CHAPTER 2: NORTHEAST AND MIDWEST REGIONAL SPECIES AND HABITATS AT GREATEST RISK AND MOST VULNERABLE TO CLIMATE IMPACTS

Authors:

Michelle Staudinger (USGS, Northeast Climate Science Center (NE CSC)), Laura Hilberg (University of Massachusetts Amherst), Maria Janowiak (Northern Institute of Applied Climate Science, U.S. Forest Service), Chris Swanston (Northern Institute of Applied Climate Science, U.S. Forest Service)

Contents

Tables

Figures

Appendix

Appendix 2.3: List of all fish and wildlife species evaluated in 14 studies for their vulnerability to climate change across the region.

Appendix 2.4: Counts of vulnerability rankings across 5 studies using the NatureServe CCVI method by study, taxonomic groups, and species.

Appendix 2.5: Species-specific vulnerability rankings across five studies using a mixture of approaches (Does not include those using the NatureServe CCVI framework).

Appendix 2.6: Trait and Response-based scores quantified in Sievert (2014) for Missouri freshwater fishes.

Appendix 2.7: List of all habitats evaluated across 11 regional studies for their vulnerability to climate change.

Appendix 2.8: Counts of vulnerability rankings across 5 studies using the Climate Change Response Framework by study and major habitat types.

Appendix 2.9: Matrix showing the vulnerability designations for each habitat type evaluated by CCRF across 5 studies.

Appendix 2.10: Counts of vulnerability rankings across 5 studies using a mixture of approaches (Does not include those using the CCRF).

Appendix 2.11: Vulnerability descriptions from New Hampshire Fish & Game Department (2013) ecosystems and wildlife climate change adaptation plan.

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Summary Points

- *Vulnerability* is defined as the susceptibility of a species, system or resource to the negative effects of climate change and other stressors.
- *Climate change vulnerability* is comprised of three separate but related components: exposure, sensitivity, and adaptive capacity.
- *Climate Change Vulnerability Assessments* targeting ecological systems can be focused at the species, habitat, or ecosystem level; there are different interpretations, treatments, and approaches to assessing climate change vulnerability. Therefore, it is important to examine the specific factors that were considered and the definitions used to evaluate the vulnerabilities of conservation targets within each study.
- NatureServe's Climate Change Vulnerability Index (CCVI) was the most commonly used framework across studies included in this synthesis to assess fish and wildlife species across the Northeast and Midwest; freshwater mussels, amphibians, and fish were scored as either extremely or highly vulnerable, while the majority of birds and mammals received low vulnerability rankings.
- Other (non-CCVI) species-focused vulnerability assessment frameworks ranked marine fish and invertebrates as highly vulnerable, and the majority of birds and mammals as having moderate or low vulnerability.
- Overall, birds were the most frequently assessed taxonomic group across the region, but generally yielded relatively low vulnerability scores. However, vulnerability of migratory birds and other species may be underestimated when the full life-cycle or connections among breeding, wintering, and migratory habitats are not taken into account.
- The Climate Change Response Framework (CCRF) was the most commonly used methodology across studies included in this synthesis to assess habitats in the Northeast and Midwest; spruce-fir, lowland conifer, and Appalachian northern hardwood forests were classified as highly vulnerable to climate change as well as bogs and fens.
- Other (non-CCRF) habitat-focused assessments generally scored tundra, freshwater aquatic, and coastal habitats as highly vulnerable to climate change.
- Forests were the most frequently assessed habitat group across the region.

The objectives of this Chapter are to describe climate change vulnerability, it's components, the range of assessment methods being implemented regionally, and examples of training resources and tools. Climate Change Vulnerability Assessments (CCVAs) have already been conducted for numerous Regional Species of Greatest Conservation Need and their dependent habitats across the Northeast and Midwest. This chapter provides a synthesis of different assessment frameworks, information on the locations (e.g., States) where vulnerability assessments were conducted, lists of individual species and habitats with their respective vulnerability rankings, and a comparison of how vulnerability rankings were determined among studies.

