that were identified in the 2005 ME CWCS (n=206) and (2) state-listed Threatened or Endangered plant species (n=163). Reviewers also added fifty-eight species to the online survey, most of which were not reviewed by other participants. For each species, reviewers were asked to assess the vulnerability of the species based on specific traits in six trait categories: habitat specificity, edge of range, environmental or physiological tolerance, interspecific or phenological dependence, mobility, and exotic pathogens or invasive species (Table 1). For each trait category, reviewers could select none, one, or more traits, or add their own. We took this approach to (1) stimulate comprehensive thinking by each reviewer, (2) reduce bias and error among reviewers by systematizing the review process, and (3) better understand key factors related to the vulnerability of each species. Reviewers also identified the CWCS Key Habitats that were the primary habitats (habitats required for successful reproduction and/or survival) for each species.

2 Whitman, A., B. Vickery, P. deMaynadier, S. Stockwell, S. Walker, A. Cutko, and R. Houston. 2013a. Climate Change and Biodiversity in Maine: A climate change exposure summary for participants of the Maine Climate Change Species Vulnerability Assessment. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Adaptation Working Group) Report NCI-2010-2. 22 pp. Brunswick, Maine.

Table 1. A description of trait categories and vulnerability traits used in the online survey.

TRAIT CATEGORIES	DEFINITION (THE DEGREE TO WHICH A SPECIES…)	TRAIT CATEGORY SHORT NAME, TRAIT NUMBER, AND VULNERABILITY TRAIT DEFINITIONS
Habitat specificity	…is restricted to habitats with narrow or well-defined physical or biotic characteristics.	**Habitat Specificity** 1. Exhibits high degree of habitat specialization (i.e., only occurs in fewer than six Natural Community types). 2. A critical part of its life cycle is associated with a single microhabitat feature with distinguishing microclimates (e.g., limestone outcrops, large woody debris, large-diameter trees). 3. Other (user defined).
Edge of range	…is reaching the southern edge of its range in Maine, whose populations are highly fragmented, and/or occupy habitats highly vulnerable to climate change.	**Edge of Range** 1. The species' southern range distribution includes less than half of northern Maine (>45 degrees latitude). 2. The species' occupied habitat in Maine is likely to experience significant declines (i.e., two-thirds of occupied area). 3. The species' occupied range in Maine is highly fragmented either due to patchy habitat availability and/or low occupancy of potential habitat. 4. Other (user defined).
Environmental or physiological tolerance	…is restricted to a narrow range of temperature, hydrology, or snow pack conditions, including both edge-of-range species with distributions most likely determined by climate (as opposed to habitat) and specialists with narrow physical niche tolerance.	**Tolerance** 1. Maximum critical temperature for survival of some life stages likely to be exceeded. 2. Growth or reproduction likely to be negatively impacted by heat stress. 3. Survival and reproduction dependent on specific or stable hydrological regimes. 4. Other (user defined).
Interspecific or phenological dependence	…has high dependencies requiring special environmental cues (e.g., temperature, moisture) or interspecific interactions (e.g., predation, competition, mutualisms) that are likely to be disrupted by climate change.	**Dependence** 1. Disruption of environmental cues for critical life stages by climate change is likely (e.g., migration, hibernation, pupation/enclosure). 2. Disruption of highly specialized relationship with very few prey or host species that are vulnerable to climate change (if so, name in comments field). 3. Dependent on or susceptible to any other close interspecific interaction (e.g., competition, predation, parasitism, mutualisms) likely to be modified by climate change. 4. Other (user defined).
Mobility	…has limited capacity for long-distance migration or dispersal and/or high sensitivity to landscape matrix barriers (e.g., roads, development).	**Mobility** 1. Relatively low intrinsic maximum migration and dispersal distances. 2. Dispersal significantly limited by natural and anthropogenic barriers. 3. Suspected low genetic diversity or known previous genetic bottleneck. 4. Other (user defined).
Exotic pathogens or invasive species	..is sensitive to exotic pathogens or invasive species that may increase or arrive with climate change.	**Exotic** 1. Vulnerable to existing or novel exotic pathogens that are expected to increase. 2. Vulnerable to habitat degradation by invasive species that are expected to increase. 3. Populations vulnerable to increased herbivory by non-native pests. 4. Vulnerable to increased control measures for addressing exotic species and pathogen issues above (e.g., spraying of herbicides or pesticides). 5. Other (user defined).

We developed this list of vulnerability traits based on Foden et al. (2008) and Young et al. (2010). We considered using NatureServe's Climate Change Vulnerability Index (CCVI; Young et al. 2010). Most CCVI efforts have used few experts and focused on less than two-hundred species, so they could afford to spend an hour or more assessing each species (A. Whitman, pers. obs.). We chose an alternative approach because using the CCVI might compromise our ability to achieve our goals (1) to assess many species (nearly twice that of recent CCVI efforts, see below) and (2) to involve many experts with a goal of multiple reviewers per species. Hence, we created a new online survey tool using a streamlined set of criteria that would allow the review of many species and the voluntary participation of many regional experts.

The online survey included an automatic vulnerability scoring algorithm to provide guidance to reviewers and make it easier for reviewers to score the vulnerability of each species. Within each trait category, a species scored low when no traits were selected, medium when one trait was selected, and high when two or more traits were selected. When all trait categories scored low, the species received an automatic score of low vulnerability. When only one trait category scored high and/or more than one trait category scored medium, then the species received an automatic score of medium vulnerability. When more than two trait categories scored high or more than three trait categories scored medium, then the species received an automatic score of high vulnerability. After reviewing the trait groups, selected categories, traits, and the automatic algorithm score of each species, reviewers assigned a vulnerability score to each species and rated their confidence in their vulnerability score with a confidence score (Table 2). For each species, reviewers also identified which of 21 ME CWCS Key Habitats were essential for a species' successful survival and reproduction. After completing the survey, reviewers were asked to rate their confidence in using the survey results to accurately describe the vulnerability of Maine species: low confidence (likely not to be useful), medium confidence (likely to be moderately useful), or high confidence (likely to be very useful).

After the survey, the following flaw in the automatic vulnerability scoring algorithm was detected: species with only one high-scoring vulnerability trait category and more than one medium-scoring vulnerability trait category should have received an automatic score of high vulnerability. There was some concern that reviewers would uncritically accept automatic algorithm scores and this algorithm flaw would create a bias wherein some species would receive too low a score. Across all species, the survey results revealed that reviewers generally changed their vulnerability score from the automatic algorithm score 37% of the time (N=837), increasing the score 57% of the time and reducing the score 43% of the time. Eighty reviewers participated in the survey.

Table 2. Species vulnerability scores and confidence scores.

SCORE	SCORE NAME	DEFINITION
Vulnerability Scores		**(Climate change is likely to have…)**
1	Low Vulnerability	….little negative impact (<33% loss) or a positive impact on this species' range area and/or population size in Maine 50 to 100 years from now.
2	Medium Vulnerability	…an intermediate impact (33-66% loss) on this species' range and/or population size in Maine 50 to 100 years from now.
3	High Vulnerability	…a large negative impact (>66% loss) on this species' range area and/or population size in Maine, including potential state-level extirpation 50 to 100 years from now.
Confidence Scores		**(I have a…)**
1	Not very confident	0-30% certainty in species vulnerability score.
2	Somewhat confident	>30-70% certainty in species vulnerability score.
3	Very confident	>70% certainty in species vulnerability score.

Step 2: Workshop Assessments

The second step entailed the use of two sets of breakout groups of experts at a May 19, 2010, workshop to discuss and possibly revise the species vulnerability scores from the survey in Step 1 and to assess the vulnerability of selected habitats. The goal of the first set of breakout groups was to review vulnerability scores of 131 species selected for discussion by the workshop Steering Committee. These 131 species were selected for further review because they (1) had not been assessed in the online exercise or (2) had high vulnerability scores and had only one reviewer or vulnerability scores that varied greatly among reviewers. The goal of the second set of breakout groups was to assess the vulnerability of CWCS Key Habitats and a limited number of associated Natural Community types. Notice of the workshop was sent to one-hundred people, including survey participants, other agency staff, and conservation groups several weeks before the workshop. The primary audience for the workshop was survey participants; however, other participants were invited so that they might also learn about the climate change vulnerability of species and ecosystems in Maine and contribute their field experience. Although most workshop participants had participated in the survey, some workshop participants had not. Forty-two ecologists participated in the workshop.

The workshop was composed of presentations describing climate change impacts and exposure of ecosystems, followed by breakout sessions by major taxa to discuss and modify survey results. The first set of breakouts added 24 additional species to the vulnerability assessment and evaluated the vulnerability and confidence score for each species. After thorough discussions among participants in each group, breakout groups also changed some scores, the results of which are described in "A Review of the Three-Step Process" in Appendix D. Breakout groups also summarized their rationale for making these changes (these can be found in the Comments of Species Group tables in Appendix A). Participants in the second set of breakout groups were asked to score the vulnerability of ME CWCS Key Habitats and selected natural communities and groupings of similar natural communities from Gawler and Cutko (2010). The results of the second set of breakout groups were largely consistent with a Key Habitat assessment based on constituent species (see Section *6.1 Species Vulnerability Associations with ME CWCS Key Habitats*) and regional analyses (see *Synthesis of Results from Maine and Other Regional Assessments*). Therefore, we considered further expert elicitation assessing habitats and natural communities to add little value.

Step 3: Assessment by Key Agency Staff and Other Experts

The third step was a focused effort by key agency staff to conduct further research or obtain input from key regional experts for species that had not been thoroughly reviewed in Steps 1 or 2. After the workshop, 59 SGCN either had not been reviewed by anyone or were only reviewed by a single reviewer. These species received further review by BwH Climate Change Adaptation Subcommittee members and their colleagues (Andy Cutko, Don Cameron, Arthur Haines, plants; Steve Walker, birds and mammals; Phillip deMaynadier and Beth Swartz, herpetofauna and invertebrates) in an effort to ensure that all species were assessed for their climate change vulnerability. Many of these species were unknown to the original reviewers because they were very rare, cryptic, and/or only known from historical records. When possible, these agency staff identified vulnerability and confidence scores for these species and/or solicited input from other key experts for a few species. These results were compiled together with initial survey results and species scores modified by workshop breakout groups to create a final list of SGCN species, state-listed Threatened or Endangered plant species, and other species and their vulnerability and confidence scores for Maine. The vulnerability scores, confidence scores, numbers of reviewers, and comments in this report are from this final list (Step 3), while vulnerability trait data were derived from the online survey (Step 1).

The Eastern Moose (*Alces alces americana*) is a northern species that is found as far south as York County. Moose may be vulnerable to climate and accompanying changing interspecific relationships. The southern range limit of moose may be determined in part by thermoregulatory stress (Renecker and Hudson 1986). At the southern edge of its range, links between declining populations and rising air temperatures related to climate change have been shown (Murray et al. 2006, Lenarz et al. 2010). Both winter thaws and extreme summer temperatures may lead to heat stress. Moose are also vulnerable to Winter Moose Ticks (*Dermacentor albipictus*) that survive mild winters well and can cause stressful hair loss and increased calf mortality (Murray et al. 2005).
Photograph by Corey Raimond.

Climate Change Vulnerability of Plant and Wildlife Species

This three-step, expert-opinion elicitation process of species vulnerability included 442 species, including 369 species pre-selected for Step 1 (206 SGCN and 163 state-listed Threatened or Endangered plant species), 58 species added in Step 1 by reviewers, and 24 species added during the workshop (Step 2) or after the workshop (Step 3). This is twice the number of species that have been assessed by any other state: Illinois - 163 species (Walk et al. 2011), New York - 121 species (Schlesinger et al. 2011), Pennsylvania - 85 species (Furedi et al. 2011), Nevada - 263 species (Nevada Natural Heritage Program 2011), and West Virginia - 185 species (Byers and Norris 2011). This effort included more species than efforts by other states because it also included 163 plant species. Because many invertebrate SGCN and state-listed Threatened or Endangered plant species by their nature are very rare, cryptic, only known from historical records, and/or otherwise known by few experts, many species in these two groups were assessed by fewer than three reviewers.

Most SGCN, state-listed Threatened or Endangered plant species, and added species were scored as having medium or high vulnerability to climate change. One hundred and sixty-eight species (37%) had high vulnerability scores and another 171 species (38%) had medium vulnerability scores. The following sections describe the vulnerability of different wildlife and plant groups. The vulnerability of species within each group is summarized in Appendix A.

Climate Change Vulnerability of Major Taxonomic Groups

The distribution of species across vulnerability scores (low, medium, and high) varied across the major taxa (Fig. 1). Fungi and lichen species and state-listed Threatened or Endangered vascular plants had the highest proportion of high-vulnerability species and, in this sense, are the taxa most vulnerable to climate change. All fungi and lichen species were added during the online survey, as none were state-listed Threatened or Endangered species. They are epiphytic (living on live plants) or epixylic (living on dead wood) species dependent on northern tree species as hosts, tree species with populations that are projected to decline due to climate change (Prasad et al. 2007). Their climate change vulnerability may not be indicative of that of other fungi and lichen species. Many vascular plant species were highly vulnerable because (1) Maine is the southern edge of their range, (2) their ability to disperse and migrate is relatively low, and/or (3) their populations are highly fragmented. Their lack of mobility and fragmented populations emphasize the importance of maintaining landscape connectivity as an adaptation to climate change.

Bird SGCN are also a taxon with a high level of climate change vulnerability. This taxon had similar numbers of species in each vulnerability category with nearly two-thirds of bird species having medium or high vulnerability. Many vulnerable bird species are at the southern edge of their range or use habitats that are particularly vulnerable to climate change, such as mountaintops and salt marshes.

Invertebrate and fish taxa had more medium-vulnerability species than low- or high-vulnerability species. Species in these taxa vary in their vulnerability traits. Species dependent on wetland systems (e.g., aquatic invertebrates, fish) may be moderately vulnerable to changes in climate, specifically changes in hydrological regimes and increased water temperatures. These and other aquatic species taxa averaged confidence scores <2 while most terrestrial taxa averaged confidence scores >2 (see Appendix A). The high uncertainty regarding precipitation projections may have led many reviewers to score the vulnerability of these species as medium and be less certain of their vulnerability scores for aquatic species than for terrestrial species. Also, terrestrial biologists maybe more knowledgeable about terrestrial species than aquaitc biologist are about aquatic species and this may have affected their respective confidence scores. Other aquatic species are at the edge of their range or occur in highly fragmented populations (Appendix A). The habitats of many cold-water aquatic species are predicted to decline in the region as air temperatures warm and, subsequently, water temperatures increase.

Amphibian and reptile SGCN had similar numbers of low-, moderate-, and high-vulnerability species. Herpetofauna are somewhat mobile and have ranges that extend south of Maine, often having northern limits of their range in Maine. A notable exception is the Mink Frog (*Lithobates septentrionalis*) – Maine's only amphibian reaching the southern edge of its range in the state, and thus assessed as having higher vulnerability because of its breeding association with cold water. Conservation strategies that allow amphibians and reptiles to persist within relatively intact landscapes with diverse microclimates may be essential to their long-term persistence in Maine.

Mammal SGCN had similar numbers of low-vulnerability species and high-vulnerability species combined. Mammal species are mobile and many have wide habitat preferences. Many occur at the northern limits of their range in Maine and so have relatively low vulnerability and may persist in Maine with climate change. A few species are northern species that have higher vulnerability to climate change, in some cases because of their adaptations to deep snow cover (e.g., Canada Lynx, *Lynx canadensis*; American Marten, *Martes americana*). Strategies that allow mammal species to shift their ranges across landscapes may be useful adaptation strategies for many of these species.

Other states have conducted similar taxonomic assessments of animal species. Pennsylvania showed a similar pattern of taxonomic group vulnerability with birds among the most vulnerable groups (Furedi et al. 2011), whereas taxonomic groups of aquatic species were the most vulnerable in Illinois (Walk et al.2011), New York (Schlesinger et al. 2011), and West Virginia (Byers and Norris 2011). Aquatic species in Maine may be less vulnerable to climate change than those in the other three states, as their habitats are relatively intact given the rural, largely forested context in which they occur. Maine may also have a greater proportion of terrestrial species reaching the southern edge of their range compared with terrestrial and aquatic species in these other states.

To better understand the trends within vascular plant, invertebrate, and bird groups, we graphically reviewed the vulnerability of sub-groups in these three taxonomic groups (Figs. 2, 3, and 4). These three groups were selected for further analysis because each contained several sub-groups that varied in their life history and included a large number of species (see sections titled: *Vulnerability of State-listed Threatened or Endangered Plant Species by Major Habitat*, *Vulnerability of Invertebrate Taxa*, and *Vulnerability of Bird Taxa*, below).

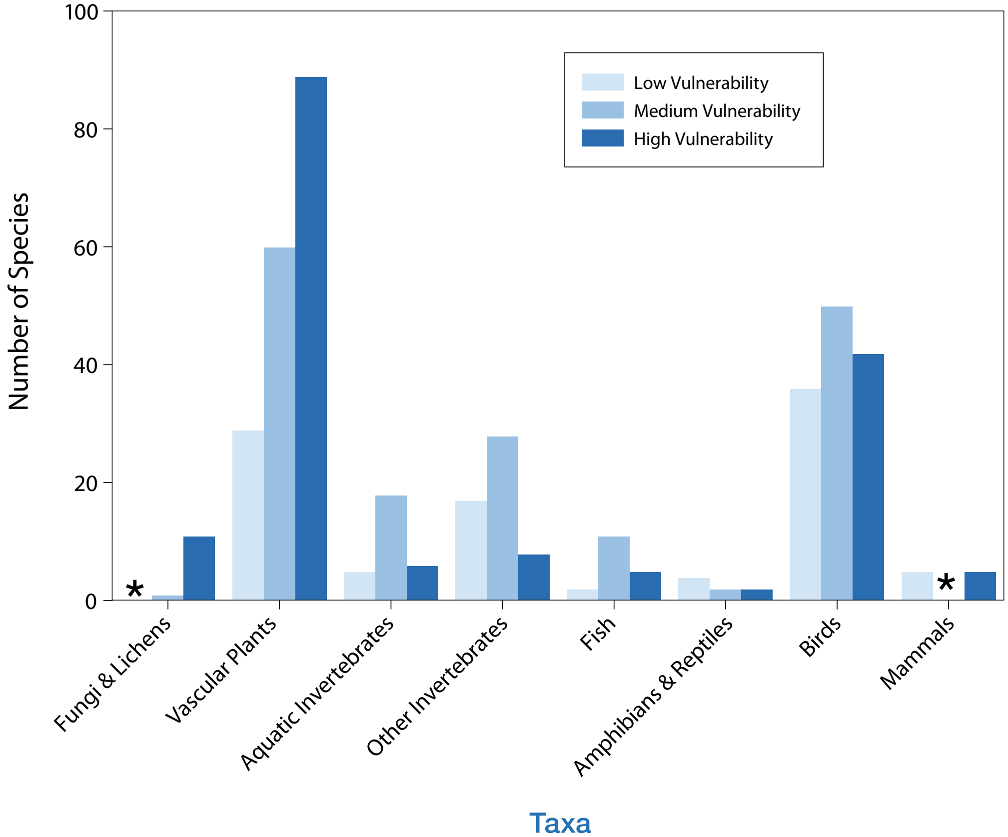

Figure 1. The climate change vulnerability of species in eight major taxonomic groups in Maine.

Vulnerability of State-listed Threatened or Endangered Plant Species by Major Habitat

The distribution of state-listed Threatened or Endangered plant species across vulnerability scores (low, medium, and high) varied across habitats. Most of the plants in the wetland habitat groups had medium or high vulnerability to climate change (Fig. 2). Climate change is projected to increase drought and affect wetland hydrology in ways that may be detrimental to many wetland plants. Moreover, many wetland species may be challenged to successfully disperse or migrate because their wetland habitats are naturally fragmented, and wetlands are particularly vulnerable to some invasive species (e.g., Purple Loosestrife, *Lythrum salicaria*; Common Reed [*Phragmites australis*]). Many species of coastal wetlands were considered vulnerable because of concerns about sea level rise and loss or alternation of tidal marshes. A number of vulnerable plant species in these groups are also at the southern edge of their range in Maine. Alpine and central northern uplands plant species were also groups with a high proportion of species that had medium or high vulnerability to climate change. Many of these species may be vulnerable to climate change because they are at the southern edge of their range, occur in naturally fragmented habitats that limit dispersal and migration, and may have narrow habitat requirements in terms of substrate, elevation, and landform. Species of barrens/disturbed ground and southern uplands were considered the least vulnerable to climate change.

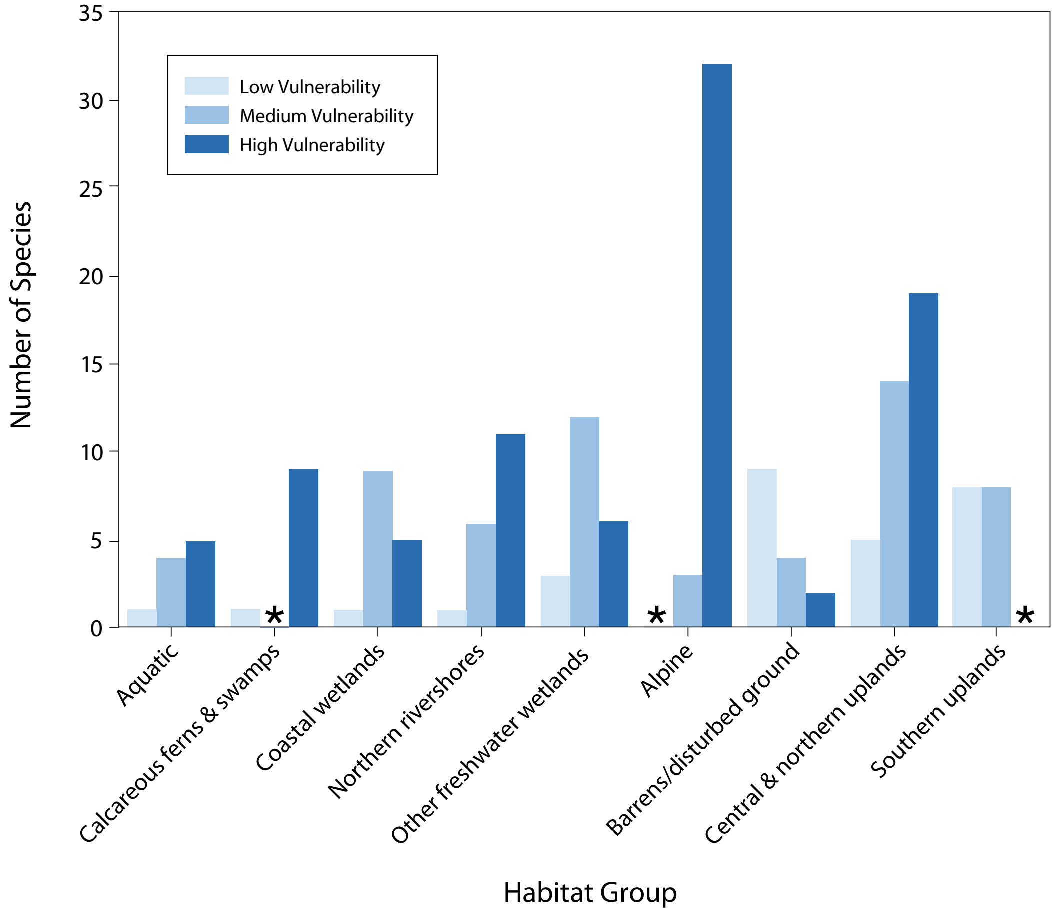

Figure 2. The climate change vulnerability of state-listed Threatened or Endangered plant species in nine taxonomic groups in Maine.

Vulnerability of Invertebrate Taxa

The distribution of invertebrate species across vulnerability scores (low, medium, and high) varied among major invertebrate taxa (Fig. 3). Most invertebrate species in each taxonomic group received a rating of either medium or high. The taxon with the greatest proportion of species with low vulnerability to climate change was moths and butterflies (*Lepidoptera*). Many moth and butterfly SGCN in Maine are at the northern edge of their range and so may be less vulnerable to climate change, or even expand their ranges due to climate change. The group with the greatest proportion of species with high vulnerability to climate change was aquatic invertebrates. Many aquatic invertebrate SGCN in Maine are at the southern edge of their range, limited to cold-water habitats and peatlands, have fragmented distributions, and/or other dispersal and migration limitations in the face of climate change.

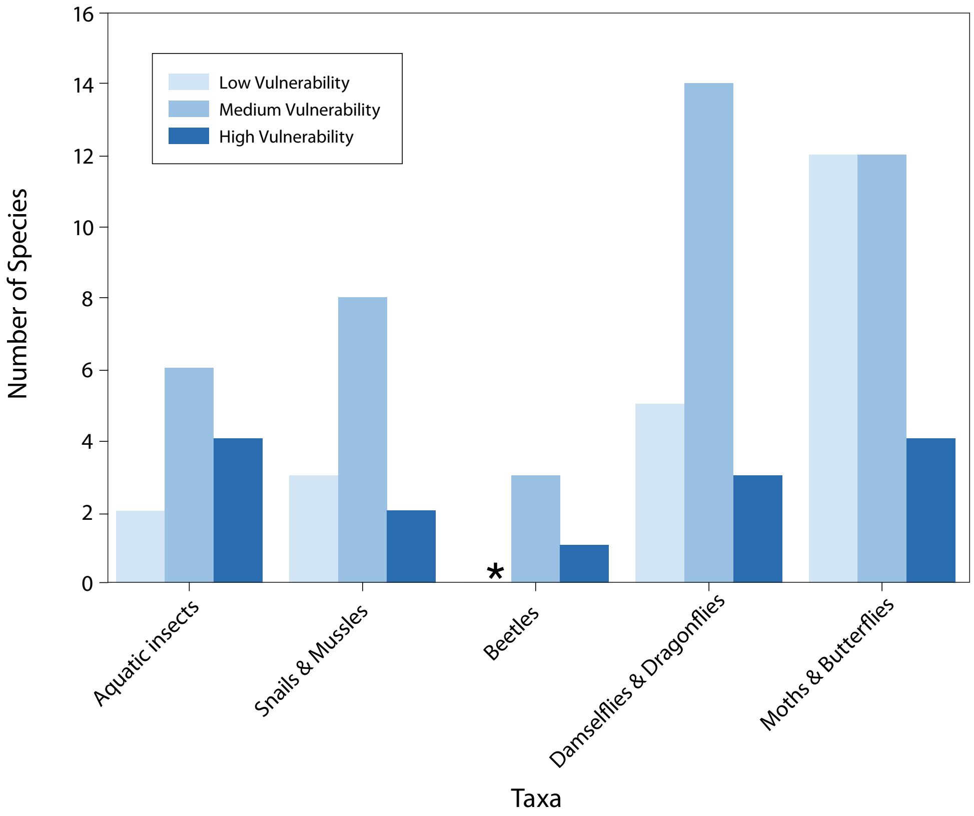

Figure 3. The climate change vulnerability of invertebrate SGCN species in five taxonomic groups in Maine.

Vulnerability of Bird Taxa

The distribution of bird taxa across vulnerability scores (low, medium, and high) varied among major bird groups (Fig. 4). Seabird species have medium to high vulnerability because climate change may shift marine food webs and reduce the availability of their prey (Irons et al. 2007). Most shorebirds also have medium to high vulnerability because the completion of their annual cycles relies upon a number of highly vulnerable marine habitats during migration (Durell et al. 2006) and (for most shorebird species) Arctic habitats for breeding (IPCC 2002). In the Northeast, sea level rise may reduce nesting, feeding, and roosting habitat for shorebirds (New Hampshire Fish and Game Department 2005). Many waterbirds and waterfowl have medium to high vulnerability because climate change may negatively affect the availability of wetland breeding habitats. These species may face an increasingly variable hydrological cycle where some wetlands dry out in some years and result in smaller clutch sizes, nesting failures, and reduced fecundity (Wormworth and Mallon 2006). As a species group, raptors may be relatively less vulnerable to climate change.

About one-third of land bird SGCN (Woodpeckers and other species, and Passerines) have low vulnerability to climate change. Nonetheless, Passerines make up the bulk of bird species that have medium to high vulnerability to climate change. Populations of species associated with northern forest habitats (boreal forest and northern hardwoods) may decline significantly, as the extent of their forest habitats decline (Rodenhouse et al. 2008). Many Passerines are migrants that may be at higher risk than non-migrant species because they are affected by climate change on their wintering areas, during migration, and on their breeding grounds (Ahola et al. 2004). The additive exposure to climatic risk to each habitat could add up to a cumulative catastrophic effect (Huntley et al. 2006).

Chestnut Oak (*Quercus montana*) is a frequent component of oak-hickory forests from the southern Appalachian states through southern New England, and it reaches its northernmost point around Mount Agamenticus in York County, Maine. Because of its current rarity in Maine, this species is listed as State Threatened. However, warmer temperatures and drier summers are favorable to this species, and given sufficient forest connectivity from Massachusetts and New Hampshire through southern Maine, chestnut oak is likely to expand in the state during the next century (Prasad et al. 2008 but see Abrams 2003). Likely for these reasons, reviewers in this study ranked this species as 'least vulnerable' with high confidence. **Photo by Maine Natural Areas Program.**

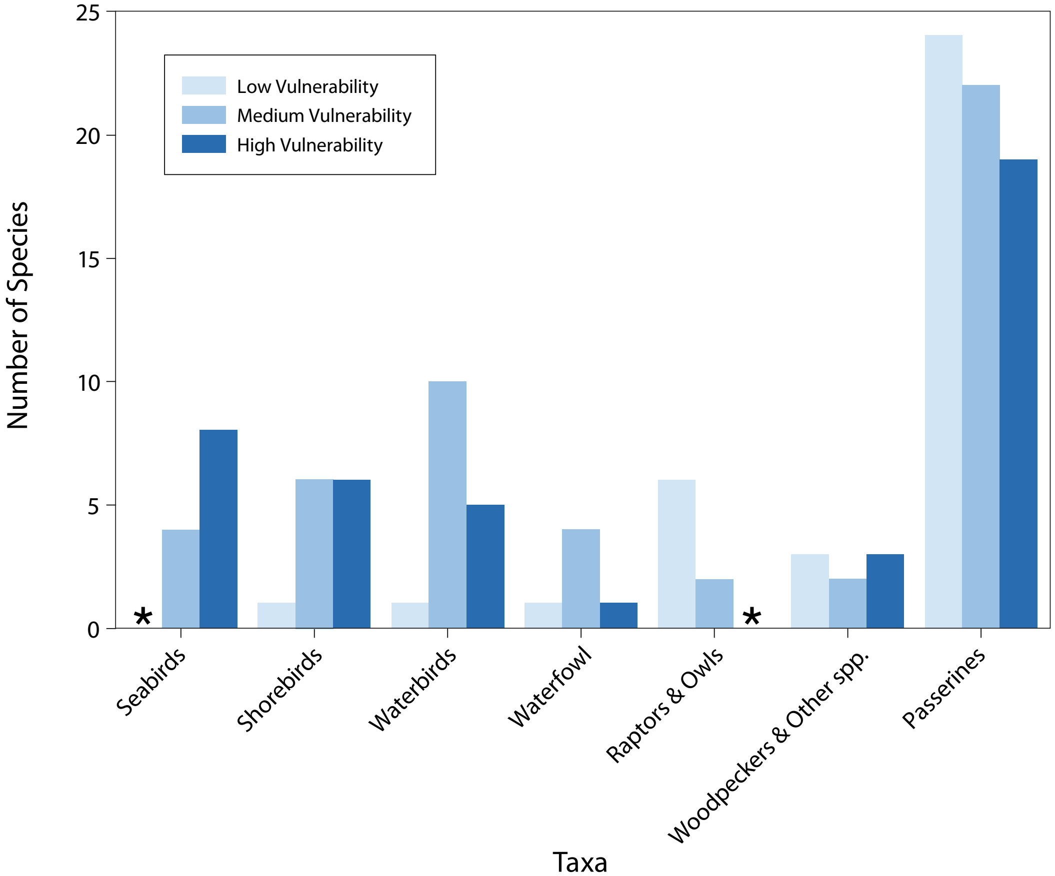

Figure 4. The climate change vulnerability of bird SGCN in seven taxonomic groups in Maine.

High-vulnerability Species

One hundred and sixty-eight species, including many SGCN, state-listed Threatened or Endangered plant species, and reviewer-added species, were scored as having high vulnerability to climate change. This included species from every major taxa (Fig. 5). Major taxa ranged from 15% to 92% of reviewed species being ranked as high vulnerability to climate change. Fifty percent of SGCN mammal and state-listed Threatened or Endangered plant species had high vulnerability to climate change. Both taxa include many northern species reaching their southern range limits in Maine, increasing their vulnerability to climate change. Nearly 30% of SGCN bird and fish species had high vulnerability to climate change, and these two taxa also include many northern species reaching their southern range limits in Maine. While the remaining SGCN taxa also include many high-vulnerability species, they also include many southern species that are much less affected by climate change. Although it is important to conserve the range of taxa in Maine, on-the-ground efforts should focus on specific life history traits (see section titled *Traits Associated with Species Vulnerability*) and habitat requirements of high-vulnerability species (see section titled *Climate Change Vulnerability of Habitats and Natural Communities*).

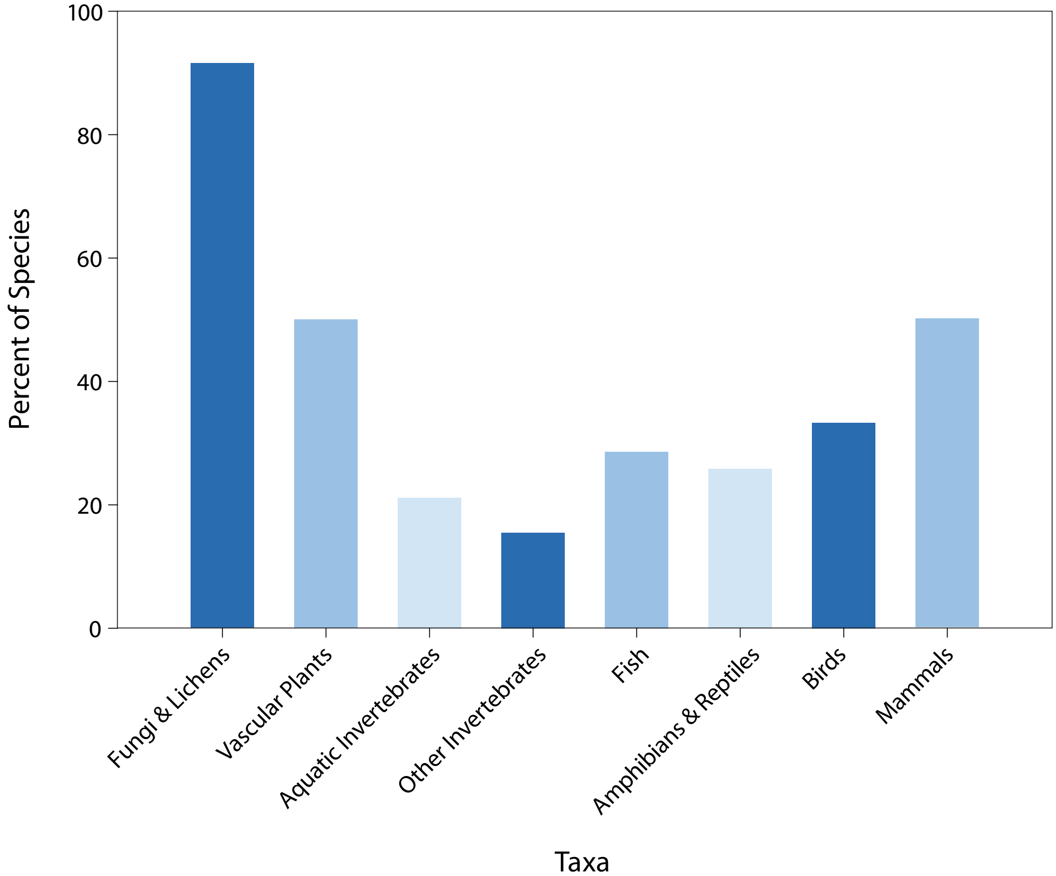

Figure 5. Percent of reviewed species that had high vulnerability to climate change for eight major taxa.

Fungi and lichens: Ten fungi and lichen species had high vulnerability to climate change because their host tree species were vulnerable to climate change (Table 3; Appendix B, Table B1). Fungi and lichen species are not currently state listed in Maine. Two species, Powdery Axil-Bristle Lichen (*Menegazzia terebrata*) and Methuselah's Beard Lichen (*Usnea longissima*), are very rare species that occur only on host boreal tree species. None of the species had more than two reviewers and so merit further investigation before considering a possible state listing.

Table 3. A list of 10 fungi and lichen species that have high vulnerability to climate change.

Fungi Species	Lichen Species
Unnamed shelf fungus (*Fomitopsis cajanderi*)	Witch's Hair (a lichen) (*Alectoria sarmentosa*)
Red Banded Polypore Fungus (*F. pinicola*)	Smooth gray horsehair lichen (*Bryoria capillaris*)
Hemlock varnish shelf fungi (*Ganoderma tsugae*)	Foliose Shingle Lichen (*Fuscopannaria ahlneri*)
Birch Polypore (*Piptoporus betulinus*)	Powder-headed tube lichen (*Hypogymnia tubulosa*)
	Powdery axil-bristle lichen (*Menegazzia terebrata*)
	Methuselah's beard lichen (*Usnea longissima*)

Wetland plant species: Thirty-seven wetland plant species were ranked to have high vulnerability to climate change (Table 4; Appendix B, Table B2). Twenty-five are S1 species and thus already have an elevated conservation status. Eleven species were S2 species and may have greater vulnerability than formerly noted. Showy Lady's-slipper (*Cypripedium reginae*) was added to the assessment and so may merit review for elevating its conservation status because of vulnerability to climate change. Reviewers indicated that they had high confidence in their vulnerability scores for 22 of the 37 high-vulnerability species. Thirty species only had one or two reviewers and so likely merit further review of their climate change vulnerability before changing their conservation status.

Table 4. A list of 37 wetland plant species that have high vulnerability to climate change. All species were state-listed Threatened or Endangered species except for Showy Lady;s-slipper (*Cypripedium reginae*), which is marked with an astrisk (*).

Aquatic Species

Prototype Quillwort (*Isoetes prototypus*)
Slender Rush (*Juncus subtilis*)
Pygmy Water-lily (*Nymphaea leibergii*)
Small Yellow Water Crowfoot (*Ranunculus gmelinii* var. *purshii*)
Slender Pondweed (*Stuckenia filiformis* ssp. *occidentalis*)

Calcareous Fens and Swamps

Small Round-leaved Orchis (*Amerorchis rotundifolia*)
Prairie Sedge (*Carex prairea*)
Showy Lady's-slipper (*Cypripedium reginae*)*
English Sundew (*Drosera anglica*)
Slender-leaved Sundew (*D. linearis*)
Prairie White-fringed Orchid (*Platanthera leucophaea*)
Lapland Buttercup (*Ranunculus lapponicus*)
Hoary Willow (*Salix candida*)
Low Spike-moss (*Selaginella selaginoides*)

Coastal Wetlands

Nova Scotia False-foxglove (*Agalinis neoscotica*)
Long's Bitter-cress (*Cardamine longii*)
Saltmarsh sedge (*Carex vacillans*)
Lilaeopsis (*Lilaeopsis chinensis*)
Marsh Felwort (*Lomatogonium rotatum*)
Beach Plum (*Prunus maritima*)

Northern River Shores

Cut-leaved Anemone (*Anemone multifida*)
Neglected Reed-grass (*Calamagrostis stricta* ssp. *stricta*)
Northern Gentian (*Gentianella amarella* ssp. *acuta*)
Robinson's Hawkweed (*Hieracium robinsonii*)
St John Oxytrope (*Oxytropis campestris* var. *johannensis*)
Furbish's Lousewort (*Pedicularis furbishiae*)
Mountain Timothy (*Phleum alpinum*)
Horned Beak-rush (*Rhynchospora capillacea*)
Blue-leaf Willow (*Salix myricoides*)
Canada Buffaloberry (*Shepherdia canadensis*)
Anticosti Aster (*Symphyotrichum anticostense*)

Other Freshwater Wetlands

Tundra Dwarf Birch (*Betula glandulosa*)
Moonwort (*Botrychium lunaria*)
Long-tubercled Spike-rush (*Eleocharis tuberculosa*)
Auricled Twayblade (*Listera auriculata*)
White Adder's-mouth (*Malaxis monophyllos*)
Jacob's Ladder (*Polemonium vanbruntiae*)

Upland plant species: Fifty-two upland plant species were ranked to have high vulnerability to climate change (Table 5; Appendix B, Table B3). Forty-six species are S1 species and thus already have an elevated conservation status. One species, Kidneyleaf Violet (*Viola renifolia*), is not a state-listed Threatened or Endangered plant species, but may merit further consideration for elevating its conservation status in the future. Many species only had one or two reviewers and so their climate change vulnerability should be scrutinized more fully before changing their conservation status based on climate change vulnerability. Most of these high-vulnerability plant species are alpine species or northern species reaching their southern range limits in Maine.

Table 5. A list of 52 upland plant species that have high vulnerability to climate change. All species were state-listed Threatened or Endangered species except for Kidneyleaf Violet (*Viola renifolia*), which is marked with an astrisk (*).

Alpine Species

Boreal Bentgrass (*Agrostis mertensii*)
Alpine Bearberry (*Arctostaphylos alpine*)
Hairy Arnica (*Arnica lanceolata*)
Dwarf White Birch (*Betula x minor*)
Alpine Bitter-cress (*Cardamine bellidifolia*)
Bigelow's Sedge (*Carex bigelowii*)
Russett Sedge (*C. saxatilis*)
Alpine Willow-herb (*Epilobium anagallidifolium*)
Hornemann's Willow-herb (*Epilobium hornemannii*)
Oakes' Eyebright (*Euphrasia oakesii*)
Arctic Red Fescue (*Festuca prolifera*)
Moss Bell-heather (*Harrimanella hypnoides*)
Alpine Clubmoss (*Huperzia selago*)
Alpine Azalea (*Loiseleuria procumbens*)
Northern Wood-rush (*Luzula confuse*)
Spiked Wood-rush (*L. spicata*)
Silverling (*Paronychia argyrocoma*)
Alpine Bistort (*Persicaria vivipara*)
Mountain Heath (*Phyllodoce caerulea*)
Wavy Bluegrass (*Poa fernaldiana*)
Boott's Rattlesnake Root (*Prenanthes boottii*)
Dwarf Rattlesnake Root (*P. nana*)
Lapland Rosebay (*Rhododendron lapponicum*)
Arctic Willow (*Salix arctophila*)
Dwarf Willow (*S. herbacea*)
Tea-leaved Willow (*S. planifolia*)
Bearberry Willow (*S. uva-ursi*)
Star Saxifrage (*Saxifraga foliolosa*)
Cutler's Goldenrod (*Solidago multiradiata* var. *arctica*)
Mountain Hairgrass (*Vahlodea atropurpurea*)
Alpine Speedwell (*Veronica wormskjoldii*)
Alpine Marsh Violet (*Viola palustris*)

Barrens/Disturbed Ground Species

Variable Sedge (*Carex polymorpha*)

Central and Northern Maine Uplands Species

Aleutian Maidenhair Fern (*Adiantum aleuticum*)
Green Spleenwort (*Asplenium trichomanes-ramosum*)
New England Northern Reed Grass (*Calamagrostis stricta* ssp. *inexpansa*)
Intermediate Sedge (*Carex norvegica* ssp. *inferalpina*)
Northern Wild Comfrey (*Cynoglossum virginianum* var. *boreale*)
Ram's-head Lady's-slipper (*Cypripedium arietinum*)
Squirrel-corn (*Dicentra canadensis*)
Rock Whitlow-grass (*Draba arabisans*)
Lance-leaved Draba (*D. cana*)
Male Fern (*Dryopteris filix-mas*)
Boreal Bedstraw (*Galium kamtschaticum*)
Giant Rattlesnake-plantain (*Goodyera oblongifolia*)
Northern Stickseed (*Hackelia deflexa* var. *americana*)
Arctic Sandwort (*Minuartia rubella*)
Common Butterwort (*Pinguicula vulgaris*)
White Bluegrass (*Poa glauca*)
Canada Burnet (*Sanguisorba canadensis*)
Kidneyleaf Violet (*Viola renifolia*)*
Smooth Woodsia (*Woodsia glabella*)

Invertebrate species: Fourteen invertebrate species were ranked as being highly vulnerable to climate change (Table 6; Appendix A3, Table B4). Two species, the Salt Marsh Tiger Beetle (*Cicindela marginata*) and Northern Blue Butterfly (*Lycaeides idas scudderii*) are not SGCN but may merit consideration for elevating their conservation status in the future because of rarity and vulnerability to climate change. Although 11 species were reviewed by a panel of experts at the workshop, confidence scores were low or moderate for most species because so little is known about the biology and distribution of most rare invertebrate species. Many of these high-vulnerability species reach their southern range limits in Maine, are associated with cold-water, peatland, or alpine habitats, or are affected by sea level rise.

Table 6. A list of 14 invertebrate species that have high vulnerability to climate change. Species marked with an asterisk (*) were not included as a Species of Greatest Conservation Need in the 2005 State Wildlife Action Plan.

Aquatic Insects

A Mayfly (*Baetisca rubescens*)
Roaring Brook Mayfly (*Epeorus frisoni*)
A Stonefly (*Neoperla mainensis*)
Tomah Mayfly (*Siphlonisca aerodromia*)

Beetles

Salt Marsh Tiger Beetle (*Cicindela marginata*)*

Damselflies and Dragonflies

Sedge Darner (*Aeshna juncea*)
Canada Whiteface (*Leucorrhinia patricia*)
Quebec Emerald (*Somatochlora brevicincta*)

Moths and Butterflies

Purple Lesser Fritillary (*Boloria chariclea grandis*)
Frigga Fritillary (*Boloria frigga*)
Northern Blue (*Lycaeides idas scudderii*)*
Katahdin Arctic (*Oeneis polixenes katahdin*)

Snails and Mussels

Brook Floater (*Alasmidonta varicosa*)
Six-whorl Vertigo (*Vertigo morsei*)

Vertebrate species: Fifty-five vertebrate species were ranked as having high vulnerability to climate change (Table 7; Appendix B, Table B5). Sixteen species are not SGCN but may merit further consideration for elevating their conservation status in the future because of vulnerability to climate change. Twenty species only had one or two reviewers and so likely merit further review of their climate change vulnerability before considering a change in their conservation status (see Appendix B, Table A3.5). Many of these high-vulnerability species reached their southern range limits in Maine, are associated with cold-water or boreal habitats, are wetland species vulnerable to fluctuating water levels during nesting periods, or are marine species affected by sea level rise, altered ocean chemistry, or changes in marine food webs.

Table 7. A list of 55 vertebrate species that have high vulnerability to climate change. Species marked with an asterisk (*) were not included as a Species of Greatest Conservation Need in the 2005 State Wildlife Action Plan.

Inland Fish Species

Lake Whitefish (*Coregonus clupeaformis*)
Rainbow Smelt (*Osmerus mordax*)
Round Whitefish (*Prosopium cylindraceum*)
Landlocked Salmon (*Salmo salar sebago*)
Arctic Charr (*Salvelinus alpinus oquassa*)

Diadromous Fish Species

Atlantic Salmon (*Salmo salar*)

Amphibian and Reptile Species

Blanding's Turtle (*Emydoidea blandingii*)
Mink Frog (*Lithobates septentrionalis*)*

Seabird Species

Razorbill (*Alca torda*)
Black Tern (*Chlidonias niger*)
Atlantic Puffin (*Fratercula arctica*)
Least Tern (*Sterna abutkkarum*)
Roseate Tern (*S. dougallii*)
Arctic Tern (*S. paradisaea*)
Common Murre (*Uria aalge*)

Waterbird Species

Yellow Rail (*Coturnicops noveboracensis*)
American Coot (breeding) (*Fulica americana*)
Common Moorhen (*Gallinula chloropus*)
Common Loon (*Gavia immer*)
Least Bittern (*Ixobrychus exilis*)

Waterfowl Species

Harlequin Duck (*Histrionicus histrionicus*)

Shorebird Species

Red Knot (*Calidris canutus*)
Least Sandpiper (*C. minutilla*)
Semipalmated Sandpiper (*C. pusilla*)
Willet (*Catoptrophorus semipalmatus*)
Piping Plover (*Charadrius melodus*)
American Oystercatcher (*Haematopus palliatus*)
Red-necked Phalarope (*Phalaropus fulicaria*)

Woodpecker and Other Species

Spruce Grouse (*Falcipennis canadensis*)*
Black-backed Woodpecker (*Picoides arcticus*)
Am. Three-toed Woodpecker (*P. dorsalis*)*

Passerine Species

Saltmarsh Sharp-tailed Sparrow (*Ammodramus caudacutus*)
Nelson's Sharp-tailed Sparrow (*A. nelsoni*)
American Pipit (breeding) (*Anthus rubescens*)
Bicknell's Thrush (*Catharus bicknelli*)
Swainson's Thrush (*Catharus ustulatus*)*
Evening Grosbeak (*Coccothraustes vespertinus*)*
Blackpoll Warbler (*Dendroica striata*)*
Cape May Warbler (*D. tigrina*)*
Yellow-bellied Flycatcher (*Empidonax flaviventris*)*
Red Crossbill (*Loxia curvirostra*)
White-winged Crossbill (*L. leucoptera*)*
Lincoln's Sparrow (*Melospiza lincolnii*)*
Mourning Warbler (*Oporornis philadelphia*)*
Northern Parula (*Parula americana*)
Gray Jay (*Perisoreus canadensis*)
Pine Grosbeak (*Pinicola enucleator*)*
Boreal Chickadee (*Poecile hudsonicus*)*
Ruby-crowned Kinglet (*Regulus calendula*)*
Tennessee Warbler (*Vermivora peregrina*)*

Small Mammal and Bat Species

Northern Bog Lemming (*Synaptomys borealis*)

Medium and Large Mammal Species

Eastern Moose (*Alces alces americana*)*
Snowshoe hare (*Lepus americanus*)*
Canada Lynx (*Lynx canadensis*)
American marten (*Martes americana*)*

The Piping Plover (*Charadrius melodus*) depends on coastal beach habitats for breeding, migration, and over-wintering that will be greatly affected by rising sea level and increasing storm frequency. In areas where breeding habitat is seaward of armored roads and development, habitat inundation by rising seas could lead to permanent habitat loss (Seavey et al. 2011), as may be the case for over 50% of the species' wintering sites (U.S. Fish and Wildlife Service 2009). In undeveloped areas, habitat may be able to migrate toward the mainland (Scavia et al. 2002). Habitat losses in some areas may be offset by gains in other locations (Galbraith et al. 2002). However, an increased number and intensity of storms (Emanuel 2005, Webster et al. 2005) may make beach species such as piping plovers especially susceptible. What could occur is a time lag between when nesting habitats are eroded away and when new nesting habitats are formed (Galbraith et al. 2002). Increased numbers and intensity of storms during the breeding season could also reduce breeding success by increasing rates of nest inundation, nest abandonment, or chick mortality (US Fish and Wildlife Service 2009). **Photograph by Dave Mahler.**

Traits Associated with Species Vulnerability

To determine the species traits most frequently associated with species vulnerability, we also calculated the percent of SGCN and state-listed Threatened or Endangered plant species where reviewers identified a link between a species vulnerability trait and its climate change vulnerability (Fig. 6). This analysis included all species (not just those ranked as high vulnerability) so that specific strategies might be identified to address the most frequent vulnerability traits. Reviewers linked the climate change vulnerability of 70% of species to a high degree of habitat specialization for species; this was the most commonly cited vulnerability trait for species considered highly vulnerable. Habitat specialization was cited as a species vulnerability trait only in Pennsylvania (Furedi et al. 2011) and not by other northeastern vulnerability studies (WV, Byers and Norris 2011; NY, Schlesinger et al. 2011). Of the six most frequently cited traits, three were associated with species' edge of range: species' range being highly fragmented in Maine (Range3) (the second most cited trait), species at the southern end of their range in ME (Range1), and species' occupied habitat likely to decline (Range2). This is not entirely surprising because Maine's biophysical regions span from temperate to boreal conditions (Jacobson et al. 2009). The third most cited trait was dispersal limitations by barriers (Mobility2). Barriers to dispersal (both natural and anthropogenic) were also cited as a key species vulnerability factor by other studies in the Northeast (Byers and Norris 2011, Furedi et al. 2011, Schlesinger et al. 2011). The fourth trait most frequently linked to species vulnerability was a species' requirement for stable hydrological regimes (Tolerance3), which also was cited as an important factor in other northeastern vulnerability analyses (Byers and Norris 2011, Furedi et al. 2011, Schlesinger et al. 2011, Walk et al. 2011). The seventh trait most frequently linked by reviewers to species vulnerability was habitat vulnerability to increasing invasive species. This trait was not highlighted by other northeastern vulnerability studies (Byers and Norris 2011, Furedi et al. 2011, Schlesinger et al. 2011, Walk et al. 2011). The remaining traits that were in the top 10 most frequently linked with species vulnerability were dependent on environmental cues affected by climate change (Dependence1) and use of micro-habitat with special micro-climate (Habitat2).

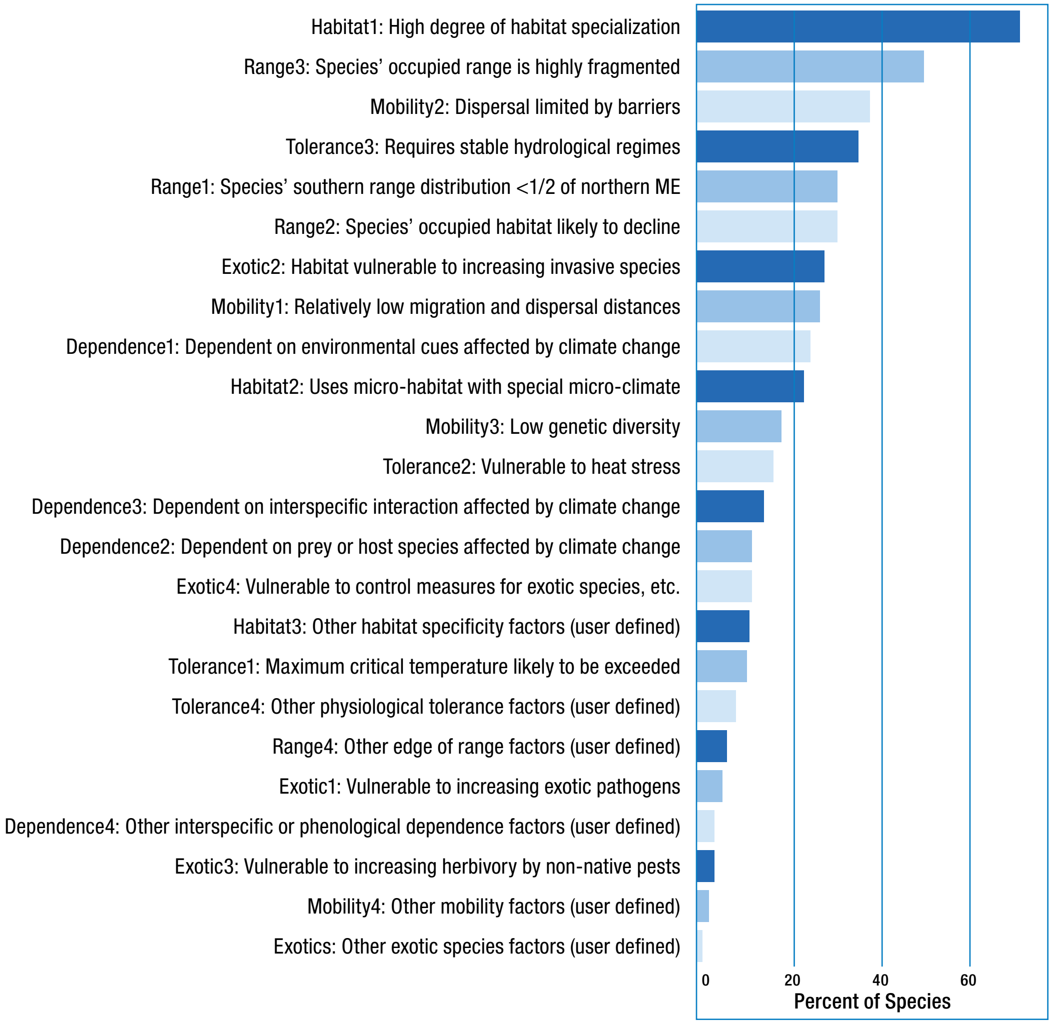

Figure 6. The percent of SGCN and state-listed Threatened or Endangered plant species with different vulnerability traits.

Climate Change Vulnerability of Habitats and Natural Communities

The Rusty Blackbird (*Euphagus carolinus*) is an uncommon and rapidly declining northern wetland species favoring bogs, beaver ponds and other often ephemeral boreal forested wetlands. Its southern range boundary has shifted northward by an average of 143 km since 1966, perhaps in part due to climate change impacts on wetland invertebrates, its chief food (McClure et al. 2012). Climate change may be altering the species' wetland breeding habitat, affecting wetland water chemistry, and shifting emergence times and abundance of its macroinvertebrate prey (Greenberg and Matsuoka 2010, Matsuoka et al. 2010). Currently listed as a species of Special Concern in Maine, the conservation status of Rusty Blackbird may need to be elevated if climate change is determined to be a significant negative stressor for the species. **Photograph: Geoffrey Hill.**

There are two conceptual approaches for prioritizing habitats for conservation, restoration, and adaptation. The first approach assesses the vulnerability of constituent species, both plant and animal, to identify habitats that host a disproportionate number of vulnerable species. The second approach assesses the inherent vulnerability of each habitat type based on its geographic, topographic, and compositional characteristics. This approach was recently piloted by NatureServe at the national level (Comer et al. 2012) and the Northeastern Association of Fish and Wildlife Agencies (NEAFWA) and Northeast Landscape Conservation Cooperative at the regional level (Manomet and National Wildlife Federation 2012). Both approaches are science-based and can be complementary in prioritizing habitats for conservation. We applied both approaches. In the section titled *Species Vulnerability Associations with ME CWCS Key Habitats*, we describe the results of the first approach that identified climate change vulnerabilities of habitats based on our expert assessments of SGCN and state-listed Threatened or Endangered plant species. We applied the second approach by asking experts at the May 19, 2010, workshop (Step 2) to assess habitat vulnerabilities of CWCS Key Habitat types and habitat subdivisions based on natural communities in Gawler and Cutko (2010) and describe the results in the section titled *Synthesis of Results from Maine and Other Regional Habitat Vulnerability Assessments*.

Species Vulnerability Associations with ME CWCS Key Habitats

The species vulnerability scores varied among the ME CWCS Key Habitats (Table 8). Three Key Habitats hosted the greatest proportion of high-vulnerability species: Alpine, Mountain Top Forest, and Peatlands. These Key Habitats have been projected to have high exposure to climate change in Maine (Table 8) and their extent is likely to decline as temperatures rise. These three Key Habitats also had high percentages of species exhibiting a great degree of habitat specialization (Habitat1, Table 4). These are relatively limited habitats where many species are specialized and adapted to a narrow set of conditions that persist on the landscape. They also include a high percentage of species that may be restricted to a narrow range of temperature, hydrology, or snow pack conditions (Tolerance1 – sensitive temperature, Tolerance2 – sensitive to heat stress, and Tolerance3 – dependence on specific or stable hydrological regimes).

Species associated with Alpine and Mountain Top Key Habitats are restricted to a narrow range of weather and snow pack conditions. The areal extent of these two Key Habitats is predicted to decline, though they are likely to persist in Maine (Rodenhouse et al. 2008, Kimball 1997). Some specialized plant communities in these two Key Habitats may be lost (e.g., snow melt communities, Schöb et al. 2009) and other communities may shift in composition (Walther 2002).

Peatland species are dependent on specific or stable hydrological conditions. Peatlands and their species are projected to experience increasing fluctuations in precipitation, water levels, and drought. Many North American peatlands have persisted for millennia through long wet and dry periods, but their future stability under climate change is uncertain (Environment Canada 2004). Maine's peatlands may be vulnerable to climate change because their distribution is governed primarily by temperature and precipitation regimes (Davis and Anderson 2001) and these are expected to change significantly with climate change (Jacobson et al. 2009).

The coastal habitats formed a second group of Key Habitats with many medium- and high-vulnerability species, but fewer than the first group. Five coastal Key Habitats had >80% species with medium or high vulnerability: Marine Open Water, Rocky Coastline and Islands, Estuaries and Bays (including estuarine marshes), Unconsolidated Shore (beaches and mudflats), and Estuarine Emergent Saltmarsh (Table 8). These habitats had a large percent of species exhibiting a high degree of habitat specialization and/or dependence on specific habitat (Habitat1) or stable hydrological regimes (Tolerance3). Coastal Key Habitats will be exposed to the full suite of climate change stressors. Open water and estuarine ecosystems may principally be affected by sea level rise and possibly by changes in water temperature, salinity, and pH (Ashton et al. 2007). Changes in seasonal patterns of precipitation and runoff may alter hydrological and chemical characteristics of coastal marine ecosystems, affecting species composition and ecosystem productivity of coastal and estuarine ecosystems (Melzner et al.

2012). The distribution of these Key Habitats will become less stable and their hydrological regimes will likely be modified.

The remaining five freshwater-wetland Key Habitats formed a third group of Key Habitats with 75% to 90% of their species with medium- or high- vulnerability species (Table 8). Species found in the wetland habitats exhibited a high degree of habitat specialization (Habitat1), dependence on specific or stable hydrological regimes (Tolerance3), and/or had southern range distribution (less than one-half of northern Maine, >45 degrees latitude; Range1). Freshwater habitats are likely to be exposed to many stressors related to climate change: temperature change, drought, hydrological changes, etc. The uncertainty of precipitation projections makes it difficult to predict impacts (Jacobson et al. 2009). Changes in seasonal patterns of precipitation and runoff due to climate change will likely alter hydrologic characteristics of aquatic systems, affecting their composition and ecosystem productivity (Hayhoe et al. 2007). Populations of aquatic organisms may decline in response to changes in the frequency, duration, and timing of extreme precipitation events, such as floods or droughts. Changes in the seasonal timing of snowmelt will alter stream flows, potentially interfering with the reproduction of many aquatic species. Open water bodies will also be strongly affected by increasing water temperature, as air temperatures are likely to increase, and by an extended period of low-water conditions in the summer. Wetlands may be affected by longer periods of low-water conditions in late summer.