I. VULNERABILITY TO CLIMATE CHANGE

A) CLIMATE CHANGE VULNERABILITY AND ITS COMPONENTS

Vulnerability is defined by the Intergovernmental Panel on Climate Change (IPCC 2007, 2014) as the susceptibility (of a species, system or resource) to the negative effects of climate change and other stressors. Under this definition, vulnerability is composed of three separate but related components: exposure, sensitivity and adaptive capacity. *Exposure* is the character, magnitude, and rate of change a species experiences, and includes both direct and indirect impacts of climate change. For example, exposure may take the form of changes in temperature, precipitation, and extreme events, but could also include habitat shifts due to changing vegetation or ocean acidification. *Sensitivity* to climate change provides an indication of the degree to which a species or habitat is likely to be affected or responsive to climate change, and is linked to its dependence on current environmental and ecological conditions. Sensitivity factors could include temperature requirements or dependence on a specific hydrological regime. Finally, *adaptive capacity* is the ability of a species to cope and persist under changing conditions through local or regional acclimation, dispersal or migration, adaptation, and/or evolution (Dawson et al. 2011; Glick et al. 2011). A species' potential for behavioral changes, dispersal ability, and genetic variation are all good examples of factors relating to adaptive capacity. Additional examples of all three components of climate change vulnerability are presented in **Table 1**.

Climate Change Vulnerability Assessments (CCVA) are emerging tools in the fields of climate science, conservation, management, and adaptation. By assessing climate change vulnerability and considering risk in the context of other environmental stressors (e.g., exploitation, pollution, land use change, disease), natural resource managers can identify which species and systems are relatively more vulnerable or resilient to climate change, ascertain why they are vulnerable or resilient, and use this information to prioritize management decisions (Glick et al. 2011). Federal and State agencies as well as conservation organizations have begun conducting vulnerability assessments on a variety of management and conservation targets.

Table 1: Examples of the three components of climate change vulnerability: exposure, sensitivity, and adaptive capacity. Note that examples are organized by column, and examples from each row are not related. Examples were extracted from the references in **Table 3**.

Exposure	Sensitivity	Adaptive capacity
Air and water temperatures	Species geographic range	Genetic diversity
Precipitation	Environmental or physiological niche	Genetic bottlenecks
Humidity	Thermal tolerance	Behavioral adaptation
Soil moisture	Hydrological niche and/or tolerance	Dispersal and/or migration ability
Wind	Low or intolerance to disturbance	Phenotypic plasticity
Solar radiation	Habitat specificity	Genotypic plasticity
Sea level rise	Prey specificity	Ecological plasticity
Flooding	Dependent or competitive trophic relationships	Adaptive evolution
Drought	Low tolerance or intolerance to invasive species	Phenological shifts
Water runoff	Population or stock size	Mobility
River flow (timing, intensity and frequency)	Population size and age structure	Distribution relative to natural and anthropogenic barriers
Evapotranspiration	Mobility	Resiliency to stressors
Ocean acidification	Reproductive strategy	
Currents	Spawning cycle	
Salinity	Early life history survival and settlement requirements	
Extreme events	Population growth rate	
Snow-pack depth, ice cover, ice-edge cover	Interspecific or phenological dependence	
Fire regimes	Low tolerance or intolerance to non-climate anthropogenic stressors such as pollution	
Impacts from other anthropogenic stressors such as land-use change or harvest		

Differences exist in the interpretation of climate change vulnerability in the literature as well as across different sectors (e.g., policy, scientific, natural resources) and institutions. The vulnerability of a species, system, or resource to climate change has been considered a starting point for conservation efforts and a characteristic brought about by other stressors (e.g., environmental, anthropogenic) that is exacerbated by climate change (O'Brien et al. 2004). Vulnerability may also be viewed as the consequence or result of the net impacts of climate change minus actions to reduce the effect of climate change (i.e., adaptation) (O'Brien et al. 2004). These different interpretations have important implications for how research, management decisions, and actions related to a resource are made.

Different approaches and methodologies for evaluating vulnerability may also differ in how they consider the three components of exposure, sensitivity, and adaptive capacity. For example, some assessments evaluate adaptive capacity; some have combined it as part of sensitivity, and some have ignored it completely and just assessed exposure and/or sensitivity (Joyce et al. 2011; Thompson et al. In press; Beever et al. In press). Our ability to understand and predict species' and system's responses to climate change is limited when adaptive capacity is not explicitly considered. Therefore, an integral activity of assessing vulnerability should be to evaluate the uncertainties related to each of the three components and other relevant factors including those that were or were not able to be assessed. This will highlight the places where additional research or monitoring is needed to inform future decisions and actions. Where there is limited information available on adaptive capacity, a vulnerability assessment might suggest research or monitoring to fill in that knowledge gap.

B) TRAITS AND CHARACTERISTICS AFFECTING SPECIES' VULNERABILITY TO CLIMATE CHANGE

A recent study conducted by Pacifici et al. (2015) reviewed 97 studies published during the last decade reporting on the risk and vulnerability of global species to climate change. They concluded that species traits rather than taxonomy and distribution were relatively more important in determining climate change vulnerability.