A fourth group of Key Habitats has about 75% of their species with medium or high vulnerability and is formed by two terrestrial Key Habitats: Cliff Face & Rocky Outcrops (including talus) and Conifer Forest (Table 8). Cliff Face & Rocky Outcrops include talus communities that contain northern species that use specialized habitats (Habitat1), and are potentially sensitive to temperature increases and drought (Tolerance1 and Tolerance3). Conifer Forest is composed of spruce-fir, hemlock, and pine forest types, and includes many species sensitive to heat stress (Tolerance2). Spruce-fir forests and the ranges of their associated species may decline with temperature increases and droughty summers (Iverson et al. 2008). Hemlock forests are projected to decline, as warming will allow the non-native Hemlock Wooly Adelgid (*Adelges tsugae*) to infest and greatly damage many areas (Paradis et al. 2008).

Deciduous and Mixed Forest habitat only had about 66% of species with medium or high vulnerability (Table 8). The natural communities with northern distributions in this group are projected to decline significantly (e.g., boreal mixed forest, northern hardwood forests), while the natural communities with southern distributions (e.g., oak communities) are projected to expand (Iverson et al. 2008). Fewer than 50% of the species associated with this Key Habitat possessed climate change vulnerability traits.

A sixth and final group was composed of five terrestrial Key Habitats that had >50% of the species with low vulnerability (Table 8): Dry Woodlands and Barrens; Shrub/Early Successional and Regenerating Forest; Grassland Agriculture, Old Field; Urban/Suburban; and Caves and Mines. Little is known about how climate change might affect most of these Key Habitats (Whitman et al. 2013a), but the impacts may be relatively low. For the first three of these habitats, more than 50% of species had their vulnerability linked to the trait for habitat specificity (Habitat1) and yet few species in these habitats had medium or low vulnerability.

Table 8. Twenty-one ME CWCS Key Habitats, their climate change exposure, numbers of SGCN and state-listed Threatened or Endangered plant species associated with each habitat, and percent of these species with different vulnerability traits associated with each Key Habitat.

ME CWCS KEY HABITAT NAME	CLIMATE CHANGE EXPOSURE (LOW, MEDIUM, HIGH) 1	N	VULNERABILITY SCORES (PERCENT OF SPP.)			PERCENT OF SPECIES WITH TRAIT2											
			LOW (1)	MEDIUM (2)	HIGH (3)	HABITAT1	HABITAT2	HABITAT3	RANGE1	RANGE3	TOLERANCE1	TOLERANCE2	TOLERANCE3	DEPENDENT3	MOBILITY1	MOBILITY3	EXOTIC2
Marine Key Habitats																	
Marine Open Water	H	20	5	50	45	75	55	50	40	20	20	40	55	35	55	55	20
Rocky Coastline & Islands	M	31	10	55	35	58	26	45	48	29	16	35	71	19	35	26	10
Estuaries & Bays	M	34	9	65	26	59	47	26	68	38	9	35	74	44	53	18	18
Unconsolidated Shore	H	32	9	56	34	69	19	22	44	31	13	38	56	41	44	6	13
Estuarine Emergent Saltmarsh	H	40	18	50	33	68	30	10	53	33	13	28	60	65	33	8	13
Freshwater Key Habitats																	
Rivers & Streams	H	104	15	51	34	75	26	17	50	21	26	18	67	58	26	13	46
FW Lakes & Ponds	H	66	17	62	21	63	25	9	56	34	14	13	61	52	22	14	44
Emergent Marsh & Wet Meadows	M	55	24	51	25	51	38	15	55	38	13	20	67	56	24	18	22
Shrub-scrub Wetland	M	38	21	61	18	47	39	8	55	53	18	26	71	53	21	5	16
Peatlands	H	47	9	40	51	72	30	6	30	11	51	40	55	64	23	13	36
Forested Wetland	M	72	28	46	26	44	21	11	32	22	24	32	53	39	18	18	36
Upland Key Habitats																	
Alpine	H	35	3	9	89	97	31	3	6	6	89	71	80	37	17	26	74
Cliff Face & Rocky Outcrops (incl. talus)	M	34	24	32	44	85	44	3	26	6	53	21	65	12	9	9	76
Mountaintop Forest (incl. krummholz)	H	22	23	14	64	64	55	9	23	14	59	68	50	18	32	41	32
Coniferous Forest	M	66	23	39	38	38	30	11	29	21	29	56	42	15	21	20	12
Deciduous & Mixed Forest	M	110	37	43	20	48	21	11	32	16	13	30	37	13	21	16	33
Dry Woodlands & Barrens	L	67	54	36	10	67	21	7	22	30	12	7	34	3	43	9	30
Shrub / Early Succ. & Regen. Forest	L	46	50	33	17	50	28	15	24	11	26	33	50	15	33	17	26
Grassland, Ag., Old Field	L	52	54	40	6	60	27	17	31	19	21	10	54	15	29	8	25
Urban / Suburban	L	16	50	44	6	38	31	25	19	19	25	13	38	6	38	13	19
Caves & Mines	L	1	100	0	0	100	100	0	0	100	0	0	0	0	100	0	0

[1] From Whitman et al. 2013a

[2] (See Table 1 for trait definitions). Underlined percentages indicate that >50% of species associated with a Key Habitat had a trait. Summary data for 11 traits were not included because <50% of species associated with each Key Habitat had these traits: Range2, Tolerance4, Dependence1, Dependence2, Dependence 4, Mobility2, Mobility4, Exotic1, Exotic3, Exotic4, and Exotic5.

Synthesis of Results from Maine and Other Regional Habitat Vulnerability Assessments

In this section, we compare our species-based results (Section 6.1) and workshop-generated vulnerability rankings to habitat vulnerabilities recently assigned by NEAFWA and other regional efforts. One challenge is that the ME CWCS, Gawler and Cutko (2010), and NEAFWA vary in the coarseness of their classification systems. The NEAFWA effort used NatureServe's Ecological Systems for its habitat classification system (Manomet and National Wildlife Federation 2012). The Ecological Systems program is a nationwide land cover classification system used by The Nature Conservancy and many state and federal agencies (Comer et al. 2003; see http://www.natureserve.org/getData/USecologyData.jsp). Ecological Systems are finer-scaled than the CWCS key wildlife habitats in Section 6.1, but are more coarsely scaled than Maine's Natural Community types (see Gawler and Cutko 2010). Maine supports about 21 CWCS types, 40 Ecological System types, and 100 Natural Community types. NatureServe habitat vulnerability assessments are not available for northeastern states, but the NEAFWA assessments are available for about 15 Ecological Systems that occur in Maine (Manomet and National Wildlife Federation 2012)[3].

The NEAFWA results are largely consistent with our inferred vulnerabilities for many plant habitat groups (see section titled *Vulnerability of State-listed Threatened or Endangered Plant Species by Major Habitat*) and ME CWCS Key Habitats (see section titled *Species Vulnerability Associations with ME CWCS Key Habitats*), and are also generally consistent with our assessment of climate change exposure in Maine (Whitman et al. 2013a; Table 9). The most vulnerable Key Habitats and habitat sub-types are alpine and montane systems, peatlands, northern rivershores, spruce flats, and cedar lowlands. Many species in these habitats are considered vulnerable to warming temperatures, altered hydrology, and/or competition from other species. The least vulnerable habitats include pine barrens, oak-pine forests, grasslands, and other disturbance-adapted systems. These habitats are likely to remain stable or even expand in Maine. Habitats considered intermediate in vulnerability include many intertidal, freshwater, and aquatic systems, although there is greater uncertainty with these groups because of variable projections regarding sea level rise and groundwater and surface water flows (discussed below). Northern forest types (e.g., upland spruce-fir and northern hardwoods) are also intermediate in vulnerability, with changes in species range and composition likely varying from south to north (Tang and Beckage 2010, Iverson et al. 2008). Appendix C provides a detailed cross-reference of habitat vulnerabilities and associated species rankings, assessed across multiple levels of ecological classification.

One difference between the NEAFWA approach and our assessment is that the NEAFWA approach also included non-climate stressors, such as development and fragmentation, in the asessment and scoring of habitats. For example, the NEAFWA approach ranked oak-pine forests as less vulnerable than pine barrens, while our Climate Change Exposure Assessment and species-based approach suggest the reverse order (i.e., oak pine forests more vulnerable than pine barrens). A shift of human population from other regions to the Northeast might be one human response to climate change and will likely increase development pressures in some rare upland communities, including pine barrens (Whitman et al. 2013a). These non-climate stressors may have a larger impact on pine barrens than oak-pine forests because pine barrens are already smaller, rarer and more fragmented than oak-pine forests. Our approach placed much less emphasis on such secondary stressors. Recent or ongoing vulnerability assessments in Massachusetts (Manomet 2010b) and New Hampshire (NH DES 2012) have also ranked pine barrens as low and low-moderate vulnerability respectively.

[3] Co-authors A. Cutko, P. deMaynadier, and S. Walker served as reviewers for the NEAFWA project.

Table 9. Vulnerability of the NEAFWA Ecological Systems (Manomet and National Wildlife Federation 2012) and of ME CWCS Key Habitat Sub-types (from May 2010 Species Vulnerability Workshop).

VULNERABILITY OF NEAFWA ECOLOGICAL SYSTEMS		VULNERABILITY OF ME CWCS KEY HABITAT SUB-TYPES		
ECOLOGICAL SYSTEM	VULNERABILITY	KEY HABITAT TYPE	SUB-TYPE	VULNERABILITY
Appalachian - Acadian Alpine Tundra	*Highly Vulnerable*	Alpine	Alpine Bog	*High*
			Alpine Snowbank	*High*
			Heath Alpine Ridge	*High*
			Alpine Snowbank	*High*
			Alpine Cliff	*Medium*
Boreal - Laurentian Acidic Fen	*Highly Vulnerable*	Peatlands	Fens	*High*
North Central Interior Acidic Peatland	*Highly Vulnerable*			
Boreal - Laurentian Bog	*Highly Vulnerable*		Bogs	*Medium*
Appalachian - Acadian Montane Spruce-Fir Forest	*Vulnerable*	Mountaintop Forest	Subalpine Fir Forest	*Medium*
			Upland Spruce – Fir	*Medium*
Aquatic Systems (multiple types)	*Vulnerable*	Rivers and Streams	Snowpack Dominated Systems	*High*
			Low Order/Low Gradient	*Medium*
			High Order Floodplain Riverine Systems	*Medium*
			High Order Hydro Pulse Riverine Systems	*Low*
			Low Order / High Gradient	*Low*
		Lakes and Ponds	Unstratified Ponds/High Elevation	*High*
			Stratified Ponds	*Medium*
			Unstratified Ponds/Low Elevation	*Low*
Laurentian - Acadian Freshwater Marsh	*Vulnerable*	Emergent Marsh & Wet Meadows	Emergent marsh	*Low*
Laurentian - Acadian Shrub Swamp	*Vulnerable*	Shrub-scrub Wetland	Shrub-scrub	*Low*
Coastal Estuaries and Bays (multiple types)	*Vulnerable*	Marine Open Water	Open Bays	*Low*
		Estuaries and Bays		
		Estuarine Emergent Saltmarsh	Tidal Marsh	*High*
		Rocky Coastline and Island	Rocky Intertidal	*Low*
			Islands	*Medium*
		Unconsolidated Shore	Beaches and Dunes	*High*
			Mudflats	*High*
Laurentian - Acadian Northern Hardwood Forest	*Vulnerable*	Deciduous & Mixed Forest	Northern Hardwood	*Medium*
			Northern Mixed Wood	*Medium*
			Aspen - Birch	*Medium*
Northern Atlantic Coastal Plain Heathland and Grassland	Not assessed	Grasslands/Old Fields	Agricultural grasslands	*Low*
			Sandplain grassland	*Medium*
			Early successional shrubland	*Medium*
Pine Barrens	*Less Vulnerable*	Dry Woodlands & Barrens	Pitch Pine Scrub Oak Barren	*Low*
			Jack Pine/Red Pine Woodlands	*Medium*
Central Oak-Pine Forest	*Least Vulnerable*	Deciduous & Mixed Forest	Hemlock	*Medium*
			Oak - Pine	*Low*

To evaluate the vulnerability of coastal and aquatic habitats, Manomet and the National Wildlife Federation (2012a and 2012b) reviewed other recent climate change assessments across the region. For coastal habitats the authors could not reach conclusions because reviewed studies had only limited agreement and wide variation about the vulnerabilities of tidally influenced habitats. For example, an assessment of salt marshes in the National Wildlife Refuge System determined that these habitats are highly vulnerable and subject to major contractions from sea level rise, while multiple state studies concluded that in the absence of development or topographic constraints, salt marshes may migrate inland. Much remains unknown regarding rates of sediment accretion (that could enable marshes to keep pace with rising sea levels) and other factors such as human development patterns in the coastal zone. The vulnerability of salt marshes in mid-coast and southern Maine may be high because (1) projections of sea level rise rates continue to increase and rapid sea level rise will likely overwhelm compensatory sediment accretion and (2) development adjacent to salt marshes is expected to block landward migration of marshes. Salt marsh is a unique habitat because it is the only habitat where human development may preclude its upslope shift and ultimately its survival. However, vulnerability of salt marshes is not ranked quite as high as some other habitats because of the uncertainty in estimates of sea level rise and development.

While participants in this study recognized the variation in vulnerabilities of other coastal habitats, these habitats still scored at least moderately vulnerable. In our species assessment, 56% of species associated with coastal wetlands were ranked as medium in vulnerability and 32% were considered high. These results were also consistent across our coastal Key Habitats, which each had >80% species with medium or high vulnerability (Table 4 and also Appendix C). Nonetheless, two coastal habitats, the rocky intertidal zone and open bays, were considered less vulnerable because of their lower susceptibility to sea level rise, although some participants expressed concerns about impacts of ocean acidification.

Manomet and the National Wildlife Federation (2012b) reviewed several recent and ongoing studies of cold-water aquatic habitats across the Northeast and determined these habitats to be vulnerable to current and future stressors, including climate change, with vulnerability increasing over time. In one recent study, for example, Jones et al. (2012) estimate that by 2030 at least 5% of the Northeast's cold-water habitats will be converted to warm water, primarily in Massachusetts, Connecticut, Rhode Island, and New Jersey. By 2100 between 60% and 90% of cold-water habitat in the Northeast will likely be converted to warm water, with only Maine's western mountains and a section of the Southern Appalachians remaining unaffected. The vulnerability of cold-water habitats is influenced both by warming air temperatures, ground water flow, and altered stream flow patterns (increased and earlier flow in the spring, decreased flow in the summer) (Comte et al. 2012, Moore et al. 2012).

These regional findings regarding cold-water habitats are consistent with our vulnerability assessment of brook trout, which scored medium-high (2.5), suggesting that significant impacts on population distribution and status are expected, but near-term loss is unlikely on a statewide basis. Brook trout vulnerability assessments using NatureServe's Climate Change Species Vulnerability Index have been conducted in West Virginia, New York, and Maryland (Schlesinger et al. 2011, Byers and Norris 2011). Brook trout were determined to be highly vulnerable to climate change in the first two states and extremely vulnerable in Maryland.

Notably, Manomet and the National Wildlife Federation (2012b) also suggest an evolution in thinking about the magnitude of the risk posed by climate change to aquatic systems. Their vulnerability may be lower than initially presumed, in part because changes in future water temperatures are likely to be more complex than is suggested using a standard air/water temperature ratio that was previously assumed. In one ongoing Mid-Atlantic study, researchers found that the often-used 0.8 air/water temperature ratio is not borne out by field measurements. The ratio usually varied between 0.3 and 0.5, and in some streams, which were presumably more driven by groundwater, there was no relationship at all (Manomet and National Wildlife Federation 2012b). In other words, warming air temperatures do not necessarily translate into warmer groundwater. Some aquatic systems, such as low-elevation un-stratified ponds, were considered less vulnerable by participants in our workshop.

Furbish's Lousewort (*Pedicularis furbishiae*) lives only on the shores of the St. John River. It is dependent on periodic ice scouring to remove competing vegetation (Gawler et al. 1987). While a scour event destroys some colonies, it also opens habitat space for new colonies. This species seems to thrive for three to eight years after an ice scour event until it is outcompeted by other plant species in the absence of such disturbances. Ice regimes of rivers are changing and flood and ice scour events are becoming more frequent (Beltaos and Burrell 2003). Factors that limit this species include its inherent rarity, specific habitat needs, limited dispersal, and possibly its lack of genetic variation and ability to adapt to changing conditions. Climate change may increase the frequency of ice scouring in the short term and increase the frequency of extreme events, like severe floods, which could eliminate more habitat than it creates (Waller et al. 1987). **Photo by Maine Natural Areas** Program.

The vulnerability of fine-scale habitats (i.e., small in acreage) was not included in the NEAFWA assessment because of the coarse scale of the Ecological Systems used in the NEAFWA approach. Where fine-scaled habitats are closely tied to specific enduring features, such as certain bedrock or surficial geology types (e.g., calcareous cliffs), they are likely to persist despite some changes in species composition. On the other hand, where fine-scaled habitats are dependent on certain hydrological conditions (e.g., spruce flats, cedar lowlands), their vulnerability to climate change may be higher. Our workshop results support these hypotheses; spruce flats and cedar lowlands were ranked as having high vulnerability, while both acidic and calcareous cliffs were ranked as having low vulnerability.

Interestingly, in evaluating impacts of climate change on habitats, few studies make the distinction between outright habitat *loss* (e.g., submergence of tidal marshes to rising sea level) and habitat *alteration* caused by changes in species composition (e.g., red oak and white pine joining sugar maple and yellow birch in northern hardwood stands). Our workshop-based assessment of habitats attempted to recognize some of these distinctions. Some studies assume a simple northward trajectory of forest types, with oak-pine types replacing northern hardwoods and spruce-fir (Tang and Beckage 2010), yet others increasingly suggest tree and other plant species will migrate independently, potentially forming novel associations and habitats whose composition varies from what we see today (Dombroskie et al. 2010; Zhu et al. 2010, DeHayes et al. 2000). Many studies may have avoided this habitat loss versus alteration distinction because of significant uncertainties about species movements, inter-specific competition, lag times involved in tree migration, the effects of climate change on tree pathogens, and other factors that make these types of predictions nearly impossible. Nonetheless, if historic patterns are any indication, it is almost certain Maine's habitats in the future will look different than they do today, and some habitats may be significantly reduced in extent (Jacobson et al. 2009).

In summary, there has been a recent flurry of activity assessing the vulnerability of habitats to climate change across the Northeast, with several studies recently completed and others currently underway. These studies generally corroborate the inferences made about habitats in our study – that is, the most vulnerable habitats include alpine and montane systems, peatlands, northern rivershores, spruce flats, and cedar lowlands. While there is some uncertainty regarding coastal and aquatic systems, with significant questions remaining about processes such as tidal marsh accretion and ground water flows and temperatures, these systems are considered at least moderately vulnerable by all assessments. Northern forest types are also moderately vulnerable, while oak-pine forests and barrens are likely to remain stable or expand.

Implications for Managers

In our survey, the key factors evaluated as potential contributors to species vulnerability to climate change in Maine included habitat specialization, range fragmentation, southern range distribution, use of habitats likely to decline with climate change, dispersal limitations, sensitivity to hydrological changes, vulnerability to invasive species, dependence on environmental cues affected by climate change, and use of specialized micro-habitats and associated micro-climates.

Climate change-related stressors will likely amplify the effects of landscape stressors, such as habitat loss, habitat fragmentation, invasive species, pollution, and alterations to natural disturbance patterns. Hence, existing strategies for maintaining habitat integrity and connectivity will become increasingly important to implement as adaptation strategies. Adaptation strategies for conservation are simply the "process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" for biodiversity (Staudinger et al. 2012). For example, traditional conservation approaches focused on protecting functional riparian buffers, enhancement of stream connectivity, conserving large contiguous habitat patches, and protecting and managing strategic landscape parcels rich in biodiversity that are important today, but will become more important in the future (Heller and Zavaleta 2010). Furthermore, maintaining both terrestrial and aquatic

MANOMET
Center for Conservation Sciences

habitat connections will be critical to ensure species can move between patches and across the landscape as conditions and habitats change (Heller and Zavaleta 2010). Projections of increasing temperatures, rising sea levels, and changes in timing and severity of precipitation all necessitate refinement of current conservation approaches, but not wholesale changes. Climate change projections for storm and precipitation regimes should be incorporated into the planning of surface water buffers. This should include careful consideration of current and future floodplains, movement of sediment, and groundwater discharge sites. Up-to-date sea level rise projections should be used for land use planning in coastal areas and identifying conservation sites where topography and lack of development would allow migration of intertidal wetlands (Thorne et al. 2012).

Given uncertainties of how species' ranges might respond to various climate change scenarios, maintaining large unfragmented and well-connected habitat patches will likely improve the abilty of species to disperse and find favorable habitat (Hodgson et al. 2009). Aquatic connectivity also merits consideration. As both the public and private sectors evaluate infrastructure needs given the increasing likelihood of flood events, proposed improvements, such as installation of larger culverts and overpasses, provide opportunities to restore and enhance passage for fish and other aquatic species, thereby increasing the adaptive capacity of these ecosystems (Muir et al. 2012). Changes in some land management practices may also offer opportunities for climate change adaptation. For example, even-age silvicultural timber harvesting practices could be used to hasten change in forest composition on some sites by favoring the regeneration of native (to the U.S.) southern tree species. This might help avoid forest loss and maintain forest continuity. In contrast, new linear right-of-ways and road corridors may facilitate the establishment and spread of southern invasive plant species and exacerbate their growing threat to wetland and forest habitats.

Planning is the first step that municipalities and land conservation groups should undertake to design landscapes that will conserve biodiversity through climate change. A number of strategies will facilitate adaptation by species (Game et al. 2010, Heller and Zavaleta 2010, Hodgson et al. 2009), including:

PLANNING

- Integrate climate change science into state-level species listing status assessments – Explicitly consider climate change vulnerability during future state species listing status assessments (e.g., SGCN, species of Special Concern, Threatened species, or Endangered species).
- Integrate climate change information into state and local planning – Local (e.g., comprehensive land use plans, land trust plans, watershed groups plans) and state planning (e.g., CWCS, endangered species recovery plans, state forest plans, the Statewide Comprehensive Outdoor Recreation Plan [SCORP]) should integrate available climate change assessments into their plans to reduce its negative impacts on species, habitats, and related key ecosystem services.

RESEARCH

- Develop science-based strategies for conserving coastal lines – Re-assess development practices and standards in coastal areas so as to better allow for intertidal wetland and beach migration (Thorne et al. 2012, Klein et al. 2001). Analyze benefits of restoring or removing existing tidal barriers (Klein et al. 2001).
- Track and report on climate change – Data from existing monitoring programs (e.g., U.S.G.S. Breeding Bird Survey, U.S. Forest Service's FIA Program, NOAA weather data, ME IF&W wildlife atlasing projects) should be periodically reviewed to determine potential climate change-associated patterns, facilitating appropriate levels of adaptation.
- Vulnerable species research – Facilitate greater focus by state agencies, NGOs, and academia on researching limiting factors for climate-vulnerable taxa.

KEY POLICIES

- Update stream crossing policies – Implement stream crossing design policies that provide fish passage and withstand increased storm flows (Muir et al. 2012, Wilby et al. 2010, Palmer et al. 2009).
- Foster local adaptation planning – Re-align conservation funding mechanisms (e.g. Land for Maine's Future Fund, Maine Outdoor Heritage Fund) to incentivize the development of local climate change adaptation plans and strategies (Muir et al. 2012, Hopkins et al. 2007).
- Improve stream buffers – Enhance riparian buffer standards along small streams and around wetlands to maintain connectivity of aquatic and terrestrial habitats (Muir et al. 2012, Heller and Zavaleta 2010, Palmer et al. 2009).
- Conserve large habitat blocks – Designate growth and rural areas to slow fragmentation of large areas of habitat (Heller and Zavaleta 2010).
- Maintain landscape corridors – Use open space allocations and development design standards to maintain habitat connections between large habitat patches and conserved areas (Game et al. 2010).

PRACTICES

- Conserve existing diversity – Strategically conserve representative landscape types to protect a diversity of habitat types and conditions (Heller and Zavaleta 2010).
- Conserve space for tomorrow's intertidal habitats – Strategically conserve or protect lands best suited for supporting future intertidal wetland habitats (Thorne et al. 2012, Klein et al. 2001).
- Conserve biodiversity hotspots – Strategically protect sites/landscapes where biodiversity is likely always to be high because of the unique or unusual bio-physical characteristics of the site/landscape.
- Protect climate refugia – Protect habitats in montane areas where steep elevation gradients make it possible to retain species on smaller areas, coastal habitats where ocean water will ameliorate climate warming (Jacobson et al. 2009), and groundwater discharge and recharge areas that aid in maintaining surface water temperatures for cold-water species (Moore et al. 2012, Muir et al. 2012, Wilby et al. 2010, Palmer et al. 2009, Hopkins et al. 2007).

These results support the approach of many existing conservation efforts and assure biologists and land managers that standard habitat conservation practices will also help conserve species and habitats under climate change. They also reveal key species and habitat vulnerabilities not previously recognized. In these cases, other adaptation strategies might be necessary to achieve specific conservation goals under climate change. For example, salt marsh migration, beach habitat erosion, and shrinkage of alpine habitat are novel stressors not likely considered by most land managers and conservation biologists until recently. Addressing these stressors will require new approaches to habitat protection, restoration and management, and other landscape practices that will conserve habitats most likely to be resilient reservoirs of species diversity in the long term. These results can also be used to revise the list of species considered high priority for investing limited conservation resources. In some cases, species currently considered uncommon but secure might be elevated to a higher conservation action status because of their vulnerability to climate change.

This vulnerability assessment is a first step toward the conservation of Maine's biodiversity in the face of climate change. Using expert opinion from a diversity of scientists, this assessment applied a rigorous approach to identify species most likely to decline and those most likely to persist in the coming decades due to climate change. With this information, landowners, wildlife managers, and conservation biologists can begin to build a more comprehensive strategy for conserving Maine's diverse biological resources (Glick et al. 2011). Although beyond the scope of this assessment, conservationists may also have to consider the conservation needs of species in southern New England and the Mid-Atlantic states. Many of these species will eventually move into Maine and a robust conservation strategy will help create conditions in Maine to facilitate their settlement (Meretsky et al. 2012).

MANOMET Center for Conservation Sciences

Conclusions

Though the future path of climate change mitigation remains uncertain, all likely scenarios lead to significant increases in temperature and sea level rise (Jacobson et al. 2009). Ecosystem complexity will continue to limit our ability to confidently predict specific responses of species and habitats, despite a great increase in climate change research (Beckage et al. 2010). Some habitats and species may be more or less vulnerable than indicated in this report. Despite our limited ability to precisely predict the future for Maine's biodiversity, efforts like this vulnerability assessment will help identify many high-risk species and habitats that should be a focus of increased research, planning, and conservation.

This assessment included fully 442 species, nearly twice the number of species assessed by any other state to date. Based on expert input by a diverse panel of biologists, a relatively large proportion of Maine's species (168 or 37%) were found to have high vulnerability to climate change. While vulnerable species were found among all taxonomic groups, a disproportionate number are comprised of plants, fungi, lichens, and mammals. Those habitats hosting the greatest percentage of at-risk taxa included Alpine, High Elevation Forest, and Peatland. The loss of any species from Maine as a result of climate change, from moose to mayfly, has potential ecosystem-wide implications and should be a basis for concern.

Yet, the current situation is also encouraging because Maine's vertebrate species pool is dominated by relative generalists that tend to be highly adaptable, mobile, and associated with diverse habitat conditions (see Gawler et al. 1996). Like other northern latitude species pools, a fair number of Maine's vertebrates may be able to keep up with climate changes (e.g., mammals, Schloss et al. 2012). Moreover, many of Maine's habitats remain largely unfragmented and undeveloped (Ritter et al. 2002), which provides a promising setting for conserving biodiversity under dynamic future conditions. This combination of species and landscape conditions may improve Maine's biological resiliency to climate change.

These conditions may change as development, intensification of forestry practices, invasive terrestrial and aquatic species, and air pollution increasingly threaten Maine's biodiversity (Gawler et al.1996). In the face of climate change, our best hope for retaining Maine's biodiversity is to minimize the impacts of these additive threats which can be managed by the state and local policy and to maintain existing large blocks of habitat and landscape corridors. In the next 100 years, habitats may shift northward and Maine may need to provide suitable areas for species and habitats from the southern New England and Mid-Atlantic states (Frumhoff et al. 2007). If we maintain connectivity, large habitat blocks, areas that sustain remnant populations, and enduring biological hot spots, then regional species will be better able to shift ranges and to occur in large populations (Game et al. 2010). We may then retain many of our current species and habitats and be able to provide refuge to new species from areas south of Maine.

Hence, there is a need to think regionally as well as locally. The present approach, where jurisdictions work independently, may fail to conserve Maine's future species and habitats (Meretsky et al. 2012). Greater efforts across state and provincial boundaries may be necessary to ensure that Maine is able to receive a full complement of southern species and successfully "export" some of Maine's species to Canada. Thus, a key climate threat to Maine's future biodiversity might arise if states to the south fail to maintain the habitat connectivity necessary to allow southern species to move north. Similarly, Maine should form planning partnerships with the neighboring provinces of New Brunswick and Quebec to facilitate a northward movement of Maine's species. The prognosis for Maine and its current suite of species and habitats is arguably fair to good, with the possible exception of sensitive endemics and other specialists, assuming key climate change policies and practices are thoughtfully considered by the region's natural resource professionals. To this end, we hope the current report helps inform the discussion.

One of Maine's few endemic species, the Katahdin Arctic Butterfly (*Oeneis polixenes katahdin*) is found only on Mount Katahdin. Climate change may reduce the extent of tundra habitat for this and other specialized alpine invertebrates in New England (McFarland 2003). Cloudy, rainy summers, projected as likely with climate change, might affect adult survival and recruitment of alpine butterflies with short growing seasons. Additionally, research in Massachusetts detected that the start of the adult flight period for several butterflies advanced on average by two days for each degree Fahrenheit increase in temperature (Polgar et al. 2013). The response of these butterfly species to temperature is similar to plant flowering times and bee flight times and is significantly greater than bird arrival times, which are less sensitive to temperature increases. This difference in taxonomic sensitivity to temperature change increases the likelihood of an ecological mismatch, with migratory birds arriving after the first spring flush of their insect food.
Photograph by Billy Weber.

Literature Cited

Abrams, M. D. 2003. Where has all the white oak gone? BioScience 53:927–939.

Ahola, M., T. Laaksonen, K. Sippola, T. Eeva, K. Rainio and E. Lehikoinen. 2004. Variation in climate warming along the migration route uncouples arrival and breeding dates. Global Change Biology 10:1610-1617.

Almendinger, J. and J. Leete. 1998. Peat characteristics and groundwater geochemistry of calcareous fens in the Minnesota River Basin, U.S.A. Biogeochemistry 43:17-41.

Ashton, A., J. Donnelly, and R. Evans. 2007. A Discussion of the Potential Impacts of Climate Change on the Shorelines of the Northeastern USA. Prepared for the Northeast Climate Impacts Assessment, Union of Concerned Scientists, Woods Hole Oceanographic Institution, Woods Hole, MA.

Association of Fish and Wildlife Agencies. 2009. Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans & Other Management Plans. A Collaboration of the Association of Fish and Wildlife Agencies' Climate Change and Teaming With Wildlife Committees, Washington, D.C.

Beltaos, S. and B.C. Burrell. 2003. Climate Change and river ice breakup. Canadian Journal of Civil Engineering. 30:145-155.

Bierbaum, R., J. Smith, A. Lee, M. Blair, L. Carter, F. Chapin III, P. Fleming, S. Ruffo, M. Stults, S. McNeeley, E. Wasley, and L. Verduzco. 2012. A comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitigation and Adaptation Strategies for Global Change. http://dx.doi.org/10.1007/s11027-012-9423-1.

Brinson, M. and A. Malvarez. 2002. Temperate freshwater wetlands: types, status, and threats. Environmental Conservation, 29:115-133.

Broders, H. G., Coombs, A. B., & McCarron, J. R. (2012). Ecothermic responses of moose (Alces alces) to thermoregulatory stress on mainland Nova Scotia. Alces 48: 53-61. Adger W.N., S. Agrawala, M.M.Q. Mirza, C. Conde C, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit, and K. Takahashi. 2007. Assessment of adaptation practices, options, constraints and capacity. In: Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson. Eds. Cambridge: Cambridge University Press. pp. 717-43.

Brooks, R. T. 2009. Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. Climatic Change 95:469–483.

Burkett, V. and J. Kusler. 2000. Climate change: potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association 36:313-320.

Butler, R. and R. Vennesland. 2000. Integrating climate change and predation risk with wading bird conservation research in North America. Waterbirds 23:523-540.

Byers, E. and S. Norris. 2011. Climate Change Vulnerability Assessment of Species of Concern in West Virginia Project Report. West Virginia Division of Natural Resources, Elkins, WV.

Cahill, A., M. Aiello-Lammens, M. Fisher-Reid, X.Hua, C. Karanewsky, H. Ryu, G.Sbeglia, F. Spagnolo, J. Waldron, O. Warsi and J. Wiens. 2012. How does climate change cause extinction? Proc. R. Soc. B doi:10.1098/rspb.2012.1890.

Cherry, D., K. Dickson, and J. Cairns Jr, J. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. Journal of the Fisheries Research Board of Canada 34:239–246.

Comer, P. J., B. Young, K. Schulz, G. Kittel, B. Unnasch, D. Braun, G. Hammerson, L. Smart, H. Hamilton, S. Auer, R. Smyth, and J. Hak. 2012. Climate Change Vulnerability and Adaptation Strategies for Natural Communities: Piloting methods in the Mojave and Sonoran deserts. Report to the U.S. Fish and Wildlife Service. NatureServe, Arlington, VA.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems. NatureServe, Arlington, Virginia.

Comte, L., L. Buisson, M. Daufresne, and G. Grenouillet. 2012. Climate-induced changes in the distribution of freshwater fish: observed and predicted trends. Freshwater Biology.

Davis, M. B. and R. G. Shaw. 2001. Range shifts and adaptive responses to quaternary climate change, Science 292:673-679.

Davis, R. and D. Anderson. 2001. Classification and distribution of freshwater peatlands in Maine. Northeastern Naturalist 8:1-50.

DeHayes, D., G. Jacobson, P. Schaber, B. Bongarten, L. Iverson, and A. Dieffenbacker-Krall. 2000. Forest Responses to Changing Climate: Lessons from the Past and Uncertainty for the Future. in Reponses of Northern Forests to Environmental Change (ed. by R. Mickler, R. Birdsey, and J. Hom). pp. 495-540. Ecological Studies Series. Springer-Verlag, NY.

Dombroskie, S., M. McKendy, C. Ruelland, W. Richards, P. Charles, A. Bourque, and F. Meng. Assessing Impact of Projected Future Climate on Tree Species Growth and Yield: Development of an Evaluation Strategy. 2010. Mitig. Adapt. Strateg. Glob. Change 12:307-320.

Drummond, M. and T. Loveland. 2010. Land-use pressure and a transition to forest-cover loss in the eastern United States. BioScience 60:286-298.

Durell, S., R. Stillman, R. Caldow, S. McGrorty, A. West, and J. Humphreys. 2006. Modeling the effect of environmental change on shorebirds: A case study on Poole Harbor, UK. Biological Conservation 131:459-473.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436:686-688.

Environment Canada. 2004. Threats to Water Availability in Canada. National Water Research Institute, Burlington, Ontario. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. 128 p.

Flaxman, M. and J. C. Vargas-Moreno. 2011. Considering Climate Change in State Wildlife Action Planning: A Spatial Resilience Planning Approach [Research Report FWC-2011]. Department of Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge, MA.

Flebbe, P., L. Roghair, and J. Bruggink. 2006. Spatial modeling to project southern Appalachian trout distribution in a warmer climate. Transactions of the American Fisheries Society 135:1371-1382.

Foden, W., G. Mace, J.-C. Vié, A. Angulo, S. Butchart, L. DeVantier, H. Dublin, A., Gutsche, S. Stuart, and E. Turak. 2008. Species susceptibility to climate change impacts. In: J.-C. Vié, C. Hilton-Taylor and S.N. Stuart (eds). The 2008 Review of The IUCN Red List of Threatened Species. IUCN Gland, Switzerland.

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007. Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists (UCS).

Furedi, M., B. Leppo, M. Kowalski, T. Davis, and B. Eichelberger. 2011. Identifying species in Pennsylvania potentially vulnerable to climate change. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, PA.

Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2005. Global Climate Change and Sea Level Rise: Potential Losses of Intertidal Habitat for Shorebirds. USDA Forest Service Gen. Tech. Rep. PSW-GTR-191.

Game, E., C. Groves, M. Andersen, M. Cross, C. Enquist, Z. Ferdaña, E. Girvetz, A. Gondor, K. Hall, J. Higgins, R. Marshall, K. Popper, S. Schill, and S. Shafer. 2010. Incorporating climate change adaptation into regional conservation assessments. The Nature Conservancy. Arlington, Virginia.

Gawler, S. and A. Cutko. 2010. Natural Landscapes of Maine: A Guide to Natural Communities and Ecosystems. Maine Natural Areas Program, Department of Conservation, Augusta, ME.

Gawler, S., J. Albright, P. Vickery, and F. Smith. 1996. Biological Diversity in Maine: an assessment of status and trends in the terrestrial and freshwater landscape. Report prepared for the Maine Forest Biodiversity Project. Natural Areas Program, Maine Dept. Cons., Augusta, ME. 80 pp. + app.

Gawler, S., D. Waller, and E. Menges. 1987. Environmental factors affecting establishment and growth of Pedicularis furbishiae, a rare endemic of the St. John River Valley, Maine. Bulletin of the Torrey Botanical Club 114:280-292.

Gedan, K. B. and M. D. Bertness. 2009. Experimental warming causes rapid loss of plant diversity in New England salt marshes. Ecological Letters 12:842–848.

Giller, P. and B. Malmqvist. 1998. The biology of streams and rivers. New York: Oxford University Press, 296 pp.

Glick, P. and B. Stein, eds. 2010. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Draft. National Wildlife Federation, Washington, D.C.

Glick, P., B. A. Stein, and N. A. Edelson (Eds.). 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, DC.

Gonzalez P., R. Neilson, J. Lenihan, and R. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography 19:755-768.

Greenberg, R. and S. Matsuoka. 2010. Rusty Blackbird: mysteries of a species in decline. The Condor 112:770-777.

Hamburg, S. and C. Cogbill. 1988. Historical decline of red spruce populations and climatic warming. Nature 331:428–431.

Hayhoe, K., C. P. Wake, T. G. Huntington, L. Luo, M. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T. Troy, and D. Wolfe. 2007. Past and future changes in climate and hydrological indicators in the U.S. northeast. Climate Dynamics 28:381-407.

Heller, N. and E. Zavaleta. 2010. Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biological Conservation. 142:14-32.

Herman, T. and F. Scott. 1994. Protected areas and global climate change: assessing the regional and/or local vulnerability of vertebrate species. In: Pernetta, J. C., R. Leemans, D. Elder, and S. Humphrey (eds.). Impacts of Climate Change on Ecosystems and Species: Implications for Protected Areas. IUCN, Gland, Switzerland.

Hobbs, R., E. Higgs, and J. Harris. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology and Evolution 24:599-605.

Hodgson, J., C. Thomas, B. Wintle, and A. Moilanen. 2009. Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology 46:964-969.

Hopkins J., H. Allison, C. Walmsley, M. Gaywood, and G. Thurgate. 2007. Conserving biodiversity in a changing climate: guidance on building capacity to adapt. Published by Defra on behalf of the UK Biodiversity Partnership, London, England.

Hunter, M. L., C. Burns, P. deMaynadier, L. Incze, W. Krohn, P. Vaux, and B. Vickery. 2009. Biodiversity. Pages 30-33 in Jacobson, G. L., I. J. Fernandez, P. A. Mayewski, and C. V. Schmitt (editors). Maine's climate future: An initial assessment. University of Maine, Orono, Maine. 70 pp.

IPCC. 2002. Climate change and biodiversity. Gitay, H., R. T. Suarez, and O. Watson (Eds) Technical Paper V, IPCC Working Group II Technical Support Unit.

Irons, D.B. et al. 2007. Fluctuations in circumpolar seabird populations linked to climate oscillations. Global Change Biology 14: 1455-1463.

Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern U.S. tree species under six climate scenarios. Forest Ecology and Management 254:390-406.

Iverson, L., A. Prasad, and M. Schwrtz. 1999. Modeling potential future individual tree-species distributions in the Eastern United States under a climate change scenario: a case study with Pinus virginiana. Ecological Modelling 115:77-93.

Jacobson, G. L., I. J. Fernandez, P. A. Mayewski, and C. V. Schmitt (editors). 2009. Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. Accessed online at: http://www.climatechange.umaine.edu/mainesclimatefuture/.

Jones, R., C. Travers, C. Rodgers, B. Lazar, E. English, J. Lipton, J. Vogel, K. Strzepek, and J. Martinich. 2012. Climate change impacts of freshwater recreational fishing in the United States. Mitig. Adapt. Strateg. Glob. Change. Online, pending print publication.

Kelley, J. T. and S. M. Dickson. 2000. Low-cost bluff-stability mapping in coastal Maine: providing geological hazard information without alarming the public. Env. Geosci. 7:46–56.

Kelly, M. and N. Adger. 2000. Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation. Climatic Change 47:325-352.

Kimball, K. 1997. New England Regional Climate Change Impacts on Recreation and Tourism. New England Regional Climate Change Impacts Workshop Summary Report, Sept. 3-5. pp. 129-131.

Klein, R. J., R. Nicholls, S. Ragoonaden, M. Capobianco, J. Aston, and E. Buckley. 2001. Technological options for adaptation to climate change in coastal zones. Journal of Coastal Research 17:531-543.

Kuhnert, P., T. Martin, and S. Griffiths. 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecological Letters 13:900-914.

Leidner, A. K. and M. Neel. 2011. Taxonomic and geographic patterns of decline for threatened and endangered species in the United States. Conservation Biology 25:716-725.

Lenarz, M., J. Fieberg, M. Schragage, and A. Edwards. 2010. Living on the edge: viability of moose in northeastern Minnesota. Journal of Wildlife Management 74:1013-1023.

Lockie, S. 2012. 'Market-Based Resource Managements Policy and Environmental Uncertainty: Outsourcing Risk Calculation', in Thomas Measham and Stewart Lockie (ed.), Risk and Social Theory in Environmental Management, CSIRO Publishing, Australia, pp. 79-90.

Lumbreras, A., G. Navarro, C. Pardo, and J. Molina. 2011. Aquatic Ranunculus communities in the northern hemisphere: A global review. Plant Biosystems 145, sup1:118-122.

MacMillan, D. and K. Marshall. 2006. The Delphi process – an expert-based approach to ecological modeling in data-poor environments. Anim. Conserv. 9:11–19.

Maine Department of Inland Fisheries and Wildlife. 2003. Beginning with Habitat. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine. 52 pp.

Maine Department of Inland Fisheries and Wildlife. 2005. Maine's comprehensive wildlife conservation strategy. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

Maine Natural Areas Program. 2012. Rare, Threatened or Endangered Plant Taxa. Maine Natural Areas Program, Augusta, ME.

Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife. 2010. Climate Change and Massachusetts Fish and Wildlife: Volume 2 Habitat and Species Vulnerability. Massachusetts Division of Fisheries and Wildlife, Westborough, MA.

Manomet Center for Conservation Sciences and the National Wildlife Federation. 2012. The vulnerabilities of northeastern fish and wildlife habitats to sea level rise. A report to the Northeastern Association of Fish and Wildlife Agencies and the North Atlantic Landscape Conservation Cooperative, Manomet, Plymouth, MA.

Martin, T.G., M.A. Burgman, F. Fidler, P. Kuhnert, S. Low-Choy, M. McBride, and K. Mengersen. 2012. Eliciting expert knowledge in conservation science. Conservation Biology 26: 29-38.

Matsuoka, S. M., D. Shaw, and J. A. Johnson. 2010. Estimating the abundance of nesting Rust Blackbirds in relation to wetland habitats in Alaska. The Condor 112:825-833.

McClure, C., B. Rolek, K. McDonald, and G. Hill. 2012. Climate change and the decline of a once common bird. Ecol Evol. 2:370–378.

McFarland, K. 2003. Conservation assessment of two endemic butterflies (White Mountain arctic, Oeneis melissa semidea, and White Mountain fritillary, Boloria titania montinus) in the Presidential Range alpine zone, White Mountains, New Hampshire. VT Institute of Natural Science, Woodstock, VT.

Melzner, F., J. Thomsen, W. Koeve, A. Oschlies, M. Gutowska, H. Bange, H. Hansen, and A. Körtzinger. 2012. Future ocean acidification will be amplified by hypoxia in coastal habitats. Marine Biology 159:1-14.

Meretsky, V. J., L. A. Maguire, F. W. Davis, D. M. Stoms, J. M. Scott, D. Figg, D. D. Goble, B. Griffith, S. E. Henke, J. Vaughn, and S. L.Yaffee. 2012. A State-Based National Network for Effective Wildlife Conservation. BioScience 62:970-976.

Mertz, O., K. Halsnæs, J. E. Olesen, and K. Rasmussen. 2009. Adaptation to climate change in developing countries. Environmental Management 43:43-752.

Miller, N. and R. Spear. 1999. Late quaternary history of the alpine flora of the New Hampshire White Mountains. Géographie physique et Quaternaire 53:33.

Moore, A., B. Bendall, J. Barry, C. Waring, N. Crooks, and L. Crooks. 2012. River temperature and adult anadromous Atlantic salmon, Salmo salar, and brown trout, Salmo trutta. Fisheries Management and Ecology 19:1365-2400.

MANOMET Center for Conservation Sciences

Moore, M., M. Pace, J. Mather, P. Murdoch, R. Howarth, C. Folt, C. Chen, H. Hemond, P. Flebbe, and C. Driscoll. 1997. Potential effects of climate change on freshwater ecosystems of the New England/Mid-Atlantic Region. Hydrological Processes: 925-947.

Muir, M., C. Spray, and J. Rowan. 2012. Climate change and standing freshwaters: informing adaptation strategies for conservation at multiple scales. Area 44:411–422.

Murray, D., E. Cox, W. Ballard, H. Whitlaw, M. Lenarz, T. Custer, T. Barnett, and T. Fuller. 2005. Pathogens, nutritional deficiency, and climate Influences on a declining moose population. Wildlife Monogr. 166:1-30.

Myer, J., M. Sale, M. MulHolland, and L. Poff. 1999. Impacts of climate change on aquatic ecosystem functioning and health. Journal of the American Water Resources Association 35:1373-1386.

NatureServe. 2012. Terrestrial Ecological Systems of the United States. http://www.natureserve.org/getData/USecologyData.jsp.
New Hampshire Fish and Game Department. 2012. DRAFT Climate Change Vulnerability Assessments. Available at http://www.wildnh.com/Wildlife/Wildlife_Plan/climate_change/.

Nevada Natural Heritage Program. 2011. Climate Change Vulnerability Index (Release 2.01): Nevada Results as of September 29, 2011. Nevada Natural Heritage Program, Reno, NV.

New Hampshire Fish and Game Department. 2005. New Hampshire State Wildlife Action Plan. Concord, NH.

Ollinger, S., C. Goodale, K. Hayhoe, J. Jenkins. 2008. Potential effects of climate change and rising CO2 on ecosystem processes in northeastern U.S. forests. Mitigation and Adaptation Strategies for Global Change 13:467-485.

Palmer, M. A., D. Lettenmaier, N. Poff, L. Postel, and B. Richter. 2009. Climate change and river ecosystems: protection and adaptation options. Environmental Management 44: 1053–1068.

Paradis, A., J. Elkinton, K. Hayhoe, and J. Buonaccorsi. 2008. Effect of winter temperatures on the survival of hemlock woolly adelgid, Adelges tsugae, and the potential impact of global warming on its future range in eastern North America. Mitigation and Adaptation Strategies for Global Change. In press.

Parmesan, C., N. Ryrholm, C. Stefanescu, J. K. Hill, C. D. Thomas, H. Descimon, B. Huntley, L. Kaila, J. Kullberg, T. Tammaru, J. Tennent, J. A. Thomas, and M. Warren. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming, Nature, 399: 579-583.

Polgar et al. 2013. Climate Effects on the Flight Period of Lycaenid Butterflies in Massachusetts. Biological Consrvation 160:25-31.

Prasad, A., L. Iverson., S. Matthews, and M. Peters. 2007-ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [database]. http://www.nrs.fs.fed.us/atlas/tree, Northern Research Station, USDA Forest Service, Delaware, Ohio.

Riitters, K., J. Wickham, R. O'Neill, K. Jones, E. Smith, J. Coulston, and J. Smith. 2002. Fragmentation of continental United States forests. Ecosystems 5:815-822.

Rodenhouse, N., L. Christenson, D. Perry, and L. Green. 2009. Climate change effects on native fauna of northeastern forests. Canadian Journal of Forest Research 39:249-263.

Rodenhouse, N., S. Matthews, K. McFarland, J. Lambert, L. Iverson, A. Prasad. T. Sillett, and R. T. Holmes. 2008. Potential effects of climate change on birds of the Northeast. Mitigation and Adaptation Strategies for Global Change 13:517-540.

Scavia, D., J. C. Field, D. F. Boesch, R. W. Buddemeier, V. Burkett, D. R. Cayan, M. Fogarty, M. A. Harwell, R. W. Howarth, C. Mason, D. J. Reed, T. C. Royer, A. H. Sallenger, and J. G. Titus. 2002. Climate change impacts on U.S. coastal and marine ecosystems. Estuaries 25:149-164.

Schlesinger, M. D., J. D. Corser, K. A. Perkins, and E. L. White. 2011. Vulnerability of at-risk species to climate change in New York. New York Natural Heritage Program, Albany, NY.

Schneider, S. H., S. Semenov, A. Patwardhan, I. Burton, C. H. D. Magadza, M. Oppenheimer, A. B. Pittock, A. Rahman, J. B. Smith, A. Suarez, and F. Yamin. 2007. Assessing key vulnerabilities and the risk from climate change. Pages 779-810 in Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, Eds.). Cambridge University Press, Cambridge, UK.

Schob, C., P. Kammer, P. Choler, and H. Veit. 2009. Smallscale plant species distribution in snowbeds and its sensitivity to climate change. Plant Ecology 200:91-104.

Seavey, J. R., B. Gilmer, and K. McGarigal. 2011. Effect of sea-level rise on piping plover (Charadrius melodus) breeding habitat. Biological Conservation, 144:393-401.

Siegel, D. and P. Glaser. 2006. Potential effects of climate change on spring fens and their endangered floral species. Geological Society of America Abstracts 38:328.

Slovinsky, P. and S. Dickson. 2008. 309-06b: Demonstration Project: Impacts of Future Sea Level Rise on the Coastal Floodplain. MGS Open-File 06-14. A report prepared by the ME Geological Survey for the ME Coastal Program/ME State Planning Office for National Oceanic and Atmospheric Administration. Augusta, ME.

Smith, W. B., P. D. Miles, C. H. Perry and S. A. Pugh (coordinators). 2009. Forest Resources of the United States, 2007. General Technical Report WO-78. U.S. Department of Agriculture, Forest Service. Washington, DC.

Sydeman, W., S. Thompson, and A. Kitaysky. 2012. Seabirds and climate change: roadmap for the future. Martine Ecology Progress Series 454:107–117.

Tang, G. and B. Beckage. 2010. Projecting the Distribution of Forests in New England in Response to Climate Change. Diversity and Distributions. 16:144-158.

Thorne, K., J. Takekawa, and D. Fisk. 2012. Ecological Effects of Climate Change on Salt Marsh Wildlife: A Case Study from a Highly Urbanized Estuary. Journal of Coastal Research 28: 1477 - 1487.

U.S. Fish and Wildlife Service. 2009. Climate Change Adds Challenges to Freshwater Mussel Conservation. Fort Snelling, MN. Accessed on January 5, 2010 at: http://www.fws.gov/midwest/climate/mussels.htm).

U.S. Fish and Wildlife Service. 2009. Piping plover (Charadrius melodus) 5-year review: Summary and evaluation. U.S. Fish and Wildlife Service. U.S. Fish and Wildlife Service, Hadley, MA and East Lansing, MI.

Vasseur, L.; N. Catto, D. Burton, O. Chouinard, J. Davies, L. DeBaie, G. Duclos, P. Duinker, D. Forbes, L. Hermanutz, J. Jacobs, L. Leger, K. McKenzie, K. Parlee, and J. Straatman. 2008. Atlantic Canada. In: D.S. Lemmen, F.J. Warren, J. Lacroix, and E. Bush (eds.). From Impacts to Adaptation: Canada in a Changing Climate 2007. Government of Canada, Ottawa, ON, p. 119-170.

Walk, J., S. Hagen, and A. Lange. 2011. Adapting Conservation to a Changing Climate: An Update to the Illinois Wildlife Action Plan. Report to the Illinois Department of Natural Resources. Prepared by Illinois Chapter of The Nature Conservancy.

Waller, D. M., D. M. O'Malley, and S. C. Gawler. 1987. Genetic variation in the extreme endemic Pedicularis furbishiae (Scroph ulariaceae). Conservation Biology, 4(1), 335-340.

Webster, P., G. Holland, J. Curry, and H. Chang. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. Science 309:1844-1846.

Whitman, A., B. Vickery, P. deMaynadier, S. Stockwell, S. Walker, A. Cutko, and R. Houston. 2013a. Climate Change and Biodiversity in Maine: A climate change exposure summary for participants of the Maine Climate Change Species Vulnerability Assessment. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Adaptation Working Group) Report NCI-2010-2. 22 pp. Brunswick, Maine.

Whitman, A., B. Vickery, P. deMaynadier, S. Stockwell, S. Walker, A. Cutko, and R. Houston. 2013b. Survey results and final scores from a species vulnerability analysis for wildlife and plant species in Maine. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Adaptation Working Group) Report NCI-2013-4. Brunswick, Maine.

Wilby, R. , H. Orr, G. Watts, R. Battarbee, P. Berry, R. Chadd, and P. Wood. 2010. Evidence needed to manage freshwater ecosystems in a changing climate: Turning adaptation principles into practice. Science of the Total Environment 408:4150-4164.

Williams, J., A. Haak, N. Gillespie, H. Neville, and W. Colyer. 2007. Healing Troubled Waters Preparing Trout and Salmon Habitat for a Changing Climate. Trout Unlimited, Arlington, VA.

Williams, S. E., L. P. Shoo, J. L. Isaac, A. A. Hoffmann, and G. Langham. 2007. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biology 6:2621-2626.

Wilson, I. T. and T. Tuberville. 2003. Virginia's Precious Heritage: A Report on the Status of Virginia's Natural Communities, Plants, and Animals, and a Plan for Preserving Virginia's Natural Heritage Resources. Natural Heritage Technical Report 03-15. Virginia Department of Conservation and Recreation, Division of Natural Heritage, 217 Governor Street, 3rd Floor, Richmond, Virginia. 82 pages plus appendices.

Wormworth, J. and K. Mallon. 2006. Bird Species and Climate Change: The Global Status Report version 1.0 A report to: World Wide Fund for Nature, United Kingdom.

Young, B. E., E. Byers, K. Gravuer, K. R. Hall, G. A. Hammerson, A. Redder, K. Szabo, J. E. Newmark. 2009. Using the NatureServe Climate Change Vulnerability Index: A Nevada Case Study. NatureServe, Arlington, Virginia, U.S.A.

Yousuf, M. 2007. Using Experts' Opinions through Delphi Technique. Practical Assessment Research & Evaluation 12:1-8.

Zhu, K., C. Woodall, and J. Clark. 2011. Failure to migrate: lack of tree range expansion in response to climate change Global Change Biology DOI: 10.1111.

Appendix A: Narratives of Species' Vulnerability by Species Group

A1. Introduction

The vulnerability scores and other information are summarized in a narrative and table for each species group. The narrative explains broad themes regarding the linkages between species vulnerability and vulnerability traits for many species. It does not describe these linkages for each species because this would require an individual account for each species. Wildlife species were grouped based on taxonomic classifications while plants were grouped by broad habitat affiliations. Each species group table includes the following:

- Status: State rank for state-listed Threatened and Endangered plant species (S1 or S2; Maine Natural Areas Program 2012) or wildlife species (SGCN, priority rank 1 or 2; Maine Department of Inland Fisheries and Wildlife 2005). NA indicates not applicable for species added to this effort as they lacked state-level designation.
- Vulnerability scores: 1 = low, 2 = medium, or 3 = high (based on final scores from Step 3).
- Confidence scores: 1 = not very confident (0-30% certainty in species vulnerability scores); 2 = somewhat confident (>30-70% certainty in species vulnerability scores); or 3 = very confident (>70% certainty in species vulnerability scores) (based on final scores from Step 3).
- Reviewer (n): The total number of reviewers from all steps. W = reviewed in a workshop breakout group by at least five people and otherwise < 2 reviewers.
- Traits Selected for Each Category: For each species, the trait numbers are listed by trait category, range from 1 to 5, and are not separated by commas. For example, a species in the table with the trait code "23" for a category has traits 2 and 3. The definition of trait number codes for each trait category can be found in Table 1 (e.g., 1, 2). Species added to the assessment process after Step 1 lack trait numbers because their vulnerability traits were not assessed. Trait information was not noted for species that were not state-listed Threatened and Endangered species or SGCN (Status = NA) and the reviewer was a workshop breakout group (Reviewer = W), and so trait numbers are lacking for these species.
- Comments: Comments regarding species vulnerability were recorded for some species groups by species breakout groups in the workshop (Step 2). Additional comments can be found in the report of survey results and species scores (Whitman et al. 2013). Some workshop groups of reviewers did not record comments about the vulnerability of species and so some tables of plant groups lack comments.

A2. Wetland Plant Species (grouping by major habitats)

AQUATIC SPECIES

Nine of the ten state-listed Threatened or Endangered plant species associated with aquatic habitats were scored to have medium or high vulnerability to climate change, with five species being scored as having high vulnerability (Table A1). The habitats of these ten species are strongly susceptible to changes in hydrology, including both surface water runoff and groundwater discharge (Environment Canada 2004), which occur under many climate change projections. The five highly vulnerable species were species that tend to occupy shallow water habitats most susceptible to unusual fluctuations in water levels. The workshop review group in Step 2 did not provide additional comments for this species group.

Table A1. The status and climate change vulnerability of 10 state-listed Threatened or Endangered plant species associated with aquatic habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY					
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC
Prototype Quillwort	*Isoetes prototypus*	S1	3	2	2	1	3				2
Slender Rush	*Juncus subtilis*	S1	3	2	2	1	1	3			
Pygmy Water-lily	*Nymphaea leibergii*	S1S2	3	2	2	1	1	2	2		2
Fries' Pondweed	*Potamogeton friesii*	S1	2	2	2	1		3	2		2
Spotted Pondweed	*Potamogeton pulcher*	S1	1	2	2	1			2		2
Straight-leaved Pondweed	*Potamogeton strictifolius*	S1	2	2	2	1	3		2		2
Comb-leaved Mermaid-weed	*Proserpinaca pectinata*	S2	2	2	2			3	23		2
Small Yellow Water Crowfoot	*Ranunculus gmelinii var. purshii*	S2	3	2.5	2	1	1	2	2		
Stiff Arrow-head	*Sagittaria rigida*	S2	2	2.3	3	1	3	3			2
Slender Pondweed	*Stuckenia filiformis ssp. occidentalis*	S1	3	2	3	1	13	3	12	3	2
Mean			**2.4**	**2.1**							

COASTAL WETLANDS

Fifteen of the 16 state-listed Threatened or Endangered plant species associated with coastal wetland habitats had medium or high vulnerability to climate change (Table A2). The vulnerability of these species was linked to their narrow habitat specificity and low levels of physiological tolerance. Five species had high vulnerability because they are mostly found in salt marshes or low elevation sites (e.g., Beach Plum, *Prunus maritima*). Their habitats will be significantly reduced by rising sea level (Frumhoff et al. 2007). In Maine, many high salt marsh environments may revert to low salt marsh habitats (Slovinsky and Dickson 2008), or may disappear altogether if their landward migration is blocked (Jacobson et al. 2009), as is the case in Casco Bay where 20% of the shoreline is armored (Kelley and Dickson 2000). Also, temperature changes may favor the productivity and, hence, dominance of marsh grasses at the expense of forb species, which are likely to become rarer as a result (Gedan and Bertness 2009). The workshop review group in Step 2 did not provide additional comments for this species group.

Table A2. The status and climate change vulnerability of 16 state-listed Threatened or Endangered plant species associated with coastal wetland habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY					
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC
Nova Scotia False-foxglove	*Agalinis neoscotica*	S1	3	2	2	1	13	3	23		
Large purple false foxglove	*Agalinis purpurea*	S1	2	2	2	1		3			
Screwstem	*Bartonia paniculata*	S1	2	1	2	1		3	123		
Marsh Bulrush	*Bolboschoenus novae-angliae*	S1	2	2	2	1		3	3		
Pickering's Reed Bent-grass	*Calamagrostis pickeringii*	S1	2	3	W	1	4	3	23		3
Long's Bitter-cress	*Cardamine longii*	S2	3	2	2	1		3	13		2
Saltmarsh sedge	*Carex vacillans*	S2	3	2	2	1	13	3	23		
Coast-blite Goosefoot	*Chenopodium rubrum*	S1	2	1	W	1		3	23		
Ink-berry	*Ilex glabra*	S1	2	2	2	13		34	12		
Slender Blue Flag	*Iris prismatica*	S2	2	2	2	1		3	1		
Marsh-elder	*Iva frutescens ssp. oraria*	S1	2	2	2	1		3			
Lilaeopsis	*Lilaeopsis chinensis*	S2	3	2	2	1	2	3	1	1	2
Marsh Felwort	*Lomatogonium rotatum*	S1	3	2	2	1	13	2	23		
Beach Plum	*Prunus maritima*	S1	3	3	1	12		3	2		2
American Sea-blite	*Suaeda calceoliformis*	S2	2	1	2	1	2	3	13		
Small Salt-marsh Aster	*Symphyotrichum subulatum*	S1	1	2	2	1		3			
Mean			2.3	1.9							

CALCAREOUS FENS AND SWAMPS

Nine of the 10 state-listed Threatened or Endangered plant species associated with calcareous fens and swamps had high vulnerability to climate change (Table A3). These nine species are limited to specific, uncommon fen habitats, are at the edge of their range, and may experience barriers to dispersal and migration due to the fragmented nature of their habitats. Climate change may increase the frequency of summer drought, despite overall increasing precipitation and this could also impair fens (Gorham 1991, Burkett and Kusler 2000). Fens are vulnerable to changes in groundwater level, which plays a crucial role in the accumulation and decay of organic matter and governs plant community structure (Seigel and Glaser 2006). Under most emissions scenarios, fens could decline because groundwater levels will fall as evapotranspiration increases with temperature, unless offset by an increase in summer precipitation (Moore et al. 1997; Myer et al. 1999). Some fens may be resilient if their water input flows from deep groundwater systems (Winter 2000). If the hydraulic head in the recharge areas providing the groundwater that sustains calcareous fens decreases with climate change, non-calcareous-tolerant species may out-compete calcareous plant species (Siegel and Glaser 2006, Almendinger and Leete 1998).

Table A3. The status and climate change vulnerability of ten state-listed Threatened or Endangered plant species associated with calcareous fens and swamps.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Small Round-leaved Orchis	*Amerorchis rotundifolia*	S2	3	3	3	1	123	13	123	12	3	
Awned Sedge	*Carex atherodes*	S1	1	3	2		3		1			
Prairie Sedge	*Carex prairea*	S1	3	3	W	1	13	3	1			Habitat extremely limited.
Showy Lady's-slipper	*Cypripedium reginae*	S3	3	3	4	12	23	13	12	3		
English Sundew	*Drosera anglica*	S1	3	3	2	1	13	3	12		2	
Slender-leaved Sundew	*Drosera linearis*	S1	3	3	2	1	1	3	12		23	
Prairie White-fringed Orchid	*Platanthera leucophaea*	S1	3	3	2	12	123	3	123	3	2	
Lapland Buttercup	*Ranunculus lapponicus*	S2	3	3	2	1	123	3	12			
Hoary Willow	*Salix candida*	S1	3	3	3	1	13	3	123		2	
Low Spike-moss	*Selaginella selaginoides*	S1	3	3	2	1	13	4	1			
Mean			**2.8**	**3.0**								

NORTHERN RIVER SHORES

Seventeen of 18 state-listed Threatened or Endangered plant species associated with northern river-shore habitats have medium or high vulnerability to climate change (Table A4). Most of these species occupy habitats within a narrow environmental gradient, frequently at or near the southern edge of their range, and have limited dispersal and migration capacity. Mid-winter thaws are predicted to become more frequent, leading to more frequent ice jam conditions and river bed scouring events that might enhance habitat conditions or reduce populations of all river shore species (Beltaos and Burrell 2003). Eventually, rivers in the region may become ice free, a trend that would be enhanced by an increase in winter rainfall, and seasonal ice scouring that is essential for maintaining some river shore plant species might then disappear (Beltaos and Burrell 2003).

Table A4. The status and climate change vulnerability of 18 state-listed Threatened or Endangered plant species associated with northern river-shore habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Cut-leaved Anemone	*Anemone multifida*	S1	3	3	2	12	13	3	2		2	
Neglected Reed-grass	*Calamagrostis stricta ssp. stricta*	S2	3	3	2	1	13	3	2			
Ebony Sedge	*Carex eburnean*	S1	2	3	W	1			12		2	Occurs further south.
Slender Cliffbrake	*Cryptogramma stelleri*	S1	2	3	2	12	13	2	2			
Northern Gentian	*Gentianella amarella ssp. acuta*	S1	3	3	2	1	1	3	2		2	
Robinson's Hawkweed	*Hieracium robinsonii*	S1	3	2	2	1	1	3	3		2	
Great St John's-wort	*Hypericum ascyron*	S1	1	3	2	1	3				2	
Vasey Rush	*Juncus vaseyi*	S1	2	2	2	1	123	3	123			
St John Oxytrope	*Oxytropis campestris var. johannensis*	S1	3	3	2	12	13		23			
Furbish's Lousewort	*Pedicularis furbishiae*	S2	3	3	2	123	13	234	13	2	12	
Mountain Timothy	*Phleum alpinum*	S2	3	3	2	12	13	3	2			
Seneca Snakeroot	*Polygala senega*	S1	2	2	2	1	3		123		2	
Horned Beak-rush	*Rhynchospora capillacea*	S1	3	3	2	1		3	12		2	
Sandbar Willow	*Salix interior*	S1	2	2	2	1		3	23		2	
Blue-leaf Willow	*Salix myricoides*	S2	3	3	2	1	13	3	3			
Canada Buffaloberry	*Shepherdia canadensis*	S1	3	2	2	1	3	3	23			
Longleaf Dropseed	*Sporobolus asper*	S1	2	2	2							
Anticosti Aster	*Symphyotrichum anticostense*	S1	3	3	2	1	123	3	13		2	
Mean			**2.5**	**2.6**								

OTHER FRESHWATER WETLANDS

Eighteen of 21 state-listed Threatened or Endangered plant species associated with other freshwater wetland habitats had medium or high vulnerability to climate change (Table A5). Some of these species may be vulnerable because they have narrow habitat requirements, low tolerance to climate-induced change to wetland hydrology, or are somehow limited in their dispersal and migration capacity. Changes in seasonality of precipitation and runoff due to climate change may alter the hydrology of wetlands, affecting their composition and ecosystem productivity (Jacobson et al. 2009). Populations of wetland plant species may decline in response to changes in the frequency, duration, and timing of extreme precipitation events, such as floods or droughts. Changes in the seasonal timing of snowmelt will alter stream flows, potentially interfering with the reproduction of some wetland species.

Table A5. The status and climate change vulnerability of 21 state-listed Threatened or Endangered plant species associated with other freshwater wetland habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Tundra Dwarf Birch	*Betula glandulosa*	S1	3	2	2	1	12	2	3			
Moonwort	*Botrychium lunaria*	S1	3	3	W	12	3	2	2	3	2	Does not occur much south of here.
Cat-tail Sedge	*Carex typhina*	S1	2	1	W	1		3	3		2	Only one pop in ME, more common southward.
Long-tubercled Spike-rush	*Eleocharis tuberculosa*	S1	3	2	2			3	23		2	
Narrow-leaved Goldenrod	*Euthamia tenuifolia var. tenuifolia*	S2	2	2	2	1		3	2			
Fall Fimbry	*Fimbristylis autumnalis*	S2S3	2	2	W	1		3	1			
Sharp-scaled Manna-grass	*Glyceria acutiflora*	S1	2	2	2			3	2			
Featherfoil	*Hottonia inflate*	S1	2	2	3	12	4	3	12			
Dwarf Bulrush	*Lipocarpha micrantha*	S1	2	2	2	1		3	1			
Auricled Twayblade	*Listera auriculata*	S2	3	3	2	1	13	3	12			
Foxtail bog clubmoss	*Lycopodiella alopercuroides*	S1	1	2	2	2		3				
White Adder's-mouth	*Malaxis monophyllos*	S1	3	3	W	12	13	3	12	3		Rare throughout New England.
Jacobs Ladder	*Polemonium vanbruntiae*	S1	3	2	2	1	2	3	12	3	2	
Swamp White Oak	*Quercus bicolor*	S1	2	2	3	13	3	3				
Great Rhododendron	*Rhododendron maximum*	S1	1	3	2		3		3			
Clammy Azalea	*Rhododendron viscosum*	S1	2	2	3	1	3	3	2		2	
Tall Beak-rush	*Rhynchospora macrostachya*	S1	2	2	2	1		3			2	
Long's Bulrush	*Scirpus longii*	S2	2	2	W	1	3	3	13		2	
Pendulous Bulrush	*Scirpus pendulus*	S2	1	3	2			3				
Shining Ladies'-tresses	*Spiranthes lucida*	S1	2	2	2	1	3	3		3		
Yellow-eyed Grass	*Xyris smalliana*	S1	2	1	W			3	123			
Mean			**2.1**	**2.1**								

A3. Upland Plant Species (grouping by major habitats)

ALPINE SPECIES

All state-listed Threatened or Endangered plant species associated with alpine habitats had medium or high vulnerability to climate change (Table A6). These species occupy highly restricted habitats, exist in Maine at the southern edge of their range, have limited dispersal and migration capacity due to the highly fragmented nature of their habitats, and may have limited tolerance for changes in micro-habitat moisture regimes due to climate change. Although alpine habitat islands smaller than Mount Katahdin may be lost (Kimball 1997), the persistence of alpine communities during a warming period ~5,000 years ago (Miler and Spear 1989) suggests that many alpine plant habitats may persist through 2100. Grass species may outperform other species due to greater drought resistance and enhanced competitive ability at higher CO_2 levels. Snow bed species well adapted to sites that stay cool may be especially vulnerable to warming impacts on the persistence of these sites (Schöb et al. 2009).

Table A6. The status and climate change vulnerability of 35 state-listed Threatened or Endangered plant species associated with alpine habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Boreal Bentgrass	*Agrostis mertensii*	S2	3	3	W	13	23	2	2			Wide range, restricted habitat.
Alpine Bearberry	*Arctostaphylos alpine*	S1	3	2	4	12	1234	24	1234			
Hairy Arnica	*Arnica lanceolata*	S2	3	3	2	12	3	23		3		
Dwarf White Birch	*Betula x minor*	S1	3	2	W							Restricted open habitat, small pop. size.
Alpine Bitter-cress	*Cardamine bellidifolia*	S1	3	2	2	1	1	3	2			
Bigelow's Sedge	*Carex bigelowii*	S2	3	2	2	1	123		2	13	2	
Russett Sedge	*Carex saxatilis*	S1	3	1	2	1	13	3	12		5	
Alaskan Clubmoss	*Diphasiastrum sitchense*	S1	2	2	2	1	13		123			
Alpine Willow-herb	*Epilobium anagallidifolium*	S1	3	3	2	1	123	3	23			
Hornemann's Willow-herb	*Epilobium hornemannii*	S1	3	2	2	1	13	2	23			
Oakes' Eyebright	*Euphrasia oakesii*	S1	3	2	2	12	123	23	12	3		
Arctic Red Fescue	*Festuca prolifera*	S1	3	2	2	1	123	23	123			
Moss Bell-heather	*Harrimanella hypnoides*	S1	3	2	3	12	123	23	2	3		
Alpine Sweet-grass	*Hierochloe alpine*	S1	2	3	2	1	123		23			
Alpine Clubmoss	*Huperzia selago*	S2	3	2	2		12	2			2	
Alpine Azalea	*Loiseleuria procumbens*	S1	3	3	2	1	123	2	2			
Northern Wood-rush	*Luzula confuse*	S1	3	2	2	1	12	13	123			
Spiked Wood-rush	*Luzula spicata*	S1	3	2	2	1	123	3	123			
Alpine Cudweed	*Omalotheca supine*	S1	2	2	W							Restricted open habitat, small pop. size.
Silverling	*Paronychia argyrocoma*	S1	3	2	W	1	3	3			2	

Table A6 (cont.). The status and climate change vulnerability of 35 state-listed Threatened or Endangered plant species associated with alpine habitats.

COMMON NAME	SCIENTIFIC NAME	STATUS	SCORE: VULNERABILITY	SCORE: CONFIDENCE	REVIEWERS (N)	TRAITS SELECTED FOR EACH CATEGORY: HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Alpine Bistort	*Persicaria vivipara*	S1	3	2	2	1	13	2	12			
Mountain Heath	*Phyllodoce caerulea*	S1	3	2	2	12	123	23	2			
Wavy Bluegrass	*Poa fernaldiana*	S1	3	3	W							Restricted open habitat, small pop. size.
Boott's Rattlesnake Root	*Prenanthes boottii*	S1	3	2	2	1	23	12	3			
Dwarf Rattlesnake Root	*Prenanthes nana*	S1	3	2	W							Restricted open habitat, small pop. size.
Lapland Rosebay	*Rhododendron lapponicum*	S1	3	3	2	1	123	23	2			
Arctic Willow	*Salix arctophila*	S1	3	2	2	12	12	2	13			
Dwarf Willow	*Salix herbacea*	S1	3	2	2	1	13		12			
Tea-leaved Willow	*Salix planifolia*	S1	3	2	2	1	123	12	23			
Bearberry Willow	*Salix uva-ursi*	S1	3	3	2	1	13		1		5	
Star Saxifrage	*Saxifraga foliolosa*	S1	3	2	2	12	13	2	12	3		
Cutler's Goldenrod	*Solidago multiradiata var. arctica*	S1	3	2	2	1	1		2			
Mountain Hairgrass	*Vahlodea atropurpurea*	S1	3	2	W							Restricted open habitat, small pop. size.
Alpine Speedwell	*Veronica wormskjoldii*	S1	3	3	W							Restricted open habitat, small pop. size.
Alpine Marsh Violet	*Viola palustris*	S1	3	2	2	1	123	3	23			
Mean			2.9	2.2								

BARRENS/DISTURBED GROUND SPECIES

Only five of the 14 state-listed Threatened or Endangered plant species associated with barrens/disturbed ground habitats had medium or high vulnerability to climate change, as most of the species have southern distribution ranges (Table A7). The vulnerability of these six species is influenced by the fact that they occupy specific, narrowly defined habitats. The one high-vulnerability species occurs in isolated populations (Variable Sedge, *Carex polymorpha*). These habitats may be vulnerable to increased drought and increases in exotic plant species. On the other hand, projected increases in drought may increase the likelihood of fire and other forest disturbances (Ollinger et al. 2008), which might increase the extent of these habitats.

Table A7. The status and climate change vulnerability of 14 state-listed Threatened or Endangered plant species associated with barrens/disturbed ground habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Wild Indigo	*Baptisia tinctoria*	S1	1	2	2							
Upright Bindweed	*Calystegia spithamaea*	S2	2	2	2	1		3	12		2	
Bicknell's Sedge	*Carex bicknellii*	S1	1	1	W	1			123			More common southward.
Muhlenberg Sedge	*Carex muehlenbergii*	S1	1	3	2	1			2		2	
Orono Sedge	*Carex oronensis*	S3	2	3	2	3	4		3		2	
Variable Sedge	*Carex polymorpha*	S1	3	2	W	12	3		24	3	2	Wide range, populations are isolated & fragmented.
Clothed Sedge	*Carex vestita*	S1	1	2	3	13			2		2	
New Jersey Tea	*Ceanothus americanus*	S1S2	2	2	2	1			2		2	
Rattlesnake Hawkweed	*Hieracium venosum var. nudicaule*	S1	1	2	2	1					2	
Dwarf Dandelion	*Krigia virginica*	S1	1	2	2		34					
Northern Blazing Star	*Liatris scariosa var. novae-angliae*	S1	1	2	3	13			23			
Creeping Spike-moss	*Selaginella apoda*	S2	1	2	2	3				3	2	
Indian Grass	*Sorghastrum nutans*	S1	2	3	2	12	3				2	
Barren-strawberry	*Waldsteinia fragarioides*	S1	1	2	2		3					
Mean			1.5	2.2								

CENTRAL AND NORTHERN MAINE UPLANDS SPECIES

All but five of 38 state-listed Threatened or Endangered plant species associated with central and northern Maine upland habitats had medium or high vulnerability to climate change (Table A8). Many species occupy specific, narrowly defined habitats, are at the southern edge of their range, and are not highly dispersed. They occupy northern upland forest types that are projected to decline, with some types persisting in the mountains and in far northern Maine (Tang and Beckage 2010). The few species with low vulnerability have southern distribution ranges or are habitat generalists.

Table A8. The status and climate change vulnerability of 38 state-listed Threatened or Endangered plant species associated with central and northern Maine upland habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Mountain maple	*Acer spicatum*	NA	1	2	W		2					
Aleutian Maidenhair Fern	*Adiantum aleuticum*	S1	3	3	2	12	12	2	2	1		
Allegheny Vine	*Adlumia fungosa*	S1	2	2	2	1			2			
Nantucket Shadbush	*Amelanchier nantucketensis*	S2	1	2	3	1			4	3	2	
Smooth Rockcress	*Arabis laevigata*	S1	1	2	W	1			2			Wide range, occurs further southward.
Missouri Rockcress	*Arabis missouriensis*	S1	2	2	W	1			23		2	Wide range, occurs further south but is uncommon in most regions.
Wild Ginger	*Asarum canadense*	S1S2	2	3	4	12	3		124		2	
Green Spleenwort	*Asplenium trichomanes-ramosum*	S1	3	2	2	12	12	2	2			
New England Northern Reed Grass	*Calamagrostis stricta ssp. inexpansa*	S1	3	3	2	1	3	3	3		2	
Cut-leaved Toothwort	*Cardamine concatenata*	S1	2	3	2	1	3		2		2	
Swarthy Sedge	*Carex adusta*	S2	2	2	3	1	23	4	13		2	
Intermediate Sedge	*Carex norvegica ssp. inferalpina*	S1	3	3	W	1	13		123			Rare throughout New England.
Bur-reed Sedge	*Carex sparganioides*	S1	2	2	W	1			123			Low confidence, only one pop in state, could be lost.
Northern Wild Comfrey	*Cynoglossum virginianum var. boreale*	S1	3	2	2	13		2	13	3	2	
Ram's-head Lady's-slipper	*Cypripedium arietinum*	S1	3	2	2	1	34		123	3		
Squirrel-corn	*Dicentra canadensis*	S1	3	2	2	1			12	3		
Rock Whitlow-grass	*Draba arabisans*	S1	3	3	2	12	13		123			
Lance-leaved Draba	*Draba cana*	S1	3	3	2	1	13		12			
Smooth whitlow grass	*Draba glabella*	S1	2	3	2	12	13		2			
Mountain woodfern	*Dryopteris campyloptera*	NA	1	2	W		2					
Male Fern	*Dryopteris filix-mas*	S1	3	2	2	1	123		123		2	
Showy Orchis	*Galearis spectabilis*	S1	2	2	2	1	3		23		23	

Table A8 (cont.). The status and climate change vulnerability of 38 state-listed Threatened or Endangered plant species associated with central and northern Maine upland habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Boreal Bedstraw	*Galium kamtschaticum*	S2	3	3	4	12	123	3	12		2	
Giant Rattlesnake-plantain	*Goodyera oblongifolia*	S1	3	3	4	1	123	23	123	3	23	
Northern Stickseed	*Hackelia deflexa var. americana*	S1	3	3	W	12	3		23		2	Rare throughout New England.
Arctic Sandwort	*Minuartia rubella*	S1	3	3	2	1	1	2	2		2	
American Ginseng	*Panax quinquefolius*	S3	2	2	4	1	3		12		2	
Common Butterwort	*Pinguicula vulgaris*	S1	3	3	3	12	123	12	123			
White Bluegrass	*Poa glauca*	S1	3	2	2	1	13		12			
Braun's hollyfern	*Polystichum braunii*	NA	2	2	W	1	2	3				
Canada Burnet	*Sanguisorba canadensis*	S1	3	2	2	1	1		2		2	
Rue-anemone	*Thalictrum thalictroides*	S1	2	2	W				23		2	Only one pop in ME, could be lost.
Wild Coffee	*Triosteum aurantiacum*	S1	2	2	2	3	3		1			
Nodding Pogonia	*Triphora trianthophora*	S2	2	2	4	12	3		13	2	2	
Tall White Violet	*Viola canadensis*	S1	1	2	W	1	23		12	3	2	More common southward.
Kidneyleaf violet	*Viola renifolia*	NA	3	2	2		2					
Northern Woodsia	Woodsia alpina	S1	2	3	2	12	13		2			
Smooth Woodsia	Woodsia glabella	S1	3	3	2	12	13	2	12			
Mean			**2.4**	**2.4**								

SOUTHERN MAINE UPLAND SPECIES

None of the state-listed Threatened or Endangered plant species associated with southern Maine upland habitats had high vulnerability to climate change, as most of these species have southern distribution ranges (Table A9). Moreover, their Key Habitats, including oak and pine forest, are projected to increase in Maine (Iverson et al. 2008a). Species with medium vulnerability frequently scored high for habitat traits and/or mobility traits and occupy specific, narrowly defined habitats and have low dispersal ability.

Table A9. The status and climate change vulnerability of eastern hemlock and 15 state-listed Threatened or Endangered plant species associated with southern Maine upland habitats.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Spreading Sedge	*Carex laxiculmis*	S2	2	2	2				2			
Bitternut Hickory	*Carya cordiformis*	S1	1	3	2	1						
Spotted Wintergreen	*Chimaphila maculate*	S2	1	2	2				1			
Autumn Coral-root	*Corallorhiza odontorhiza*	S1	2	1	W	1			3		1	
Flowering Dogwood	*Cornus florida*	S1	2	2	2	1			13			
Small Whorled Pogonia	*Isotria medeoloides*	S2	2	1	W	1			12		2	Could be affected by changes in soil acidity?
Secund Rush	*Juncus secundus*	S1	2	1	2	3			3			
Hairy Bush-clover	*Lespedeza hirta ssp. hirta*	S1	1	1	W				3			
Mountain Honeysuckle	*Lonicera dioica*	S2	1	1	2	1						
Scarlet Oak	*Quercus coccinea*	S1	1	3	1	1						
Chestnut Oak	*Quercus montana*	S1	1	3	2	1			123			
Early Crowfoot	*Ranunculus fascicularis*	S1	2	2	2			3			13	
White-topped Aster	*Sericocarpus asteroids*	S1	1	3	W							More common further southward, common habitat.
Eastern hemlock	*Tsuga Canadensis*	NA	2	2	W				3			
Summer Grape	*Vitis aestivalis var. bicolor*	S2	1	2	2	1			2			
Blunt-lobed Woodsia	*Woodsia obtuse*	S1	2	2	2				2			
Mean			1.5	1.9								

FUNGI AND LICHEN SPECIES (ADDED SPECIES)

None of Maine's fungi and lichen species are state-listed as Threatened or Endangered species; these species were added to the assessment during the online survey (Table A10). Ten of the 11 species had high vulnerability, though this reflects a bias associated with added species. Reviewers most frequently added easy-to-score, high-vulnerability species and so these data may not be representative of other fungi and lichen species. Most of these species are epiphytes or epixylics dependent on northern tree species that are projected to decline due to climate change (Prasad et al. 2007). Hence, all but Smooth Lungwort (*Lobaria quercizans*) scored high for habitat traits and/or dependence traits and occupying specific, narrowly defined habitats with strong dependence on host trees species. This group was not reviewed by a workshop reviewer group in Step 2 and so no comments are listed.

Table A10. The climate change vulnerability of 11 fungi and lichen species in Maine. These were added during the survey and are <u>not</u> state-listed as Threatened or Endangered species.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Witch's Hair (a lichen)	*Alectoria sarmentosa*	NA	3	2	1	2	23	1	2			
Smooth gray horsehair lichen	*Bryoria capillaris*	NA	3	2	2					3		
Unnamed shelf fungus	*Fomitopsis cajanderi*	NA	3	2	2					3		
Red Banded Polypore Fungus	*Fomitopsis pinicola*	NA	3	2	2	1	13			3		
Foliose Shingle Lichen	*Fuscopannaria ahlneri*	NA	3	2	1					2	2	
Hemlock varnish shelf fungi	*Ganoderma tsugae*	NA	3	2	2	1	2					
Poder-headed tube lichen	*Hypogymnia tubulosa*	NA	3	2	1	1				3		
Smooth lungwort	*Lobaria quercizans*	NA	2	2	2	1				3		
Powdery axil-bristle lichen	*Menegazzia terebrata*	NA	3	3	1					3		
Birch Polypore	*Piptoporus betulinus*	NA	3	2	2	1	23	1	2	3		
Methuselah's beard lichen	*Usnea longissima*	NA	3	3	2	2	23	1	2			
Mean			**2.9**	**2.2**								

A4. Invertebrate Species (grouping by major taxa)

SNAILS AND MUSSELS

Ten of the 13 snail and mussel SGCN had medium or high vulnerability to climate change (Table A11). One high-vulnerability species has an essential host relationship with cold-water fish (Brook Floater, *Alasmidonta varicosa*); the other high-vulnerability species is at the southern edge of its range and limited in Maine to a single site (Six-whorl Vertigo, *Vertigo morsei*). Two medium-vulnerability species have critical host relationships with cold-water fish and so their reproductive success may decline as suitable thermal habitat for their host species diminishes (New Hampshire Fish and Game Department 2005): Alewife Floater (*Anodonta implicata*) and Eastern Pearlshell (*Margaritifera margaritifera*). The remaining medium-vulnerability species are found in Maine at a few sites and have limited mobility. Snail and mussel species may also be susceptible to climate change impacts such as higher water temperatures, longer periods of low flows, and floods (Byers and Norris 2011, U.S. Fish and Wildlife Service 2009).

Table A11. The climate change vulnerability of 13 snail and mussel SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Brook Floater	*Alasmidonta varicosa*	2	3	3	W	13	234	1234	123	123	23	Species relies primarily on coldwater fish species as host; low mobility and may be vulnerable to changes in hydrology, low summer water levels? Species has declined across range. Maine hosts about 75% best remaining populations, most in Northern climate.
A Spire Snail	*Amnicola decisus*	1	1	1	2		3		1			
Alewife Floater	*Anodonta implicata*	NA	2	3	1			3	2	2		Vulnerability primarily related to known reliance on anadramous fish host(s) that might be negatively impacted by CC; low mobility and may be vulnerable to changes in hydrology, low summer water levels?
Pleistocene Catinella	*Catinella exile*	2	2	1	W	1	3	3	1			Taxonomy questionable and may not be present; needs further research and expert review.
Yellow Lampmussel	*Lampsilis cariosa*	1	2	2	W	13	3	3	12	12	234	Generalist, flexible re habitat but only in three watersheds, low mobility and may be vulnerable to changes in hydrology, low summer water levels?
Tidewater Mucket	*Leptodea ochracea*	1	2	2	3	1		3	12	12	234	Generalist, flexible re habitat but only in three watersheds, low mobility and may be vulnerable to changes in hydrology, low summer water levels?
Eastern Pearlshell	*Margaritifera margaritifera*	NA	2	2	1			13	2	12		A coldwater species that relies solely on salmonids as larval host; low mobility and may be vulnerable to changes in hydrology, low summer water levels and higher water temperatures; Species added and ranked by BIS.
Lamellate Supercoil	*Paravitrea lamellidens*	2	1	2	2		3		1			Questionable validity; no modern records.

Table A11 (cont.). The climate change vulnerability of 13 snail and mussel SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Great Lakes Physa	*Physella magnalacustris*	2	1	1	2				1			Questionable taxonomy; no modern records.
Bigmouth Pondsnail	*Stagnicola mighelsi*	2	2	2	2	1	3		12			Likely a subspp (at best) of S. emarginata, itself a potentially rare species.
Six-whorl Vertigo	*Vertigo morsei*	2	3	2	W	1	12	3	1			Only one locality from calcereous fen; southern range edge.
Deep-Throat Vertigo	*Vertigo nylanderi*	2	2	2	2		1		12			
Mystery Vertigo	*Vertigo paradoxa*	2	2	2	2		1		12			
Mean			**1.9**	**1.9**								

AQUATIC INSECTS

Only two of the 17 scored aquatic insect species had low vulnerability (Table A12). The remaining medium and high-vulnerability species were generally at the southern edge of their range, limited to cold-water or small streams, and restricted to first order streams at a few sites. Aquatic insects will likely experience significant changes in hydrology (including increases in winter rain) and increased water temperatures driven by climate change (Williams et al. 2007). The former could increase the frequency of winter floods and ice flows that scour streambeds and kill aquatic insect larvae (Frumhoff et al. 2007). The cold-water habitats of many aquatic insect species are predicted to decline in the region as air temperatures warm and, subsequently, water temperatures increase. One mayfly SGCN, *Plauditus veteris*, was not scored for its vulnerability because it may not occur in Maine. Three other species lack information because they are very rare in Maine: *Hydroptila tomah, Procloeon mendax*, and *Procloeon ozburni*.

Table A12. The climate change vulnerability of 17 aquatic insect SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
A Mayfly	*Ameletus browni*	3	2	2	2	1	123	123	1	1		Restricted to cold, high elevation 1st order streams in undisturbed habitat; only other New England records are from similar habitats in VT and NH.
A Mayfly	*Baetisca rubescens*	2	3	2	W	123	123	1234	124	1		Restricted to cold, high elevation streams; this is a northern species, with only a few other U.S. and Canadian records (NH, VT, Newfoundland, Labrador); species has not been found in other potentially suitable habitats.
Roaring Brook Mayfly	*Epeorus frisoni*	1	3	2	W	123	123	123	12	1	4	Restricted to cold, high elevation headwater streams in relatively undisturbed mixed forest habitats along the Northern Appalachian Mtn range; may be New England's only endemic mayfly; much of life history is unknown; currently known from ~8 sites.
A Caddisfly	*Hydroptila tomah*	2										New species known only from type locality (Tomah Stream) - not enough information to rate.
A Mayfly	*Metretopus borealis*	3	2	2	2	1	123	12	1	1		Known from 8 sites on three widely distributed rivers (St. John, Narraguagus, and East Branch Sandy Stream); Maine is southern edge of range.
A Stonefly	*Neoperla mainensis*	2	3	1	W	13	123	123	124	12		In Maine, known from a single historic (1944) record from Kennebec Co. (specific location unknown?); is globally rare (G2G3), with few other EOs documented (OH, IL (SX), ON).
A Mayfly	*Nixe horrida*	2	2	1	1		3					Currently known from two sites on the Narraguagus River and one site on the Aroostook River; only one other global EO has been documented (ON); species is poorly known.

Table A12 (cont.). The climate change vulnerability of 17 aquatic insect SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
A Mayfly	*Nixe rusticalis*	2	2	1	W	1	23	123	1	1		Recent new state record; not restricted to northern regions; mean score adjusted from High to Medium by PGD.
A Mayfly	*Parameletus midas*	2	2	2	2	1	13	1	1	1		Currently known from two (three?) sites (Narraguagus River, Machias River in Aroostook Co); a northern species, with Maine the only U.S. record (?).
A Mayfly	*Procloeon mendax*	2	1	1	1							No listing status at this time.
A Mayfly	*Procloeon ozburni*	2	1	1	1							No listing status at this time.
A Mayfly	*Procloeon simplex*	2	2	2	1	3		2				No listing status at this time.
A Mayfly	*Rhithrogena undulata*	NA	2	2	1	1	3	12				Known from one specimen collected in Nesowadnehunk Stream in Baxter SP; rangewide, it occurs mostly in the central and southeastern U.S., with a disjunct record from Newfoundland; Maine is the only northeastern U.S. record.
Tomah Mayfly	*Siphlonisca aerodromia*	1	3	2	W	123	234	13	12	123	23	Early spring cycle of flooding sedge from snowmelt followed by receding water levels is critical to growth and development of larval stage; >90% of all extant global occurrences are found in Maine's Northern climate division; does not occur in many potential streams.
A Mayfly	*Siphlonurus barbaroides*	3	2	2	1	1	3	12				Known from only one record (Lily Bay Brook, Piscataquis Co.); is a regional endemic, with the only other documented global EOs from NY and eastern Canada; restricted to cold streams and stream inlets.
A Mayfly	*Siphlonurus demaryi*	2	2	2	2	13	123	12	12	1		Known globally only from two rivers in Maine, both in the Northern climate division above the 45 degree Lat, one site in New Brunswick and two in Nova Scotia; may be restricted to cold, headwater streams but life history largely unknown.
A Mayfly	*Siphlonurus securifer*	2	2	2	1	1	3	12				Currently known from two sites (Franklin, Hancock Cos); was found in small, murky warm ponds and flowage habitats; may be under-surveyed - possibly this species' distribution is more coastal.
Mean			2.1	1.7								

MOTHS AND BUTTERFLIES

Sixteen of the 28 moth and butterfly species had medium or high vulnerability (Table A13). Four species with high vulnerability were very rare habitat specialists that use boreal or northern habitat and are at the edge of their range in Maine: Purple Lesser Fritillary (*Boloria chariclea grandis*), Katahdin Arctic (*Oeneis polixenes katahdin*), Northern Blue (*Lycaeides idas scudderi*), and Frigga Fritillary (*Boloria frigga*). Many other moth and butterfly species with low vulnerability are near their northern range limits with populations that may grow and expand northward as a result of climate change (Parmesan et al. 1999). Two SGCN, the Precious Underwing (*Catocala p. pretiosa*) and a moth (*Cucullia speyeri*), were not scored for their vulnerability because they are believed to be absent from Maine.

Table A13. The climate change vulnerability of 28 moth and butterfly SGCN and other species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Dusted Skipper	*Atryonopsis hianna*	NA	1	2	1	1				1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Purple Lesser Fritillary	*Boloria chariclea grandis*	2	3	3	W	12	123			12		Boreal forest habitat at risk; extreme southern edge of range; only one modern location.
Frigga Fritillary	*Boloria frigga*	2	3	2	W	1				1	4	Northern peatlands at risk; extreme southern edge of range; only one location.
Juniper Hairstreak	*Callophrys gryneus*	2	1	2	2	12	123			12		Northern range edge with expansion likely.
Hessel's Hairstreak	*Callophrys hesseli*	1	2	2	2	1	13	3	3	12		Northern range edge but unlikely to expand due to specialized cedar habitat; potential for swamp hydrology impacts.
A Noctuid Moth	*Chaetaglaea cerata*	2	1	2	1	1			2	1		Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Pine Devil	*Citheronia sepulcralis*	2	2	1	1	1		3	2	1		Extinct from much of NE; no modern occurrence; likely tied to Pitch Pine.
Early Hairstreak	*Erora laeta*	2	2	2	W	1				1	4	Beech host may decline but still likely secure.
Sleepy Duskywing	*Erynnis brizo*	2	1	2	1				2	1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Graceful Clearwing	*Hemaris gracilis*	2	1	1	W							Heath habitat and blueberry host extensive; historic records only.
The Buckmoth	*Hemileuca m. maia*	2	2	2	3	1			1	12	34	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives; only two modern occurrences.
Leonard's Skipper	*Hesperia leonardus*	2	1	2	1	1				1	4	Northern range edge; some risk due to increased spraying and invasives.

Table A13 (cont.). The climate change vulnerability of 28 moth and butterfly SGCN and other species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Cobweb Skipper	*Hesperia metea*	2	1	2	1	1				1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Barrens Itame	*Itame sp. 1*	2	1	2	1	1			12	1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Pine Pinion	*Lithophane l. lepida*	2	2	1	1	1			4	1		Only one modern occurrence; requires large hard pine stands.
Northern Blue	*Lycaeides idas scudderii*	NA	3	2	W	1	13			1		Boreal forest at high risk but potentially less specialized than B.c.grandis; only one location.
Clayton's Copper	*Lycaena dorcas claytoni*	1	2	2	3	12	123	3	123	12	2	Northern peatlands at risk but hydrology uncertainty high; multiple populations.
Twilight Moth	*Lycia rachelae*	1	2	1	2	1			1	1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives; only three modern occurrences.
A Moth	*Nepytia pellucidaria*	2	2	1	1	1				1	4	Extinct from much of NE; only one known occurrence; likely tied to Pitch Pine.
Katahdin Arctic	*Oeneis polixenes katahdin*	1	3	3	W	12	1234	1234	123	123		Tundra habitat at high risk; only one location.
Spicebush Swallowtail	*Papilio troilus*	2	2	2	1	1		3		1		Northern range edge but potential for hostplant expansion probably off-set by increased habitat loss & fragmentaion in southern ME.
Crowberry Blue	*Plebejus idas empetri*	2	2	2	W	1	13	3	3	12		Downeast peatlands likely buffered from some climate impacts.
Greenish Blue	*Plebejus saepiolus amica*	2	2	2	1		13			1		Relative habitat generalist at southern edge of range; only one modern record; possibly nonnative.
Pink Sallow	*Psectraglaea carnosa*	2	2	1	1	1			4	1	4	Only one modern occurrence; probably PitchPine-ScubOak barrens.
Edwards' Hairstreak	*Satyrium edwardsii*	2	1	2	1	1				1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Coral Hairstreak	*Satyrium titus*	2	1	2	1					1		Northern range edge with expansion likely.
Pine Barrens Zale	*Zale sp. 1 nr. lunifera*	2	1	2	1	1				1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Pine Barrens Zanclognatha	*Zanclognatha martha*	2	1	2	1	1				1	4	Northern range edge but unlikely to expand greatly due to specialized barrens habitat; some risk due to increased spraying and invasives.
Mean			**1.7**	**1.9**								

DAMSELFLIES AND DRAGONFLIES

Seventeen of the 22 reviewed damselfly and dragonfly species had medium or high vulnerability (Table A14). The three high-vulnerability species are at the southern edge of their range and/or were habitat specialists that used peatlands (Hunter et al. 2009): Sedge Darner (*Aeshna juncea*), Canada Whiteface (*Leucorrhinia patricia*), and Quebec Emerald (*Somatochlora brevicincta*). Many medium-vulnerability species occur in Maine at the northern edge of their range. Although their populations might grow and expand, climate change may change the hydrology of their habitats and threaten their populations. Low-vulnerability species are described as habitat generalists.

Table A14. The climate change vulnerability of 22 damselfly and dragonfly SGCN and other species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Sedge Darner	*Aeshna juncea*	2	3	2	1		13					Southern range edge; specialist of northern fens; only known from one locale.
Dusky Dancer	*Argia translata*	2	1	2	1						2	Northern range edge; relative habitat generalist.
Arrowhead Spiketail	*Cordulegaster obliqua*	2	2	1	1	1		3				Northern range edge but relative habitat specialist requiring small low gradient headwater streams and seepages; uncertain hydrology impacts.
Tule Bluet	*Enallagma carunculatum*	2	1	2	1							Relative habitat generalist.
Big Bluet	*Enallagma durum*	2	2	2	1	1		3				Northern edge of range; some coastal brackish habitats at potential risk.
Scarlet Bluet	*Enallagma pictum*	2	1	2	2	12		3	1		2	Northern range edge; lacustrine habitat abundant.
Swamp Darner	*Epiaeschna heros*	2	2	2	1			3			4	Narrow habitat but at northern edge of range. Uncertain CC impacts to long hydroperiod vernal pools and swamps.
Rapids Clubtail	*Gomphus quadricolor*	1	2	1	1	1	3	3				Northern range edge; prefers clean, free-flowing, large rivers and streams; uncertain CC impacts to riverine ecology.
Cobra Clubtail	*Gomphus vastus*	2	2	1	1	1	3	3				Northern range edge; prefers clean, free-flowing, large rivers and streams; uncertain CC impacts to riverine ecology.
Citrine Forktail	*Ischnura hastata*	2	1	2	1							Northern edge of range; relative habitat generalist.
Rambur's Forktail	*Ischnura ramburii*	2	1	2	1		3					Northern edge of range; relative habitat generalist.
Northern Pygmy Clubtail	*Lanthus parvulus*	NA	2	1	W	1	1	3				Small headwater streams; uncertain CC impacts to stream ecology; mean score adjusted from High to Medium by PGD.
Southern Pygmy Clubtail	*Lanthus vernalis*	2	2	1	1	1	3	3				Small headwater streams; uncertain CC impacts to stream ecology.
Canada Whiteface	*Leucorrhinia patricia*	2	3	2	W	1	13	3				Southern range edge; specialist of peatlands with secondary pools.

Table A14 (cont.). The climate change vulnerability of 22 damselfly and dragonfly SGCN and other species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Boreal Snaketail	*Ophiogomphus colubrinus*	2	2	1	1	1		3				Prefers clean, free-flowing, large rivers and streams; uncertain CC impacts to riverine ecology.
Pygmy Snaketail	*Ophiogomphus howei*	2	2	1	2	1	3	3				Northern range edge; prefers clean, free-flowing, large rivers and streams; uncertain CC impacts to riverine ecology.
Spatterdock Darner	*Rhionaeschna mutata*	1	2	2	1	1		3			4	Narrow habitat but at northern edge of range.Uncertain hydrology impacts to long hydroperiod vernal pools and swamps.
Ringed Emerald	*Somatochlora albicincta*	NA	2	1	W	1	1	1				Southern edge of range but relative habitat generalist of acidic streams, ponds, and fens.
Quebec Emerald	*Somatochlora brevicincta*	2	3	2	1	1	13	3				Southern range edge; specialist of peatlands with secondary pools.
Lake Emerald	*Somatochlora cingulata*	NA	2	1	W	1	1	1				Southern edge of range but relative habitat generalist of lotic and lentic types.
Arrow Clubtail	*Stylurus spiniceps*	2	2	1	1	1	3					Northern range edge; prefers clean, free-flowing, large rivers and streams; uncertain CC impacts to riverine ecology.
Ringed Boghaunter	*Williamsonia lintneri*	1	2	2	W	12	3	3	1		4	Narrow habitat but at northern edge of range. Uncertain CC impacts to long hydroperiod vernal pools and swamps.
Mean			**1.9**	**1.5**								

BEETLES

Four beetle species were medium or high-vulnerability species, had few occurrences, and had a wide range of vulnerabilities to climate change, mostly species-specific traits associated with being habitat specialists or at the edge of their range (Table A15). One species, the beetle *Sphaeroderus nitidicollis brevoorti*, lacked sufficient information to score in the workshop.

Table A15. The climate change vulnerability of one beetle SGCN and other vulnerable beetle species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Long-lipped Tiger Beetle	*Cicindela longilabris*	NA	2	1	2							Montane and northern forest localities; southern range edge, added at Step 3 of the assessment .
Salt Marsh Tiger Beetle	*Cicindela marginata*	NA	3	3	W	12	123	3	2			Sea level rise; coastal hardening; only a few locations.
Cobblestone Tiger Beetle	*Cicindela marginipennis*	NA	2	1	W	12	3	3	12			Only one western river occurrence; hydrology needs and threats uncertain.
American Burying Beetle	*Nicrophorus americanus*	2	2	1	2		13	4	2	2	3	Extirpated, needs further research and review.
A Beetle	*Sphaeroderus nitidicollis brevoorti*	NA	?	?	W	1	12		1			Added during online survey, needs further research and review.
Mean			**2.3**	**1.5**								

A5. Fish Species (grouping by major habitat)

INLAND FISH SPECIES

Eleven of the 14 reviewed inland species had medium or high vulnerability (Table A16). The five high-vulnerability fish species had one or more tolerance traits, as they are cold-water species that are likely to be the most severely affected by climate change in Maine (Williams et al. 2007). Their cold-water habitats are predicted to decline in the region as air temperatures warm and, subsequently, water temperatures increase (Comte et al. 2012). Three other cold-water fish species have medium vulnerability: Wild Brook Trout (*Salvelinus fontinalis*), Sea Run Brook Trout (*Salvelinus fontinalis*), and Lake Trout (Togue) (*Salvelinus namaycush*). There may be adequate areas of cold-water refugia to maintain their populations at moderate levels. Two medium-vulnerability species, American Eel (*Anguilla rostrata*) and Redfin Pickerel (*Esox americanus americanus*), had medium vulnerability, in part because of potential climate change impacts on marine systems and their habitats.

Table A16. The climate change vulnerability of 14 inland fish SGCN and other inland fish species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
American Eel	*Anguilla rostrata*	1	2	1	W	2	3	123	2	1	12	Wide ranging, adaptive generalist, highly mobile, actually quite tolerant and not rare. However, the species is in decline across much of its range, particularly in the north where most individuals were female. CC that results in slowing of the Gulf Stream.
Longnose Sucker	*Catostomus catostomus*	2	2	2	1	3		4	2			Uncertain.
Lake Whitefish	*Coregonus clupeaformis*	1	3	3	W	1	23	123	2	3	2	Southern edge of range, cold-water dependent, riverine spawning.
Redfin Pickerel	*Esox americanus americanus*	1	2	2	W	1	3	3	12	3	2	Habitat MAY increase, mobile, high fecundity, wider salinity tolerance than other esocids, but sea level rise impacts? Unknown if sea level rise will comprise available habitat or actually make more available.
Swamp Darter	*Etheostoma fusiforme*	1	1	2	2		3		12		2	Northern extent of range; range may expand with CC. Prefers warmer, shallow habitats. Not a terribly mobile species to begin with, but extended periods of low water (coupled with general stream connectivity constraints) may comprise range change/expansion.
Burbot (Cusk)	*Lota lota*	2	1	2	1	1	3	2	2	1		? Not much known about the basic ecology of this species, but some level of juvenile dependency for stream habitats. General concerns regarding access/connectivity, low flow/high temp stream conditions for juvenile stages. Adults tend to occur in large.
Rainbow Smelt	*Osmerus mordax*	2	3	2	W	1	3	2	2	1		Cold water dependent; historical latitudinal range has already been reduced a considerable amount, possibly due to poor water quality in spawning habitat. Spawns in small tributaries that could be impacted by CC.

Table A16 (cont.). The climate change vulnerability of 14 inland fish SGCN and other inland fish species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Diadramous Rainbow Smelt	*Osmerus mordax*	NA	?	?	W	1	3	4	2		2	Separate out diadramous populations and evaluate vulnerability separately.
Round Whitefish	*Prosopium cylindraceum*	2	3	3	W	1	234	12	24	2	2	Southern edge of range, cold-water dependent.
Landlocked Salmon	*Salmo salar sebago*	2	3	2	W	1	13	2	123	3	2	Why wouldn't this get same rating as lake trout? May be lost from smaller, marginal habitats (highly managed situations in the first place) Native pops only occur in very large, cold lakes and will likely persist.
Arctic Charr	*Salvelinus alpinus oquassa*	1	3	2	W	12	2	1234	2	1	2	Very rare, cold-water dependent and occurs in smaller lakes more likely to lose that habitat.
Wild Brook Trout	*Salvelinus fontinalis*	2	2	2	W	1	23	124	12			Cold water dependent, susceptible to warm dry summers, mobility / access to cold-water habitats restricted by stream barriers.
Sea run Brook Trout	*Salvelinus fontinalis*	NA	2	1	W	2	3	123	2	1	12	Sea run trout should be separated out and evaluated separately- may be more vulnerable? As long as access to estuarine areas is adequate, they may be OK. Temp is a trigger that drives some individuals to migrate to the sea. Possible increase in diadromous runs.
Lake Trout (Togue)	*Salvelinus namaycush*	1	2	2	W	3		4	2			Cold water dependent, edge of range, susceptible to warm dry summers. May not persist in smaller marginal habitat lakes, but large lakes are likely to retain cold-water habitat.
Mean			**2.2**	**2.0**								

Center for Conservation Sciences

DIADROMOUS FISH SPECIES

All five diadromous species were SGCN and had medium or high vulnerability to climate change (Table A17). For several of these species, their cold-water habitats are predicted to decline in the region as air temperatures warm and, subsequently, water temperatures increase. Atlantic Salmon (*Salmo salar*) was the only species with high vulnerability with many vulnerability traits because it is a cold-water species at the southern edge of its range. Striped Bass (*Morone saxatilis*) had medium vulnerability and might be affected by climate change. For the remaining three species, climate change may disrupt temperature cues for migration and spawning. Climate change may also increase the severity of floods and droughts and reduce the frequency of successful annual spawning (Limburg and Waldman 2009).

Table A17. The climate change vulnerability of five diadromous fish SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Shortnose Sturgeon	*Acipenser brevirostrum*	1	2	2	2	12		13	24	1		Spawning migration and spawning are temperature dependent; CC may reduce spawning window and increase disruptive weather during growth period of juveniles; Particular unknowns associated with sea level rise which may shift locations of appropriate spawning.
Atlantic Sturgeon	*Acipenser oxyrhynchus*	1	2	2	1	2	4	4	4	1		Spawning migration and spawning are temperature dependent; CC may reduce spawning window and increase disruptive weather during growth period of juveniles; Particular unknowns associated with sea level rise which may shift locations of appropriate spawning.
American Shad	*Alosa sapidissima*	2	2	2	3	12	3	23	23	1	2	Mobility and habitat restricted by dams more than any other diadromous species. For all Alosa, spawning migration and spawning are temperature dependent; CC may reduce spawning window and increase disruptive weather during growth period of juveniles.
Striped Bass	*Morone saxatilis*	1	2	2	1		3			1	1	The Chesapeake Bay stock of striped bass has contributed as much as 90% to landings. Seventy percent of the adults are currently infected with mycobacteriosis, a disease that results in lesions and ultimately death. One hypothesis is that infection rate is associated with warming.
Atlantic Salmon	*Salmo salar*	1	3	3	W	123	1234	123	23	123	1234	Southern limit of range, cold-water dependent and mobility/habitat restricted by dams.
Mean			2.2	2.2								

A6. Amphibian and Reptile Species

Four of the eight amphibian and reptile species had medium or high vulnerability to climate change (Table A18). The two high-vulnerability species have different life history traits that make them vulnerable. The Mink Frog (*Lithobates septentrionalis*) has high vulnerability because it is at the southern edge of its range in Maine and a cold-water specialist. The Blanding's turtle (*Emydoidea blandingii*) scored high because its populations are sensitive to declines in water levels and how this exacerbates wetland isolation and/or overwintering success (Hermand and Scott 1994). Declines in water levels due to climate change impacts might also affect species such as Blue-spotted Salamander (*Ambystoma laterale*) and Spotted Turtle (*Clemmys guttata*) (Brooks 2009). The four remaining species had low vulnerability because they have southern distributions and so might be positively affected by climate change.

Table A18. The climate change vulnerability of eight amphibian and reptile SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Blue-spotted Salamander	*Ambystoma laterale*	2	2	2	W	2		123	12	1		Hydroperiod uncertainty high; status and distribution of pure diploid populations uncertain but likely rare, fragmented, and vulnerable to habitat or range reduction.
Spotted Turtle	*Clemmys guttata*	2	2	2	3	1	3	23	12		4	Long hydroperiod VPs and swamps may be at risk; potential increased secondary stress due to more development & road traffic from climate-driven human immigration.
Northern Black Racer	*Coluber constrictor constrictor*	2	1	3	1		3		12			At extreme northern edge of range; species may benefit from warming climate but novel stressors to barren habitats poorly understood.
Timber Rattlesnake	*Crotalus horridus*	2	1	2	1	2			12			At extreme northern edge of range; species may benefit from warming climate.
Blanding's Turtle	*Emydoidea blandingii*	1	3	1	W	3	3	13	12		14	Long hydroperiod VPs and swamps may be at risk; potential increased secondary stress due to more development & road traffic from climate-driven human immigration.
Wood Turtle	*Glyptemys insculpta*	2	1	2	1				2			Uncertain effects of riverine hydrology changes on habitat suitability.
Mink Frog	*Lithobates septentrionalis*	2	3	2	W		1	2	1			Southern edge of range; mostly aquatic cold-water specialist. Received workshop discussion.
Eastern Box Turtle	*Terrapene carolina carolina*	1	1	3	1				12			At extreme northern edge of range; species may benefit from warming climate.
Mean			**1.8**	**2.1**								

A7. Bird Species (grouping by major taxa)

SEABIRD SPECIES

All 11 seabird SGCN of Maine have medium to high vulnerable to climate change (Table A19). Seabirds may be vulnerable to reductions in prey that are likely to occur with climate change, especially during the sensitive time of their breeding cycle (Irons et al. 2007). Sea level rise may reduce nesting and loafing habitat for seabirds, especially tern species (*Sterna* spp.; New Hampshire Fish and Game Department 2005). Three of the high-vulnerability species are at the southern edge of their breeding range in Maine: Razorbill (*Alca torda*), Atlantic Puffin (*Fratercula arctica*), and Common Murre (*Uria aalge*). Populations of northern species may recede northward with climate change (Sydeman et al. 2012).

Table A19. The climate change vulnerability of 11 seabird SGCN in Maine

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Razorbill	*Alca torda*	2	3	3	3	33	33	25	0	17	7	
Black Tern	*Chlidonias niger*	1	3	3	W	22	8	17	0	17	7	Very vulnerable to flooding, along with low # sites, low population.
Atlantic Puffin	*Fratercula arctica*	2	3	3	4	42	44	19	0	31	5	
Bonaparte's Gull (breeding)	*Larus philadelphia*	2	2	2	W	22	33	0	0	0	13	Not especially vulnerable – plenty of food, nesting opportunities.
Great Cormorant (breeding)	*Phalacrocorax carbo*	2	2	3	1	33	25	0	0	25	0	
Greater Shearwater	*Puffinus gravis*	2	2	2	1	33	25	0	0	25	0	
Least Tern	*Sterna abutkkarum*	1	3	2	2	33	25	25	0	25	0	
Roseate Tern	*Sterna dougallii*	1	3	2	4	42	19	13	0	31	15	
Common Tern	*Sterna hirundo*	2	2	2	W	33	17	8	0	42	7	Maybe lower rank because more southern sub-species that might adapt to new prey species & nesting habitat.
Arctic Tern	*Sterna paradisaea*	2	3	3	5	40	30	25	0	30	20	
Common Murre	*Uria aalge*	2	3	3	2	33	25	0	0	13	0	
Mean			**2.7**	**2.6**								

SHOREBIRD SPECIES

American Woodcock (*Scolopax minor*) and Wilson's Snipe (*Gallinago gallinago*) were the only two of 16 shorebird SGCN that are not vulnerable to climate change, probably because they almost never depend on marine habitats (Table A20). The remaining shorebirds had medium and high vulnerability because most species use highly specific marine habitats (i.e., mud flats, salt marshes) during migration, 50% of which might be lost by sea level rise due to climate change (Galbraith et al. 2005). Three species also use marine habitats for breeding, which are vulnerable to loss due to sea level rise: Willet (*Catoptrophorus semipalmatus*), Piping Plover (*Charadrius melodus*), and American Oystercatcher (*Haematopus palliates*; Jacobson et al. 2009). Climate change may also increase mortality on wintering grounds by reducing the prey quality and roost site availability (Durell et al. 2006) and extensively reduce arctic breeding habitats by 40-57% (IPCC 2002). Sea level rise may reduce key roosting habitats used in migration (New Hampshire Fish and Game Department 2005).

Table A20. The climate change vulnerability of 16 shorebird SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Spotted Sandpiper	*Actitis macularius*	2	2	?	W							Flooded nests a worry. Should be on "watch list" as possible SGCN in future.
Ruddy Turnstone	*Arenaria interpres*	2	2	2	W	13	2			1		Not high confidence.
Upland Sandpiper	*Bartramia longicauda*	2	2	2	3	12	3			1		
Sanderling	*Calidris alba*	2	2	2	2	13	2			1		
Red Knot	*Calidris canutus*	2	3	2	2	1	24			1		
Purple Sandpiper	*Calidris maritima*	2	2	2	3	13	2			1		
Least Sandpiper	*Calidris minutilla*	2	3	3	W							High marsh habitat likely to decline. Should be on "watch list" as possible SGCN in future.
Semipalmated Sandpiper	*Calidris pusilla*	2	3	2	4	123	23	3		12	2	
Willet	*Catoptrophorus semipalmatus*	2	3	2	4	13	23	23	3	123	24	
Piping Plover	*Charadrius melodus*	1	3	3	6	12	123	23	2	14		
Wilson's Snipe	*Gallinago gallinago*	2	1	2	W		2					Habitat not likely to decline as a result of climate change.
American Oystercatcher	*Haematopus palliatus*	1	3	3	W	13	234	3		1		
Whimbrel	*Numenius phaeopus*	2	2	2	3	13	23	3		1		
Red-necked Phalarope	*Phalaropus fulicaria*	2	3	2	2	13	3			123		
American Woodcock	*Scolopax minor*	2	1	3	3	12	3	34		2		
Greater Yellowlegs	*Tringa melanoleuca*	2	2	2	W	1				1		Not high confidence.
Mean			**2.4**	**2.3**								

WATERBIRD SPECIES

Except for the Cattle Egret (*Bubulcus ibis*), a southern species, all assessed waterbirds had medium or high vulnerability to climate change (Table A21). Waterbirds are vulnerable because they use a narrow range of wetland habitats. Marsh-breeding rails may face an increasingly variable hydrological cycle and water levels where some wetlands dry out in some years and result in smaller clutch sizes, nesting failures, and reduced fecundity (Wormworth and Mallon 2006). Sea level rise and variable rainfall could limit access by herons to coastal feeding areas and result in a wider variation in wader reproduction (Butler and Vennesland 2000). Increased frequency of extreme weather events during the breeding season could result in more frequent nesting failures for colonial species.

Table A21. The climate change vulnerability of 18 waterbird species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Sora	*Porzana carolina*	NA	2	?	W							Flooded nests a worry. Should be on “watch list” as possible SGCN in future.
Virginia Rail	*Rallus limicola*	NA	2	?	W							Flooded nests a worry. Should be on “watch list” as possible SGCN in future.
Great Egret	*Ardea alba*	2	2	2	W		3	4		4	124	Vulnerable to changes in feeding areas and colonies subject to disaster.
Great Blue Heron	*Ardea herodias*	2	2	2	W		3	4		4	124	Vulnerable to changes in feeding areas and colonies subject to disaster.
American Bittern	*Botaurus lentiginosus*	2	2	2	W	12	2	3		1	24	Might be vulnerable to flooding of nests.
Cattle Egret	*Bubulcus ibis*	2	1	2	2		3	4			124	
Yellow Rail	*Coturnicops noveboracensis*	2	3	2	2	2	123	3			24	
Snowy Egret	*Egretta thula*	2	2	2	W		3			4	124	Vulnerable to changes in feeding areas and colonies subject to disaster.
American Coot (breeding)	*Fulica americana*	2	3	1	W	12	3	3			2	Think should be High/3 because of nest habitat plus low population, but not high confidence.
Common Moorhen	*Gallinula chloropus*	2	3	2	2	12	3	3		4	24	
Common Loon	*Gavia immer*	2	3	2	5	12	2	123	1	123	124	
Sandhill Crane	*Grus Canadensis*	2	2	1	W		3				24	Low population, vulnerable to flooding.
Little Blue Heron	*Hydranassa caerulea*	2	2	2	W		3	4		4	124	Vulnerable to changes in feeding areas and colonies subject to disaster.
Tri-colored Heron	*Hydranassa tricolor*	2	2	1	1		3			4	123	

Table A21 (cont.). The climate change vulnerability of 18 waterbird species in Maine.

COMMON NAME	SCIENTIFIC NAME	STATUS	SCORE: VULNERABILITY	SCORE: CONFIDENCE	REVIEWERS (N)	TRAITS SELECTED FOR EACH CATEGORY: HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Least Bittern	*Ixobrychus exilis*	2	3	3	2	2	3	3			24	
Black-crowned Night Heron	*Nycticorax nycticorax*	2	2	2	W		3	4		4	124	Low population, few sites. Feeding areas vulnerable.
Glossy Ibis	*Plegadis falcinellus*	2	2	2	W		3	4			124	Vulnerable to changes in feeding areas and colonies subject to disaster
Pied-billed Grebe	*Podilymbus podiceps*	2	2	3	W	12	3	3		4	234	Might be vulnerable to flooding of nests, but widespread and use open water also
Mean			**2.2**	**1.9**								

WATERFOWL SPECIES

Five of the six waterfowl SGCN had medium or high vulnerability to climate change (Table A22). Only the Harlequin Duck (*Histrionicus histrionicus*) had high vulnerability, as its food supply in winter and nesting habitats might be sensitive to climate change. The medium-vulnerability species were vulnerable because of their high habitat specificity. Only the American Black Duck (*Anas rubripes*) had low vulnerability.

Table A22. The climate change vulnerability of six waterfowl SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
American Black Duck	*Anas rubripes*	2	1	2	W	12		34		134	24	Widespread. Lots conversation about survey results – not sure why some folks rated High/3.
Greater Scaup (non-breeding)	*Aythya marila*	2	2	2	1	3	3					
Barrow's Goldeneye	*Bucephala islandica*	2	2	2	W	1	34	4		1	4	Use lots of places, may have new feeding areas open on rivers in winter.
Harlequin Duck	*Histrionicus histrionicus*	2	3	3	W	13	34	4			5	Food source likely to decline from ocean acidification. Nesting sites vulnerable. Low population #s.
Ruddy Duck	*Oxyura jamaicensis*	2	2	2	W	1	4					
Common Eider	*Somateria mollissima*	2	2	2	W	1	2	12		2	2	Increased spread of disease may occur because they congregate in dense groups. Food may disappear/reduce – key to ranking ! (Those who thought mussels would significantly decline ranked the eiders High/3, whereas those who were less worried about declining mussel ranked Medium/2.
Mean			2.0	2.2								

RAPTOR AND OWL SPECIES

One of the seven raptor and owl SGCN was scored to be vulnerable to climate change: the Golden Eagle (*Aquila chrysaetos*), as climate change may reduce availability of its prey (Table A23). Most of the remaining species are generalists that may be unaffected by climate change.

Table A23. The climate change vulnerability of seven raptors and owl SGCN in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Golden Eagle	*Aquila chrysaetos*	2	2	3	W	1	123			2	4	At very low numbers historically. May be changes in prey availability contributing to further decline.
Short-eared Owl	*Asio flammeus*	1	1	2	W	1	13					Only one nesting pair in Maine. Wintering habitat (saltmarshes, dunes) may decline, but nesting habitat (old fields) not likely to decline as direct result of climate change.
Long-eared Owl	*Asio otus*	2	1	2	W		3					May see increase in Maine as softwood habitat availability decreases to our south.
Peregrine Falcon	*Falco peregrinus*	1	1	2	W	2	3			12	4	Nesting habitats (cliffs & structures) not expected to be affected. May be changes in prey availability , but not expected to be significant.
Bald Eagle	*Haliaeetus leucocephalus*	2	1	3	2		3					
Eastern Screech-Owl	*Megmascops asio*	2	1	2	2			4		4		
Barred Owl	*Strix varia*	2	1	2	3		3					
Mean			1.3	2.3								

WOODPECKER AND OTHER SPECIES

Six of the nine woodpecker and other species had medium or high vulnerability (Table A24). In Maine, three high-vulnerability species are likely to decline due to climate change because they are at the southern edge of their range and restricted to spruce-fir habitats that are likely sensitive to climate change (Rodenhouse et al. 2008): Spruce Grouse (*Falcipennis canadensis*), Black-backed Woodpecker (*Picoides arcticus*), and American Three-toed Woodpecker (*Picoides dorsalis*). The medium-vulnerability species are the Whip-poor-will (*Caprimulgus vociferous*), Chimney Swift (*Chaetura pelagica*), and Common Nighthawk (*Chordeiles minor*), which are long-distance, aerial insectivore migrants and subject to the additive climatic risk experienced in their wintering areas, during migration, and on breeding grounds (Ahola et al. 2004).

Table A24. The climate change vulnerability of seven woodpecker and other SGCN, and other species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Whip-poor-will	*Caprimulgus vociferous*	2	2	3	4	3	3			1	4	
Chimney Swift	*Chaetura pelagica*	2	2	2	3	123		1		12	4	
Common Nighthawk	*Chordeiles minor*	2	2	2	2					12	4	
Black-billed Cuckoo	*Coccyzus erythropthalmus*	2	1	2	3	2						
Northern Flicker	*Colaptes auratus*	2	1	3	4	1	12		2			
Spruce Grouse	*Falcipennis canadensis*	NA	3	3	W	12	12					Closely tied with vulnerable spruce-fir communities.
Black-backed Woodpecker	*Picoides arcticus*	NA	3	3	W	12	123	12	13	2		Closely tied with vulnerable spruce-fir communities.
Am. Three-toed Woodpecker	*Picoides dorsalis*	2	3	3	5	2	2					
Yellow-bellied Sapsucker*	*Sphyrapicus varius*	2	1	3	W	3	3			1	4	
Mean			**1.3**	**2.3**								

PASSERINE SPECIES

Two of the 19 high-vulnerability species, Saltmarsh Sharp-tailed Sparrow (*Ammodramus caudacutus*) and Nelson's Sharp-tailed Sparrow (*Ammodramus nelson*), breed in salt marsh habitats that are likely to be highly impacted by sea level rise (Table A25). A third high-vulnerability species, American Pipit (*Anthus rubescens*), breeds in alpine habitats that may shrink in area with climate change and is at the southern edge of its range in Maine. The 16 other high-vulnerability species breed primarily in boreal habitats, which are expected to recede with climate change (Rodenhouse et al. 2008). The medium-vulnerability species include species that breed in wetland habitats where climate change may increase variation in water levels and may negatively impact their habitats and food supply (e.g., Palm Warbler, *Dendroica palmarum*), or northern species that will experience habitat decline (e.g., Magnolia Warbler, *Dendroica magnolia*; Rodenhouse et al. 2008).

Table A25. The climate change vulnerability of 64 passerine SGCN and other Passerine species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Saltmarsh Sharp-tailed Sparrow	*Ammodramus caudacutus*	1	3	3	4	12	23	3	3	1	2	
Nelson's Sharp-tailed Sparrow	*Ammodramus nelsoni*	2	3	3	3	12	23	3		1	2	
Grasshopper Sparrow	*Ammodramus savannarum*	2	2	3	4	12	13		2			
American Pipit (breeding)	*Anthus rubescens*	2	3	3	7	12	123	12	23	1		
Purple Finch	*Carpodacus purpureus*	NA	2	2	W	3	2			2		Breeds in moist coniferous forests. It is likely to decline with changes in forest composition.
Bicknell's Thrush	*Catharus bicknelli*	1	3	3	7	12	123	12	234	123		
Veery	*Catharus fuscescens*	2	2	2	W		2			12		Nests in damp deciduous habitats. Changes in moisture regime and acidity may impact species.
Hermit Thrush	*Catharus guttatus*	2	1	2	W		0	0	0	0	0	Relative forested habitat generalist.
Swainson's Thrush	*Catharus ustulatus*	NA	3	3	W		2					Closely tied with vulnerable spruce-fir communities.
Marsh Wren	*Cistothorus palustris*	2	1	2	3	1	3	3				
Sedge Wren	*Cistothorus platensis*	1	2	2	4	12	3	34		1	2	
Evening Grosbeak	*Coccothraustes vespertinus*	NA	3	2	2	23	2			2	4	
Olive-sided Flycatcher	*Contopus borealis*	2	2	2	3	3	123	3		1		
Black-throated Blue Warbler	*Dendroica caerulescens*	2	1	2	W	12	2					Breeding habitat is primarily deciduous forest which is not expected to decline.
Bay-breasted Warbler	*Dendroica castanea*	2	2	2	6	1	12			1234	4	
Prairie Warbler	*Dendroica discolor*	2	1	3	4	1	13			1		
Blackburnian Warbler	*Dendroica fusca*	2	2	2	5	2	2			123	2	
Magnolia Warbler	*Dendroica magnolia*	NA	2	2	W		2					Associated with coniferous regeneration. Likely to experience habitat declines.

Table A25 (cont.). The climate change vulnerability of 64 passerine SGCN and other Passerine species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Palm Warbler	*Dendroica palmarum*	NA	2	3	2	1	23					
Chestnut-sided Warbler	*Dendroica pensylvanica*	2	1	2	4	1				1	2	
Blackpoll Warbler	*Dendroica striata*	NA	3	3	2	1	12			1		
Cape May Warbler	*Dendroica tigrina*	2	3	3	4	1	12			14	4	
Black-throated Green Warbler	*Dendroica virens*	2	2	3	W		2			123		Breeding habitat primarily coniferous woods and favorable conditions likely to decline.
Bobolink	*Dolichonyx oryzivorus*	2	2	2	4	12	3			1		
Yellow-bellied Flycatcher	*Empidonax flaviventris*	NA	3	3	W	12	2					Breeds in moist boreal forests and bogs.
Willow Flycatcher	*Empidonax traillii*	2	1	3	2	1						
Horned Lark (breeding)	*Eremophila alpestris*	2	1	2	3	1	1					
Rusty Blackbird	*Euphagus carolinus*	2	2	3	3	1	123	3	2			
Barn Swallow	*Hirundo rustica*	NA	2	2	3	2	3	4		1		
Wood Thrush	*Hylocichla mustelina*	2	2	2	W	1	3		3	12	2	Increased acidity of soil likely to alter prey availablility.
Baltimore Oriole	*Icterus galbula*	2	1	3	2					1		
Loggerhead Shrike (non-breeding)	*Lanius ludovicianus*	2	2	2	W	1	1		1			
Red Crossbill	*Loxia curvirostra*	2	3	2	3	12	12	4		2		
White-winged Crossbill	*Loxia leucoptera*	NA	3	3	W	12	1					Closely tied with vulnerable spruce-fir communities.
Lincoln's Sparrow	*Melospiza lincolnii*	NA	3	3	W		12					Breeds in northern bogs, wet meadows, and riparian thickets. Habitat likely to be impacted by changes in hydrology.
Black and White Warbler	*Mniotilta varia*	2	1	2	3		2				2	
Great-crested Flycatcher	*Myiarchus crinitus*	2	1	2	3	2						
Mourning Warbler	*Oporornis philadelphia*	NA	3	2	W		2			1		Breeds in boreal thickets caused by disturbance. Softwood regeneration maybe a habitat requirement.
Northern Parula	*Parula americana*	2	3	3	2	2	4	1				
Gray Jay	*Perisoreus canadensis*	NA	3	3	W		12			4		Closely tied with vulnerable spruce-fir communities.
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	2	1	3	W		2			1		Relative habitat generalist. Typically found in deciduous dominated forest communities.
Pine Grosbeak	*Pinicola enucleator*	NA	3	3	W	1	123					Spruce-fir dependent species at the southern end of range in Maine.
Eastern Towhee	*Pipilo erythrophthalmus*	2	1	3	W	1	3				2	Declining due to loss of early successional habitat. Habitat not directly impacted by climate change stressors.

Table A25 (cont.). The climate change vulnerability of 64 passerine SGCN and other Passerine species in Maine.

COMMON NAME	SCIENTIFIC NAME	STATUS	SCORE: VULNERABILITY	SCORE: CONFIDENCE	REVIEWERS (N)	TRAITS SELECTED FOR EACH CATEGORY: HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Scarlet Tanager	*Piranga olivacea*	2	1	2	3	1				1		
Boreal Chickadee	*Poecile hudsonicus*	NA	3	3	W	1	12					Closely tied with vulnerable spruce-fir communities.
Blue-gray Gnatcatcher	*Polioptila caerulea*	2	1	3	2							
Vesper Sparrow	*Pooecetes gramineus*	2	2	3	4	12	3					
Purple Martin	*Progne subis*	2	2	2	W	2	3	3		123		Few colonies in Maine and prey abundance already changing.
Ruby-crowned Kinglet	*Regulus calendula*	NA	3	2	W		2					Spruce-fir dependent species at the southern end of range in Maine.
Louisiana Waterthrush	*Seiurus motacilla*	2	1	2	3	1	13	3				
Northern Waterthrush	*Seiurus noveboracensis*	NA	2	2	W		2					Changes to wetland hydrology and wetland communities could result in declines.
Red-breasted Nuthatch	*Sitta canadensis*	NA	1	2	W		2					Currently expanding range southward. Habitat requires conifer, but does not specialize on any one species.
Field Sparrow	*Spizella pusilla*	2	1	3	3	1	3					
Eastern Meadowlark	*Sturnella magna*	2	2	3	4	1	3					
Brown Thrasher	*Toxostoma rufum*	2	1	3	4	1	3				2	
Winter Wren	*Troglodytes troglodytes*	NA	1	2	W		2					Relative forested habitat generalist.
Eastern Kingbird	*Tyrannus tyrannus*	2	1	2	W	3				1	4	May be changes in prey abundance, but open habitat conditions not expected to decline as direct result of climate change.
Tennessee Warbler	*Vermivora peregrina*	NA	3	2	W		2					Closely tied to spruce budworm outbreaks.
Blue-winged Warbler	*Vermivora pinus*	1	2	3	2	1	13					
Nashville Warbler	*Vermivora ruficapilla*	NA	1	2	W		2					Relative forested habitat generalist.
Yellow-throated Vireo	*Vireo flavifrons*	2	1	2	W	13	3					Currently at northern end of range in Maine. Favored habitat conditions likely to increase.
Blue-headed Vireo	*Vireo solitarius*	NA	1	3	W	2	23	3		1		Relative habitat generalist. Typically found in deciduous dominated forest communities.
Canada Warbler	*Wilsonia canadensis*	2	2	2	W		2					Dependent on forested wetlands with dense coniferous understory. Likely to be negatively affected by changes in forest composition and wetland hydrology.
White-throated Sparrow	*Zonotrichia albicollis*	NA	2	1	W	12	3					At southern end of breeding range where changes in coniferous component of forest regeneration could impact success.
Mean			**1.9**	**2.4**								

A8. Mammalian Species

SMALL MAMMAL AND BAT SPECIES

Only one of the five small mammal and bat species from this assessment was vulnerable to climate change: Northern Bog Lemming (*Synaptomys borealis*; Table A26). This species may be vulnerable because it is at the southern edge of its range in Maine, has limited dispersal and migration capacity, and may require moderated microclimates. Although some of remaining species may have narrow habitat requirements, they have wide distributions that might buffer climate change impacts.

Table A26. The climate change vulnerability of five small mammal and bat species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Penobscot Meadow Vole	*Microtus pennsylvanicus shattucki*	1	1	3	W	13			1			Habitat loss may occur due to sea level rise.
Eastern Small-footed Myotis	*Myotis leibii*	2	1	2	W	12				1	14	Uncertain as to whether emergence of white-nose syndrome related to climate change or other factors.
New England Cottontail	*Sylvilagus transitionalis*	1	1	3	W	123	3		12		2	
Northern Bog Lemming	*Synaptomys borealis*	2	3	3	W	1	123	13	12	123	2	Northern spp.
Red squirrel	*Tamimasciurus hudsonicus*	NA	1	1	W							Absent from mid-Atlantic states at low elevations; sensitive to a reduction in coniferous forest?
Mean			1.4	2.4								

MEDIUM AND LARGE MAMMAL SPECIES

Four of the 11 large mammals in this assessment have a high vulnerability to climate change and are northern species at or near the edge of their range: Eastern Moose (*Alces alces americana*), Snowshoe hare (*Lepus americanus*), Canada Lynx (*Lynx canadensis*), and American Marten (*Martes americana*) (Table A27). Moose may be vulnerable to outbreaks of moose ticks (*Dermacentor albipictus*) that survive mild winters well and can cause stressful hair loss and increased calf mortality (Murray et al. 2005). Climate change will reduce the deep snow that helps keep competing species with Canada Lynx (Bobcat) and American Marten (Fisher) out of their core range in Maine (Jacobson et al. 2009). Five mammals were added at the workshop: Beaver (*Castor canadensis*), Otter (*Lutra canadensis*), Fisher (*Martes pennanti*), Mink (*Mustela vison*), and Muskrat (*Ondatra zibethicus*). However, only one, the Fisher, was scored to be vulnerable to climate change (Table A27). The other added species are wetland species whose populations might be affected by climate change impacts on hydrological regimes.

Table A27. The climate change vulnerability of medium and large mammal species in Maine.

			SCORE			TRAITS SELECTED FOR EACH CATEGORY						
COMMON NAME	SCIENTIFIC NAME	STATUS	VULNERABILITY	CONFIDENCE	REVIEWERS (N)	HAB. SPECIFICITY	EDGE OF RANGE	TOLERANCE	MOBILITY	DEPENDENCE	EXOTIC	COMMENTS
Beaver	*Castor canadensis*	NA	1	2	W							Reduced summer low stream flows may reduce populations.
Otter	*Lutra canadensis*	NA	1	2	W							Reduced summer low stream flows may reduce populations.
Fisher	*Martes pennanti*	NA	2	1	W							Absent from mid-Atlantic states so may decline under extreme emission scenarios.
Mink	*Mustela vison*	NA	1	2	W							Reduced summer low stream flows may reduce populations.
Muskrat	*Ondatra zibethicus*	NA	1	2	W							Reduced summer low stream flows may reduce populations.
Eastern Moose	*Alces alces americana*	NA	3	3	W	3	12	12		3	1	
Wolf	*Canis lupus*	2	1	3	W	-	-	-	-	3	-	
Snowshoe hare	*Lepus americanus*	NA	3	3	W	12	24	4	1	13	-	
Canada Lynx	*Lynx canadensis*	2	3	3	W	12	1234	34	-	23	12	
Bobcat	*Lynx rufus*	NA	1	3	W	23	1234	4	2	23	-	
American marten	*Martes americana*	NA	3	3	W	3	12	12	-	3	1	
Mean			1.8	2.5								

Appendix B: List of Species with High Vulnerability to Climate Change

B1. Introduction

The lists of high vulnerability species are summarized in a narrative and table for each group: wetland plant species, upland plant species, invertebrate species, and vertebrate species. The narrative explains broad themes regarding vulnerability. It avoids describing species-level vulnerability because this would require an individual account for each species. Each species group table includes the following:

- **Status:** State rank for state-listed Threatened and Endangered plant species (S1 or S2; Maine Natural Areas Program 2012) or wildlife species (SGCN, priority rank 1 or 2; Maine Department of Inland Fisheries and Wildlife 2005). NA indicates not applicable for species added to this effort, as they lacked state-level designation.
- **Confidence scores:** 1 = not very confident (0-30% certainty in species vulnerability scores); 2 = somewhat confident (>30-70% certainty in species vulnerability scores); or 3 = very confident (>70% certainty in species vulnerability scores) (based on final scores from Step 3).
- **Reviewer (n):** The total number of reviewers from all steps. W = reviewed in a workshop breakout group by at least five people.
- **Comments:** Comments regarding species vulnerability were recorded for some species groups by species breakout groups in the workshop (Step 2). Additional comments can be found in the report of survey results and species scores (Whitman et al. 2013). Some expert panels at the workshop did not record comments about vulnerability for each species.

B2. Fungi and Lichen Species

Ten fungi and lichen species had high vulnerability to climate change because their host tree species were vulnerable to climate change (Table B1). Fungi and lichen species are not currently state-listed in Maine. Two species had high confidence scores and were boreal species. None of the species had more than two reviewers and so merit further investigation before considering a possible state listing.

Table B1. A list of 10 high-vulnerability fungi and lichen species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Witch's Hair (a lichen)	*Alectoria sarmentosa*	NA	2	1	Host species vulnerable to CC (spruce and fir).
Smooth gray horsehair lichen	*Bryoria capillaris*	NA	2	2	Host species vulnerable to CC (spruce and fir).
Unnamed shelf fungus	*Fomitopsis cajanderi*	NA	2	2	Host species vulnerable to CC (spruce).
Red Banded Polypore Fungus	*Fomitopsis pinicola*	NA	2	2	Host species vulnerable to CC (spruce and fir).
Foliose Shingle Lichen	*Fuscopannaria ahlneri*	NA	2	1	Host species vulnerable to CC (spruce and fir).
Hemlock varnish shelf fungi	*Ganoderma tsugae*	NA	2	2	Host species vulnerable to CC (hemlock).
Powder-headed tube lichen	*Hypogymnia tubulosa*	NA	2	1	Host species vulnerable to CC (spruce and fir).
Powdery axil-bristle lichen	*Menegazzia terebrata*	NA	3	1	Host species vulnerable to CC (cedar), boreal.
Birch Polypore	*Piptoporus betulinus*	NA	2	2	Host species vulnerable to CC (birch spp.).
Methuselah's beard lichen	*Usnea longissima*	NA	3	2	Host species vulnerable to CC (spruce and fir), boreal.

B3. Wetland Plant Species

Thirty-seven wetland plant species were ranked as being highly vulnerable to climate change (Table B2). Twenty-five species are S1 species and thus already have an elevated conservation status. Twelve species were S2 species and may have greater vulnerability than formerly noted. Showy Lady's-slipper (*Cypripedium reginae*) was added to the assessment and so may merit review for elevating its conservation status because of its vulnerability to climate change. Reviewers indicated that they had high confidence in their vulnerability scores for 22 species. Thirty species only had one or two reviewers and so likely merit further review of their climate change vulnerability before changing their conservation status. Seven species had three or more reviewers and this provides a modest confidence that these seven species have high vulnerability, especially the three species that were reviewed at the workshop.

Table B2. A list of 37 high-vulnerability wetland, state-listed Threatened or Endangered plant species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Aquatic Species					
Prototype Quillwort	*Isoetes prototypus*	S1	2	2	
Slender Rush	*Juncus subtilis*	S1	2	2	
Pygmy Water-lily	*Nymphaea leibergii*	S1S2	2	2	
Small Yellow Water Crowfoot	*Ranunculus gmelinii var. purshii*	S2	2.5	2	
Slender Pondweed	*Stuckenia filiformis ssp. occidentalis*	S1	2	3	
Calcareous Fens and Swamps					
Small Round-leaved Orchis	*Amerorchis rotundifolia*	S2	3	3	
Prairie Sedge	*Carex prairea*	S1	3	W	Habitat extremely limited.
Showy Lady's-slipper	*Cypripedium reginae*	S3	3	4	Added species.
English Sundew	*Drosera anglica*	S1	3	2	
Slender-leaved Sundew	*Drosera linearis*	S1	3	2	
Prairie White-fringed Orchid	*Platanthera leucophaea*	S1	3	2	
Lapland Buttercup	*Ranunculus lapponicus*	S2	3	2	
Hoary Willow	*Salix candida*	S1	3	3	
Low Spike-moss	*Selaginella selaginoides*	S1	3	2	
Coastal Wetlands					
Nova Scotia False-foxglove	*Agalinis neoscotica*	S1	2	2	
Long's Bitter-cress	*Cardamine longii*	S2	2	2	
Saltmarsh sedge	*Carex vacillans*	S2	2	2	
Lilaeopsis	*Lilaeopsis chinensis*	S2	2	2	
Marsh Felwort	*Lomatogonium rotatum*	S1	2	2	
Beach Plum	*Prunus maritima*	S1	3	1	

Table B2 (cont.). A list of 37 high-vulnerability wetland, state-listed Threatened or Endangered plant species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Northern River Shores					
Cut-leaved Anemone	*Anemone multifida*	S1	3	2	
Neglected Reed-grass	*Calamagrostis stricta ssp. stricta*	S2	3	2	
Northern Gentian	*Gentianella amarella ssp. acuta*	S1	3	2	
Robinson's Hawkweed	*Hieracium robinsonii*	S1	2	2	
St John Oxytrope	*Oxytropis campestris var. johannensis*	S1	3	2	
Furbish's Lousewort	*Pedicularis furbishiae*	S2	3	2	
Mountain Timothy	*Phleum alpinum*	S2	3	2	
Horned Beak-rush	*Rhynchospora capillacea*	S1	3	2	
Blue-leaf Willow	*Salix myricoides*	S2	3	2	
Canada Buffaloberry	*Shepherdia canadensis*	S1	2	2	
Anticosti Aster	*Symphyotrichum anticostense*	S1	3	2	
Other Freshwater Wetlands					
Tundra Dwarf Birch	*Betula glandulosa*	S1	2	2	
Moonwort	*Botrychium lunaria*	S1	3	W	Does not occur south of here.
Long-tubercled Spike-rush	*Eleocharis tuberculosa*	S1	2	2	
Auricled Twayblade	*Listera auriculata*	S2	3	2	
White Adder's-mouth	*Malaxis monophyllos*	S1	3	W	Rare throughout New England.
Jacobs Ladder	*Polemonium vanbruntiae*	S1	2	2	

B4. Upland Plant Species

Fifty-two upland plant species were ranked as being highly vulnerable to climate change (Table A3.4). Forty-six species are S1 species and thus already have an elevated conservation status. Five species were S2 species and may have greater vulnerability than formerly noted. One species, Kidneyleaf Violet (*Viola renifolia*), is not a state-listed Threatened or Endangered plant species but may merit further consideration for elevating its conservation status in the future. Reviewers indicated that they had high confidence in their vulnerable scores for eighteen species. Thirty-six species only had one or two reviewers and so likely merit further review of their climate change vulnerability before changing their conservation status. Fifteen species had three or more reviewers and this provides a modest confidence that these species have high vulnerability, especially the 10 species that were reviewed at the workshop.

Table B3. A list of 52 high-vulnerability upland plant species. All but one species (*Viola renifolia*) is a state-listed Threatened or Endangered plant species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Alpine Species					
Boreal Bentgrass	*Agrostis mertensii*	S2	3	W	Wide range, restricted habitat.
Alpine Bearberry	*Arctostaphylos alpine*	S1	2	4	
Hairy Arnica	*Arnica lanceolata*	S2	3	2	
Dwarf White Birch	*Betula x minor*	S1	2	W	Restricted open habitat, small pop. size.
Alpine Bitter-cress	*Cardamine bellidifolia*	S1	2	2	
Bigelow's Sedge	*Carex bigelowii*	S2	2	2	
Russett Sedge	*Carex saxatilis*	S1	1	2	
Alpine Willow-herb	*Epilobium anagallidifolium*	S1	3	2	
Hornemann's Willow-herb	*Epilobium hornemannii*	S1	2	2	
Oakes' Eyebright	*Euphrasia oakesii*	S1	2	2	
Arctic Red Fescue	*Festuca prolifera*	S1	2	2	
Moss Bell-heather	*Harrimanella hypnoides*	S1	2	3	
Alpine Clubmoss	*Huperzia selago*	S2	2	2	
Alpine Azalea	*Loiseleuria procumbens*	S1	3	2	
Northern Wood-rush	*Luzula confuse*	S1	2	2	
Spiked Wood-rush	*Luzula spicata*	S1	2	2	
Silverling	*Paronychia argyrocoma*	S1	2	W	
Alpine Bistort	*Persicaria vivipara*	S1	2	2	
Mountain Heath	*Phyllodoce caerulea*	S1	2	2	
Wavy Bluegrass	*Poa fernaldiana*	S1	3	W	Restricted open habitat, small pop. size
Boott's Rattlesnake Root	*Prenanthes boottii*	S1	2	2	
Dwarf Rattlesnake Root	*Prenanthes nana*	S1	2	W	Restricted open habitat, small pop. size
Lapland Rosebay	*Rhododendron lapponicum*	S1	3	2	
Arctic Willow	*Salix arctophila*	S1	2	2	
Dwarf Willow	*Salix herbacea*	S1	2	2	

Table B3 (cont.). A list of 52 high-vulnerability upland plant species. All but one species (*Viola renifolia*) is a state-listed Threatened or Endangered plant species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Tea-leaved Willow	*Salix planifolia*	S1	2	2	
Bearberry Willow	*Salix uva-ursi*	S1	3	2	
Star Saxifrage	*Saxifraga foliolosa*	S1	2	2	
Cutler's Goldenrod	*Solidago multiradiata var. arctica*	S1	2	2	
Mountain Hairgrass	*Vahlodea atropurpurea*	S1	2	W	Restricted open habitat, small pop. size.
Alpine Speedwell	*Veronica wormskjoldii*	S1	3	W	Restricted open habitat, small pop. size.
Alpine Marsh Violet	*Viola palustris*	S1	2	2	
Barrens/Disturbed Ground Species					
Variable Sedge	*Carex polymorpha*	S1	2	W	Wide range, populations are isolated and fragmented.
Central and Northern Maine Uplands Species					
Aleutian Maidenhair Fern	*Adiantum aleuticum*	S1	3	2	
Green Spleenwort	*Asplenium trichomanes-ramosum*	S1	2	2	
New England Northern Reed Grass	*Calamagrostis stricta ssp. inexpansa*	S1	3	2	
Intermediate Sedge	*Carex norvegica ssp. inferalpina*	S1	3	W	Rare throughout New England.
Northern Wild Comfrey	*Cynoglossum virginianum var. boreale*	S1	2	2	
Ram's-head Lady's-slipper	*Cypripedium arietinum*	S1	2	2	
Squirrel-corn	*Dicentra canadensis*	S1	2	2	
Rock Whitlow-grass	*Draba arabisans*	S1	3	2	
Lance-leaved Draba	*Draba cana*	S1	3	2	
Male Fern	*Dryopteris filix-mas*	S1	2	2	
Boreal Bedstraw	*Galium kamtschaticum*	S2	3	4	
Giant Rattlesnake-plantain	*Goodyera oblongifolia*	S1	3	4	
Northern Stickseed	*Hackelia deflexa var. americana*	S1	3	W	Rare throughout New England.
Arctic Sandwort	*Minuartia rubella*	S1	3	2	
Common Butterwort	*Pinguicula vulgaris*	S1	3	3	
White Bluegrass	*Poa glauca*	S1	2	2	
Canada Burnet	*Sanguisorba canadensis*	S1	2	2	
Kidneyleaf violet	*Viola renifolia*	NA	2	2	
Smooth Woodsia	*Woodsia glabella*	S1	3	2	

B5. Invertebrate Species

Fourteen invertebrate species were ranked as being highly vulnerable to climate change (Table B4). Three species are Priority 1 species (Status = 1) and thus already have an elevated conservation status. Nine species were Priority 2 species (Status = 2) and may have greater vulnerability than formerly noted. Two species, the Salt Marsh Tiger Beetle (*Cicindela marginata*) and the Northern Blue (a moth, *Lycaeides idas scudderii*) are not SGCN but may merit further consideration for elevating their conservation status in the future because of their rarity and vulnerability to climate change. Reviewers indicated that they had high confidence in their vulnerable scores for four species. Only two species had only one reviewer and so likely merit further review of their climate change vulnerability before considering a change in their conservation status due to their climate change vulnerability. The remaining 11 species were reviewed by a panel of experts at the workshop, yet the confidence score of the panel was moderate because so little is known about the biology and distribution of many of these rare species. Many of these high-vulnerability invertebrate species reached their southern range limits in Maine; are associated with cold-water, peatland, or alpine habitats; or are affected by sea level rise.

Table B4. A list of 14 high-vulnerability invertebrate species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Aquatic Insects					
A Mayfly	*Baetisca rubescens*	2	2	W	Restricted to cold, high elevations streams; this is a northern species, with only a few other U.S. and Canadian records (NH, VT, Newfoundland, Labrador); species has not been found in other potentially suitable habitats.
Roaring Brook Mayfly	*Epeorus frisoni*	1	2	W	Restricted to cold, high elevation headwater streams in relatively undisturbed mixed forest habitats along the Northern Appalachian Mtn range; may be New England's only endemic mayfly; much of life history is unknown; currently known from ~8 sites.
A Stonefly	*Neoperla mainensis*	2	1	W	In Maine, known from a single historic (1944) record from Kennebec Co. (specific location unknown?); is globally rare (G2G3), with few other EOs documented (OH, IL (SX), ON).
Tomah Mayfly	*Siphlonisca aerodromia*	1	2	W	Early spring cycle of flooding sedge from snowmelt followed by receding water levels is critical to growth and development of larval stage; >90% of all extant global occurrences are found in Maine's Northern climate division; does not occur in many potential streams.
Beetles					
Salt Marsh Tiger Beetle	Cicindela marginata	NA	3	W	Sea level rise; coastal hardening; only a few locations.
Damselflies and Dragonflies					
Sedge Darner	*Aeshna juncea*	2	2	1	Southern range edge; specialist of northern fens; only known from one locale.
Canada Whiteface	*Leucorrhinia patricia*	2	2	W	Southern range edge; specialist of peatlands with secondary pools.
Quebec Emerald	*Somatochlora brevicincta*	2	2	1	Southern range edge; specialist of peatlands with secondary pools.

Table B4 (cont.). A list of 14 high-vulnerability invertebrate species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Moths and Butterflies					
Purple Lesser Fritillary	*Boloria chariclea grandis*	2	3	W	
Frigga Fritillary	*Boloria frigga*	2	2	W	Northern peatlands at risk; extreme southern edge of range; only one location.
Northern Blue	*Lycaeides idas scudderii*	NA	2	W	Boreal forest at high risk but potentially less specialized than B.c.grandis; only one location.
Katahdin Arctic	*Oeneis polixenes katahdin*	1	3	W	Tundra habitat at high risk; only one location.
Snails and Mussels					
Brook Floater	*Alasmidonta varicosa*	2	3	W	Species relies primarily on cold-water fish species as host; low mobility and may be vulnerable to changes in hydrology, low summer water levels?; species has declined throughout range and Maine hosts 75% of best remaining populations, most in Northern climate.
Six-whorl Vertigo	*Vertigo morsei*	2	2	W	Only one locality from calcareous fen; southern range edge.

B6. Vertebrate Species

Fifty-five vertebrate species were ranked as being highly vulnerable to climate change (Table B5). Eleven species are Priority 1 species (Status = 1) and thus already have an elevated conservation status. Twenty-seven species were Priority 2 species (Status = 2) and may have greater vulnerability than formerly noted. Sixteen species are not SGCN but may merit further consideration for elevating their conservation status in the future because of their vulnerability to climate change. Reviewers indicated that they had high confidence in their vulnerable scores for 25 species. Twenty species only had one or two reviewers and so likely merit further review of their climate change vulnerability before considering a change in their conservation status due to their climate change vulnerability. Forty-five species had three or more reviewers and this provides a modest confidence that these species have high vulnerability, especially the 30 species that were reviewed at the workshop. Many of these high-vulnerability species reached their southern range limits in Maine, are associated with cold-water or boreal habitats, are wetland species vulnerable to fluctuating water levels, or marine species affected by sea level rise or changes in marine food webs.

Table B5. A list of 55 high-vulnerability vertebrate species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Inland Fish Species					
Lake Whitefish	*Coregonus clupeaformis*	1	3	W	Southern edge of range, cold-water dependent, riverine spawning.
Rainbow Smelt	*Osmerus mordax*	2	2	W	Cold water dependent; historical latitudinal range has already been reduced a considerable amount, possibly due to poor water quality in spawning habitat. Spawns in small tributaries that could be impacted by CC.
Round Whitefish	*Prosopium cylindraceum*	2	3	W	Southern edge of range, cold-water dependent.
Landlocked Salmon	*Salmo salar sebago*	2	2	W	Why wouldn't this get same rating as lake trout? May be lost from smaller, marginal habitats (highly managed situations in the first place) Native pops only occur in very large, cold lakes and will likely persist.
Arctic Charr	*Salvelinus alpinus oquassa*	1	2	W	Very rare, cold-water dependent and occurs in smaller lakes more likely to lose that habitat.
Diadromous Fish Species					
Atlantic Salmon	*Salmo salar*	1	3	W	Southern limit of range, cold-water dependent and mobility/habitat restricted by dams.
Amphibian and Reptile Species					
Blanding's Turtle	*Emydoidea blandingii*	1	1	W	Long hydroperiod VPs and swamps may be at risk; potential increased secondary stress due to more development & road traffic from climate-driven human immigration.
Mink Frog	*Lithobates septentrionalis*	2	2	W	Southern edge of range; mostly aquatic cold-water specialist. Received workshop discussion.
Seabird Species					
Razorbill	*Alca torda*	2	3	3	
Black Tern	*Chlidonias niger*	1	3	W	Very vulnerable to flooding, along with low # sites, low population.
Atlantic Puffin	*Fratercula arctica*	2	3	4	
Least Tern	*Sterna abutkkarum*	1	2	2	

Table B5 (cont.). A list of 55 high-vulnerability vertebrate species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Roseate Tern	*Sterna dougallii*	1	2	4	
Arctic Tern	*Sterna paradisaea*	2	3	5	
Common Murre	*Uria aalge*	2	3	2	
Waterbird Species					
Yellow Rail	*Coturnicops noveboracensis*	2	2	2	
American Coot (breeding)	*Fulica americana*	2	1	W	Think should be H because of where nest plus low population, but not high confidence.
Common Moorhen	*Gallinula chloropus*	2	2	2	
Common Loon	*Gavia immer*	2	2	5	
Least Bittern	*Ixobrychus exilis*	2	3	2	
Waterfowl Species					
Harlequin Duck	*Histrionicus histrionicus*	2	3	W	Food source likely to decline from ocean acidification. Nesting sites vulnerable. Low population #s.
Shorebird Species					
Red Knot	*Calidris canutus*	2	2	2	
Least Sandpiper	*Calidris minutilla*	2	3	W	High marsh habitat likely to decline. Should be on “watch list” as possible SGCN in future.
Semipalmated Sandpiper	*Calidris pusilla*	2	2	4	
Willet	*Catoptrophorus semipalmatus*	2	2	4	
Piping Plover	*Charadrius melodus*	1	3	6	
American Oystercatcher	*Haematopus palliatus*	1	3	W	
Red-necked Phalarope	*Phalaropus fulicaria*	2	2	2	
Woodpecker and Other Species					
Spruce Grouse	*Falcipennis canadensis*	NA	3	W	Closely tied with vulnerable spruce-fir communities.
Black-backed Woodpecker	*Picoides arcticus*	NA	3	W	Closely tied with vulnerable spruce-fir communities.
Am. Three-toed Woodpecker	*Picoides dorsalis*	2	3	5	
Passerine Species					
Saltmarsh Sharp-tailed Sparrow	*Ammodramus caudacutus*	1	3	4	
Nelson’s Sharp-tailed Sparrow	*Ammodramus nelsoni*	2	3	3	
American Pipit (breeding)	*Anthus rubescens*	2	3	7	
Bicknell’s Thrush	*Catharus bicknelli*	1	3	7	
Swainson’s Thrush	*Catharus ustulatus*	NA	3	W	Closely tied with vulnerable spruce-fir communities.
Evening Grosbeak	*Coccothraustes vespertinus*	NA	2	2	
Blackpoll Warbler	*Dendroica striata*	NA	3	2	
Cape May Warbler	*Dendroica tigrina*	2	3	4	

Table B5. A list of 54 high-vulnerability vertebrate species.

COMMON NAME	SCIENTIFIC NAME	STATUS	CONFIDENCE	REVIEWERS (N)	COMMENTS
Yellow-bellied Flycatcher	*Empidonax flaviventris*	NA	3	W	Breeds in moist boreal forests and bogs
Red Crossbill	*Loxia curvirostra*	2	2	3	
White-winged Crossbill	*Loxia leucoptera*	NA	3	W	Closely tied with vulnerable spruce-fir communities
Lincoln's Sparrow	*Melospiza lincolnii*	NA	3	W	Breeds in northern bogs, wet meadows, and riparian thickets. Habitat likely to be impacted by changes in hydrology
Mourning Warbler	*Oporornis philadelphia*	NA	2	W	Breeds in boreal thickets caused by disturbance. Softwood regeneration maybe a habitat requirement
Northern Parula	*Parula americana*	2	3	2	
Gray Jay	*Perisoreus canadensis*	NA	3	W	Closely tied with vulnerable spruce-fir communities
Pine Grosbeak	*Pinicola enucleator*	NA	3	W	Spruce-fir dependent species at the southern end of range in Maine
Boreal Chickadee	*Poecile hudsonicus*	NA	3	W	Closely tied with vulnerable spruce-fir communities
Ruby-crowned Kinglet	*Regulus calendula*	NA	2	W	Spruce-fir dependent species at the southern end of range in Maine
Tennessee Warbler	*Vermivora peregrina*	NA	2	W	Closely tied to spruce budworm outbreaks
Small Mammal and Bat Species					
Northern Bog Lemming	*Synaptomys borealis*	2	3	W	Northern spp.
Medium and Large Mammal Species					
Eastern Moose	*Alces alces americana*	NA	3	W	
Snowshoe hare	*Lepus americanus*	NA	3	W	
Canada Lynx	*Lynx canadensis*	2	3	W	
American marten	*Martes americana*	NA	3	W	

Appendix C. The Vulnerability of Coarse- to Fine-Scale Habitats in Maine

Table C1. The vulnerability of ecological system or system group, ME CWCS Key Habitats, plant habitat groups (from section titled *Vulnerability of State-listed Threatened or Endnagered Plant Species by Major Habitat*), and ME CWCS habitat sub-types in Maine. Vulnerability scores for Ecological Systems or Groups were from Manomet and National Wildlife Federation (2012). Vulnerability scores for CWCS Habitat Sub-type were identified by participants in the May 2010 workshop. They also identified which key factors were considered.

Appendix C. The Vulnerability of Coarse- to Fine-Scale Habitats in Maine.

ECOLOGICAL SYSTEM OR SYSTEM GROUP		ME CWCS KEY HABITAT				PLANT HABITAT GROUP			ME CWCS HABITAT SUB-TYPE		
ECOLOGICAL SYSTEM OR GROUP	VULNERABILITY	KEY HABITAT	EXPOSURE1	SPECIES WITH MEDIUM OR HIGH VULNERABILITY (%)	SPECIES WITH HIGH VULNERABILITY (%)	PLANT HABITAT GROUP	SPECIES WITH MEDIUM OR HIGH VULNERABILITY (%)	SPECIES WITH HIGH VULNERABILITY (%)	CWCS HABITAT SUB-TYPE	VULNERABILITY	KEY FACTORS CONSIDERED
Appalachian - Acadian Alpine Tundra	*HV*	Alpine	*H*	98	89	Alpine	100	91	Alpine Bog	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Alpine Snowbank	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Heath Alpine Ridge	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Alpine Snowbank	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Alpine Cliff	*M*	Increased temperature, reduced snowfall, changes in soil moisture
Boreal - Laurentian Acidic Fen	*HV*	Peatlands	*H*	91	51	Other FW Wetlands	86	29	Fens	*H*	Dependent of specific hydrology and nutrient regimes
North Central Interior Acidic Peatland	*HV*										
Boreal - Laurentian Bog	*HV*								Bogs	*M*	
Appalachian - Acadian Montane Spruce-Fir Forest	*V*	Mountaintop Forest	*H*	78	64	Central and Northern Uplands	87	45	Subalpine Fir Forest	*M*	Increased temperature, reduced soil moisture
									Upland Spruce - Fir	*M*	Budworm outbreaks, changes in species distribution
Laurentian - Acadian Northern Hardwood Forest	*V*	Deciduous & Mixed Forest	*M*	63	20				Northern Hardwood	*M*	Change in composition likely
									Northern Mixed Wood	*M*	Change in composition likely
									Aspen - Birch	*M*	At southern limits of range
Aquatic Systems (Multiple)	*V (2)*	Rivers and Streams	*H*	51	34	Aquatic	90	50	Snowpack Dominated Systems	*H*	Decreased snowfall, seasonal drying
									Low Order/Low Gradient	*M*	Marginally cold-water systems vulnerable to temperature increases
									High Order Floodplain Riverine Systems	*M*	Changes to duration and frequency of flooding
									High Order Hydro Pulse Riverine Systems	*L*	
									Low Order / High Gradient	*L*	
		FW Lakes and Ponds	*H*	62	21				Unstratified Ponds/High Elevation	*H*	Increased temperature, reduced ice cover
									Stratified Ponds	*M*	Temperature increase resulting from loss of thermocline
									Unstratified Ponds/Low Elevation	*L*	
Appalachian - Acadian Alpine Tundra	*HV*	Alpine	*H*	98	89	Alpine	100	91	Alpine Bog	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Alpine Snowbank	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Heath Alpine Ridge	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Alpine Snowbank	*H*	Increased temperature, reduced snowfall, changes in soil moisture
									Alpine Cliff	*M*	Increased temperature, reduced snowfall, changes in soil moisture

Appendix C. The Vulnerability of Coarse- to Fine-Scale Habitats in Maine.

ECOLOGICAL SYSTEM OR SYSTEM GROUP		ME CWCS KEY HABITAT				PLANT HABITAT GROUP			ME CWCS HABITAT SUB-TYPE		
ECOLOGICAL SYSTEM OR GROUP	VULNERABILITY	KEY HABITAT	EXPOSURE1	SPECIES WITH MEDIUM OR HIGH VULNERABILITY (%)	SPECIES WITH HIGH VULNERABILITY (%)	PLANT HABITAT GROUP	SPECIES WITH MEDIUM OR HIGH VULNERABILITY (%)	SPECIES WITH HIGH VULNERABILITY (%)	CWCS HABITAT SUB-TYPE	VULNERABILITY	KEY FACTORS CONSIDERED
Boreal - Laurentian Acidic Fen	*HV*	Peatlands	*H*	91	51	Other FW Wetlands	86	29	Fens	*H*	Dependent of specific hydrology and nutrient regimes
North Central Interior Acidic Peatland	*HV*										
Boreal - Laurentian Bog	*HV*								Bogs	*M*	
Appalachian - Acadian Montane Spruce-Fir Forest	*V*	Mountaintop Forest	*H*	78	64	Central and Northern Uplands	87	45	Subalpine Fir Forest	*M*	Increased temperature, reduced soil moisture
									Upland Spruce - Fir	*M*	Budworm outbreaks, changes in species distribution
Laurentian - Acadian Northern Hardwood Forest	*V*	Deciduous & Mixed Forest	*M*	63	20				Northern Hardwood	*M*	Change in composition likely
									Northern Mixed Wood	*M*	Change in composition likely
									Aspen - Birch	*M*	At southern limits of range
Aquatic Systems (Multiple)	*V (2)*	Rivers and Streams	*H*	51	34	Aquatic	90	50	Snowpack Dominated Systems	*H*	Decreased snowfall, seasonal drying
									Low Order/Low Gradient	*M*	Marginally cold-water systems vulnerable to temperature increases
									High Order Floodplain Riverine Systems	*M*	Changes to duration and frequency of flooding
									High Order Hydro Pulse Riverine Systems	*L*	
									Low Order / High Gradient	*L*	
		FW Lakes and Ponds	*H*	62	21				Unstratified Ponds/High Elevation	*H*	Increased temperature, reduced ice cover
									Stratified Ponds	*M*	Temperature increase resulting from loss of thermocline
									Unstratified Ponds/Low Elevation	*L*	
Coastal Estuaries and Bays (Multiple)	*V(2)*	Marine Open Water	*H*	50	45	Coastal Wetlands	93	33	Open Bays	*L*	
		Estuaries and Bays	*M*	65	26						
		Estuarine Emergent Saltmarsh	*H*	50	33				Tidal Marsh	*H*	Sea level rise and need for migration inland
		Rocky Coastline and Island	*M*	55	35				Rocky Intertidal	*L*	
									Islands	*M*	
		Unconsolidated Shore	*H*	58	34				Beaches and Dunes	*H*	Sea level rise and need for migration inland
									Mudflats	*H*	Sea level rise and need for migration inland, decreased exposure

Appendix C. The Vulnerability of Coarse- to Fine-Scale Habitats in Maine.

ECOLOGICAL SYSTEM OR SYSTEM GROUP		ME CWCS KEY HABITAT				PLANT HABITAT GROUP			ME CWCS HABITAT SUB-TYPE		
ECOLOGICAL SYSTEM OR GROUP	VULNERABILITY	KEY HABITAT	EXPOSURE1	SPECIES WITH MEDIUM OR HIGH VULNERABILITY (%)	SPECIES WITH HIGH VULNERABILITY (%)	PLANT HABITAT GROUP	SPECIES WITH MEDIUM OR HIGH VULNERABILITY (%)	SPECIES WITH HIGH VULNERABILITY (%)	CWCS HABITAT SUB-TYPE	VULNERABILITY	KEY FACTORS CONSIDERED
Laurentian - Acadian Freshwater Marsh	*V*	Emergent Marsh & Wet Meadows	*M*	76	25	Other Fresh Water Wetlands	86	29			
Laurentian - Acadian Shrub Swamp	*V*	Shrub-scrub Wetland	*M*	69	18						
North Atlantic Coastal Plain Peat Swamp	*LV*	Forested Wetland	*M*	72	26						
Northern Atlantic Coastal Plain Heathland and Grassland	*NA*	Grasslands/Old Fields	*L*	40	6	Barrens/ disturbed ground	40	13	Agricultural grasslands	*L*	
									Sandplain grassland	*M*	
									Early successional shrubland	*M*	Increased exotic species; increased CO2 altering growing conditions
Pine Barrens	*LV*	Dry Woodlands & Barrens	*L*	46	10				Pitch Pine Scrub Oak Barren	*L*	Increased exotic species
									Jack Pine/Red Pine Woodlands	*M*	
Central Oak-Pine Forest	*LV*	Deciduous & Mixed Forest	*M*	63	20	Southern Uplands	50	0	Hemlock	*M*	Hemlock wooly adelgid
										L	
Other Types from May 2010 Workshop	*NA*	Cliff Faces and Rocky Outcrops	*M*	32	44	Central and Northern Uplands	87	45	Acidic or Calcareous Cliff	*L*	
									Cold-air Talus Slope	*M*	
									Spruce Rocky Woodland	*L*	Increased temperature, reduced snowfall, changes in soil moisture
									Mid Elevation Bald	*L*	
									White Cedar Woodland	*M*	Increased temperature, reduced soil moisture
									Rocky Summit Herath	*M*	Changes in temperature and soil moisture, increased ozone and exotic species
									Black Spruce Heath Woodland	*L*	
		Forested Wetland	*M*	46	26	Other Fresh Water Wetlands	86	29	Spruce Flats	*H*	Changes in ground water hydrology
						Calcareous fens and swamps	90	90	Cedar Lowlands	*H*	Changes in ground water hydrology

Appendix D: Limitations of Expert-Opinion Process

D1. Effect of Three-Step Process on Species Review

This three-step, expert-opinion elicitation process of species vulnerability assessment reviewed 453 species. In the online survey, many species could not be rigorously assessed for their climate change vulnerability because few reviewers knew the species well enough or were willing to donate enough time to score their vulnerability. Overall, 15 species lacked a reviewer (3%), 210 species had only one reviewer (47%), and 105 species had two reviewers (24%). Only 113 species had three or more reviewers (26%).

As a result, the workshop and additional consultations were instrumental in increasing the level of review for each species. The number of species with a single reviewer declined to 58 (13%) and were primarily plant and invertebrate species for which there were few experts. The number of species with three or more reviewers increased to 225 (50%), including 155 species reviewed by workshop breakout groups. Although the workshop greatly increased the level of review for each species, this still left half the species with fewer than three reviewers. Ideally, each species would have been reviewed and scored for vulnerability by at least three reviewers so that mean scores might better reflect the species' vulnerability. Nonetheless, the three-step process increased the level of species review and probably the confidence of experts in the process more than if a simple online survey had been used alone.

D2. Effect of Process on Scores

We compared vulnerability scores and confidence scores of species based on surveys results, workshop results, and final results to determine if they were affected by the process. Participants in the workshop breakout groups reviewed the vulnerability scores and confidence scores of 115 species and were permitted to modify the scores of these species after a group discussion. The average vulnerability scores for these selected species were 6% lower after the breakout process compared with their survey vulnerability scores, but the confidence scores remained unchanged (Table D1). Although the workshop breakout groups may have increased the understanding of participants regarding climate change impacts, the modest change in vulnerability scores suggest that the breakouts may not have appreciably improved the accuracy of the vulnerability scores overall. Notably, experts in breakout groups reduced the vulnerability scores of seven species from high to low: Smooth Rockcress (*Arabis laevigata*), Tall White Violet (*Viola canadensis*), Mountain maple (*Acer spicatum*), Wilson's Snipe (*Gallinago gallinago*), Hermit Thrush (*Catharus guttatus*), Winter Wren (Troglodytes troglodytes), and Nashville Warbler (*Vermivora ruficapilla*). No species vulnerability scores were increased from low to high. Forty-six species had their scores increased (n=14 species) or decreased (n=32 species) by one (e.g., increased from a "1" to a "2" or vice versa). The breakouts did not change the vulnerability scores of 58 (50%) of the 115 species reviewed. Generally, the breakout reduced some survey-generated species vulnerability scores and rarely increased them. This suggests that species vulnerability scores might decline slightly with increasing levels of scrutiny.

BwH experts on the subcommittee provided additional review for species with fewer than two reviewers. Overall, the net effect of the workshop breakout groups plus BwH experts was a statistical mean reduction in vulnerability scores by about 4% on average and no change in confidence scores. The modest effect on vulnerability scores was because the scores of 247 species (55%) were not changed. The breakout groups left about 50% of their species vulnerability scores unchanged. Hence, species less thoroughly reviewed by this process might have vulnerability scores that accurately depict the vulnerability of these species. The three-step process may have slightly improved the accuracy of the vulnerability scores, did not alter the confidence scores associated with the vulnerability scores, and increased the rigor of the process. While it may not have had a large overall effect on the average vulnerability scores, it likely helped ensure that the individual results were credible and accurate.

Table D1. Paired t-test comparisons of mean survey, workshop, and final confidence and vulnerability scores (mean and s.d.).

SURVEY VS. WORKSHOP SCORES	SURVEY MEAN (*s.d.*)	WORKSHOP MEAN (*s.d.*)	N	*t*	P – VALUE
Vulnerability	2.36 (0.67)	2.13 (0.75)	115	3.25	0.0014
Confidence	2.18 (0.57)	2.13 (0.66)	115	0.32	0.7490
SURVEY VS. FINAL SCORES	**SURVEY MEAN (*s.d.*)**	**FINAL MEAN (*s.d.*)**	**N**	***t***	**P – VALUE**
Vulnerability	2.21 (0.71)	2.12 (0.77)	442	2.27	0.0237
Confidence	2.22 (0.52)	2.19 (0.61)	440	0.60	0.5462

D3. Participants' Feedback on Online Survey

Reviewers in the online survey were generally supportive of this approach. Forty of the 81 reviewers scored their confidence in the online survey effort. About 30% (n=11) of these reviewers were confident that the online survey would be very useful for accurately describing the vulnerability of Maine species and about 60% were confident that the online survey would be moderately useful for accurately describing the vulnerability of Maine species. About 10% (n=4) indicated that the survey was not likely to be useful.

About 25% (n=20) of the online reviewers provided additional comments about their online survey experience. Their chief concerns could be sorted into the following topics: (1) online interface (too slow for some, others wished that it would have been easier to score groups of species with identical traits and scores), (2) the input data (e.g., would have liked the option to comment and provide additional information on all species, it was time consuming to provide all of the requested data), and (3) concerns about this approach yielding useful information (e.g., the selected vulnerability traits oversimplifying the biology of species, the lack of life history and distribution information for Maine undermining the ability of reviewers to accurately complete the species assessment). Seven of the 10 reviewers with negative written comments nevertheless had medium or high confidence in the online effort and were generally supportive of the approach. Overall, this approach was credible with participants and they seemed to understand its limitations.

D4. Other Limitations of the Expert-Opinion Elicitation Process

Using an expert-opinion elicitation process has at least five potential limitations (Yousuf 2007). First, judgments can be those of a select group of people and may not be representative. However, we were able to recruit a large number of diverse reviewers for Step 1 and Step 2 from Maine and across the region to avoid "groupthink" from a small number of reviewers. Second, there is social pressure to achieve consensus and extreme positions tend to be eliminated. It is possible that this occurred during the Step 2 expert panels as the vulnerability scores of a few species were changed from 3 to 1, etc. Third, it is much more time consuming than a simple group process or single survey. Fourth, it requires adequate time and participant commitment. We were fortunate that a large number of biologists were willing to donate their time and help us overcome this limitation. Fifth, participants do not necessarily understand the big picture or come with the same assumptions. We made two large efforts to ensure that participants were well informed. We created a document describing climate change exposure of species groups and habitats (Whitman et al. 2013a) and asked participants to review the document before beginning the online survey (Step 1). We also reviewed similar material at the beginning of the workshop (Step 2) to help orient reviewers on expert panels and improve the quality of the review. However, we did not ask, at that stage, either survey or workshop participants to explicitly comment on their degree of agreement with the starting assumptions of vulnerability traits used or our scoring algorithms. Doing so might have increased group consensus, but would have undoubtedly taken a great deal more time.

D5. Limitations of the Results

There are significant limitations to using these results alone to strengthen existing species-specific conservation plans. Although this assessment reviewed the vulnerability of habitats in the ME CWCS through a species lens, a much more thorough habitat vulnerability assessment is necessary to more fully inform habitat planning and conservation efforts. On average, the analyses for most species are likely very good. However, the development of species-specific strategies should build on the information from this assessment and consider other sources of information to refine the analysis. Studies from other states using the NatureServe Climate Vulnerability Index may provide more quantitative results, including species distribution models for some species. The biology and habitat requirements of many species in our assessment (e.g., plants and invertebrates) are poorly known, and even 'expert opinion' may be insufficient to project how climate changes may affect these species. Users should gather additional information for species with only one or two reviewers and that lacked careful scrutiny in Steps 2 or 3 before this information is used to develop species-specific conservation strategies.

Appendix E: Lists of Online Survey Reviewers and Workshop Reviewers

E1. List of Online Survey Reviewers

LAST NAME	FIRST NAME	AFFILIATION
Allen	Brad	Maine Department of Inland Fisheries and Wildlife
Arsenault	Matt	Stantec Consulting
Blaney	Sean	Atlantic Canada Conservation Data (NB, Canada)
Brumback	William	New England Wild Flower Society
Brunkhurst	Emily	New Hampshire Fish and Game Department
Burian	Steven	Southern Connecticut State University, Dept. of Biology
Butler	Ronald	University of Maine at Farmington
Cameron	Don	Maine Natural Areas Program
Camuso	Judy	Maine Department of Inland Fisheries and Wildlife
Connery	Bruce	Acadia National Park
Cordeiro	Jay	NatureServe
Courtemanch	David	Maine Department of Environmental Protection
Cutko	Andy	Maine Natural Areas Program
D'Auria	Danielle	Maine Department of Inland Fisheries and Wildlife
Demaynadier	Phillip	Maine Department of Inland Fisheries and Wildlife
Dembeck	Joseph	Maine Department of Inland Fisheries and Wildlife
Depue	John	Maine Department of Inland Fisheries and Wildlife
Diamond	Tony	University of New Brunswick - Fredericton
Dibble	Alison	Stewards LLC
Docherty	Molly	Maine Natural Areas Program
Dressler	Rich	Maine Department of Inland Fisheries and Wildlife
Feurt	Ward	U. S. Fish and Wildlife Service
Gallagher	Merry	Maine Department of Inland Fisheries and Wildlife
Gallo	Susan	Maine Audubon Society
Gawler	Sue	NatureServe
Gilman	Art	Gilman & Briggs Environmental
Hall	Georgia	none
Hartley	Mitschka	U. S. Fish and Wildlife Service
Hodgman	Tom	Maine Department of Inland Fisheries and Wildlife
Hoekwater	Jean	Baxter State Park
Houston	Bob	U. S. Fish and Wildlife Service
Hunt	Pamela	New Hampshire Audubon

LAST NAME	FIRST NAME	AFFILIATION
Hunter	Mac	University of Maine at Orono, Department of Wildlife Ecology
Jakubas	Walter	Maine Department of Inland Fisheries and Wildlife
Jordan	Richard	Maine Department of Inland Fisheries and Wildlife
Kantar	Lee	Maine Department of Inland Fisheries and Wildlife
Kimball	Kenneth	Appalachian Mountain Club
Krawec	Mark	University of Maine at Augusta
Krohn	Bill	USGS Maine Fish and Wildlife Co-op
Laser	Melissa	Maine Department of Marine Resources
Magee	John	New Hampshire Fish and Game Department
Mays	Jonathan	Maine Department of Inland Fisheries and Wildlife
Mccollough	Mark	U. S. Fish and Wildlife Service
Mcfarland	Kent	Vermont Center for Ecostudies
Mckinley	Peter	Forest Society of Maine
Mills	Maurice	U. S. Fish and Wildlife Service, Moosehorn NWR
Moore	Slade	Maine State Planning Office
Nedeau	Ethan	Biodiversity LLC
Nelson	Bob [Robert E.]	Colby College
Nichols	Bill	New Hampshire Natural Heritage Bureau
Obrien	Kate	Rachel Carson NWR
O'Leary	John	Massachusetts Division of Fisheries and Wildlife
Pelletier	Steve	Stantec Consulting
Rawinski	Thomas	USDA Forest Service
Royte	Joshua	The Nature Conservancy
Saunders	Rory	NOAA Marine Fisheries Service
Sferra	Nancy	The Nature Conservancy
Sheehan	Bill	Maine Birds Record Committee
Simmons	Tim	Massachusetts Division of Fisheries and Wildlife
Sperduto	Dan	Sperduto Ecological Services LLC
Stockwell	Lauren	Stockwell Environmental Consulting
Stone	Judy	Colby College
Sullivan	Kelsey	Maine Department of Inland Fisheries and Wildlife

LAST NAME	FIRST NAME	AFFILIATION
Swartz	Beth	Maine Department of Inland Fisheries and Wildlife
Tester	Chase	Maine Frameworks LLC
Todd	Charlie	Maine Department of Inland Fisheries and Wildlife
Tsomides	Leon	Maine Department of Inland Fisheries and Wildlife
Tudor	Lindsay	Maine Department of Inland Fisheries and Wildlife
Van Riper	Robert	Maine Department of Inland Fisheries and Wildlife
Vashon	Jennifer	Maine Department of Inland Fisheries and Wildlife
Vickery	Peter	Center for Ecological Research
Walker	Steve	Maine Department of Inland Fisheries and Wildlife
Weber	Jill	none
Welch	Linda	U. S. Fish and Wildlife Service
Whitman	Andy	Manomet
Wicklow	Barry	St. Anselm College, Department of Biology
Wilkerson	Ethel	Manomet
Wilson	Herb	Colby College, Department of Biology
Wright	Jed	U. S. Fish and Wildlife Service
Zydlewski	Gayle	University of Maine

E2. List of Workshop Reviewers by Break Out Groups

REVIEWERS FOR MAJOR PLANT HABITAT BREAK OUT GROUPS (IN ALPHABETIC ORDER)

Alpine

Matt Arsenault, Sean Blaney, William Brumback, Andy Cutko, Alison Dibble, Jean Hoekwater, Kenneth Kimball, Joshua Royte, Dan Sperduto, Andy Whitman,

Aquatic

Don Cameron, Andy Cutko, Art Gilman, Robert Van Riper, Ethel Wilkerson, and Jed Wright.

Barrens/disturbed ground

Sean Blaney, Don Cameron, Andy Cutko, Art Gilman, Joshua Royte, Nancy Sferra, Tim Simmons, and Judy Stone.

Calcareous fens and swamps

Matt Arsenault, Sean Blaney, William Brumback, Andy Cutko, Art Gilman, Mark McCollough, Joshua Royte, and Tim Simmons.

Central & Northern Maine uplands

Matt Arsenault, Sean Blaney, Andy Cutko, Alison+D87 Dibble, Art Gilman, Jean Hoekwater, Joshua Royte, Judy Stone, Jill Weber, Andy Whitman, and Ethel Wilkerson.

Coastal wetlands

William Brumback, Andy Cutko, Ward Feurt, Joshua Royte, Nancy Sferra, and Lauren Stockwell.

Northern rivershores

Matt Arsenault, Sean Blaney, Andy Cutko, Sue Gawler, Mark McCollough, Joshua Royte, and Robert Van Riper.

Other freshwater wetlands

Andy Cutko, Art Gilman, Maurice Mills, Joshua Royte, Nancy Sferra, Lauren Stockwell, Chase Tester, and Jill Weber.

Southern Maine uplands

Andy Cutko, Ward Feurt, Joshua Royte, Nancy Sferra, and Judy Stone.

REVIEWERS FOR ANIMAL TAXONOMIC BREAK OUT GROUPS (IN TAXONOMIC ORDER)

Aquatic insects

Steven Burian, David Courtemanch, Beth Swartz, Leon Tsomides, Robert Van Riper, and Ethel Wilkerson.

Damselflies and Dragonflies

Emily Brunkhurst, Ronald Butler, Phillip deMaynadier, and Pamela Hunt.

Snails and Mussels

Jay Cordeiro, Ward Feurt, Jonathan Mays, Mark Mccollough, Ethan Nedeau, Beth Swartz, Robert Van Riper, and Barry Wicklow.

Beetles

Jonathan Mays, Bob [Robert E.] Nelson, and Tim Simmons.

Moths and Butterflies

Phillip deMaynadier, Jean Hoekwater, Kent McFarland, Nancy Sferra, Tim Simmons, Beth Swartz, and Herb Wilson.

Herps

Bruce Connery, Phillip deMaynadier, Mac Hunter, Jonathan Mays, Mark Mccollough, Peter Mckinley, Steve Pelletier, Barry Wicklow, and Ethel Wilkerson.

Diadromous Fish

Bruce Connery, David Courtemanch, Melissa Laser, John Magee, Mark Mccollough, Slade Moore, Joshua Royte, Rory Saunders, Ethel Wilkerson, Jed Wright, and Gayle Zydlewski.

Inland Fish

David Courtemanch, Joseph Dembeck, Merry Gallagher, Richard Jordan, John Magee, John O'Leary, Robert Van Riper, and Ethel Wilkerson.

Seabirds

Brad Allen, Bruce Connery, Danielle D'Auria, Tony Diamond, Mitschka Hartley, Mark McCollough, Peter Mckinley, Peter Vickery, Steve Walker, Linda Welch, and Andy Whitman.

Waterfowl

Brad Allen, Judy Camuso, Danielle D'Auria, Ward Feurt, Mitschka Hartley, Tom Hodgman, Bob Houston, Peter Mckinley, Maurice Mills, Slade Moore, Kelsey Sullivan, Steve Walker, and Andy Whitman.

Shorebirds

Brad Allen, Sean Blaney, Judy Camuso, Danielle D'Auria, Molly Docherty, Ward Feurt, Tom Hodgman, Mark McCollough, Peter Mckinley, Maurice Mills, Kate Obrien, Lindsay Tudor, Peter Vickery, Steve Walker, Andy Whitman, and Herb Wilson.

Waterbirds

Emily Brunkhurst, Judy Camuso, Danielle D'Auria, Ward Feurt, Pamela Hunt, Mark Mccollough, Peter Mckinley, Maurice Mills, Slade Moore, Peter Vickery, and Andy Whitman.

Woodpeckers and other spp.

Sean Blaney, Judy Camuso, Ward Feurt, Mitschka Hartley, Tom Hodgman, Pamela Hunt, Peter Mckinley, Peter Vickery, Steve Walker, Andy Whitman, and Herb Wilson.

Raptors and Owls

Sean Blaney, Judy Camuso, Mitschka Hartley, Mark McCollough, Peter Mckinley, Nancy Sferra, Charlie Todd, Peter Vickery, Steve Walker, and Andy Whitman.

Passerines

Sean Blaney, Danielle D'Auria, Ward Feurt, Mitschka Hartley, Tom Hodgman, Jean Hoekwater, Pamela Hunt, Kent McFarland, Peter Mckinley, Maurice Mills, Kate Obrien, Nancy Sferra, Peter Vickery, Steve Walker, and Andy Whitman.

Large Mammals

Bruce Connery, Andy Cutko, Rich Dressler, Jean Hoekwater, Walter Jakubas, Lee Kantar, Mark Mccollough, Jennifer Vashon, and Andy Whitman.

Small Mammals and Bats

Emily Brunkhurst, Bruce Connery, John Depue, Rich Dressler, Ward Feurt, Walter Jakubas, Peter Mckinley, Kate Obrien, Steve Pelletier, and Jennifer Vashon.

MANOMET
Center for Conservation Sciences

Science at Work
for a
Sustainable World

Manomet's mission is to conserve natural resources for the benefit of wildlife and human populations. Through research and collaboration, Manomet builds science-based, cooperative solutions to improve sustainability.

The Sustainable Economies Initiative at Manomet is helping people create an economy based on sustainability.