The following is a list of biological traits and characteristics that make species relatively more or less vulnerable to climate change (Both et al. 2009; Glick et al. 2011; Bellard et al. 2012; Lurgi et al. 2012; Staudinger et al. 2013; Pacifici et al. 2015):

i. Specialized habitat and/or microhabitat requirements
ii. Specialized dietary requirements
iii. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle
iv. Populations living near the edge of their physiological tolerance or geographical range
v. Dependence on habitats expected to undergo major changes due to climate
vi. Dependence on specific environmental triggers or cues that are likely to be disrupted by climate change
vii. Dependence on interspecific interactions which are likely to be disrupted by climate change.
viii. Poor ability to disperse to or colonize a new range
ix. Low genetic diversity; isolated populations
x. Restricted distributions
xi. Rarity
xii. Low phenotypic plasticity
xiii. Long life-spans or generation times, low fecundity or reproductive potential or output

Biological traits or characteristics that may create opportunities or benefit species under future climate change include:

i. Broad habitat or dietary generalists
ii. High phenotypic plasticity
iii. Disturbance-adapted species
iv. Large thermal tolerances
v. High dispersal capabilities

xiv. Short life-spans or generation times, high fecundity and reproductive potential or output

II. CLIMATE CHANGE VULNERABILITY ASSESSMENT TOOLS

A) TYPES OF CLIMATE CHANGE VULNERABILITY ASSESSMENT APPROACHES

There is no standard method or framework to assess vulnerability to climate change. A variety of approaches are reported in the literature, and implemented by different institutions and organizations globally. Generally, the approach chosen to evaluate vulnerability should be based on the goals of the practitioners, confidence in existing data and information, and the resources available (**Table 2**).

Table 2: Types of information and models that are often used as part of climate change vulnerability assessments (Staudinger et al. 2012; Pacifici et al. 2015 and references therein).

Approach	Biological Response	Advantages	Limitations	Example
Correlative (empirical) models: Relates current or historical geographical distribution/range occurrence observations of a species or group with climate projections to identify future habitat suitability	Changes in geographical distribution and/or range	Spatially and site explicit Can be applied to diverse taxa Does not require large amounts of data (can be based on occurrence data only) Predictive Relatively inexpensive	Does not consider adaptive capacity, dispersal, and community/species interactions Resolution of biological and environmental / climate data may be at different scales May not accurately capture the full (fundamental) species' niche	Climate Envelope Models; Species Distribution Models (SDM) Matthews et al. 2004; Iverson et al. 2008; Schloss et al. 2012; DeLuca & McGarigal 2014

Approach	Biological Response	Advantages	Limitations	Example
Mechanistic (process-based) models: Evaluate fundamental niche and fitness of a species under changing environmental conditions; also accounts for specific mechanisms underlying physiological responses and simulates dispersal, functioning, and population dynamics	Adaptive capacity through behavioral shifts or coping mechanisms	Spatially and site explicit Species-specific Relatively robust Based on theory and key functional traits Accounts for physiological responses and adaptive capacity Predictive	Requires a large number of observations from laboratory and field (particularly for wide-ranging species) Does not consider community/species interactions Does not account for other anthropogenic stressors Resource intensive (may be expensive)	Individual-Based Population Models; Dynamic Global Vegetation Models (DGVM); Forest Gap Models Buckley 2008; Kearney & Porter 2009; Monahan 2009 Prevalence models and Landscape Capability (LC) models (See **Chapter 3** for more about the Designing Sustainable Landscapes project) DeLuca & McGarigal 2014
Trait-based assessments: Predicts risk of population decline and extinction by evaluating exposure to climate	Changes in population dynamics and extinction risk	Species-specific but also appropriate for multi-species evaluations Simple; does not	May use indirect measures of climate change impacts Traits may be treated equally	NatureServe's Climate Change Vulnerability Index (Young et al. 2012) Byers & Norris

Approach	Biological Response	Advantages	Limitations	Example
change and species-specific traits and characteristics; can include abundance indices, monitoring observations, population viability analysis, demographic models and/or expert opinion		necessarily require modeling techniques Relatively inexpensive	regardless of actual influence on response Trait-based vulnerability thresholds and vulnerability categories may be subjective Inconsistent indices and scoring systems across studies	2011; Furedi et al. 2011; Schlesinger et al. 2011; Cullen et al. 2013; Foden et al. 2013; Hoving et al. 2013; Sneddon & Hammerson 2014

B) SPECIFIC FRAMEWORKS AND APPROACHES USED ACROSS THE NORTHEAST AND MIDWEST

In this section we introduce and describe the methodology of CCVA frameworks that have been conducted across the Northeast and Midwest regions. These include the Nature Serve Climate Change Vulnerability Index (CCVI), Climate Change Response Framework (CCRF), Northeast Association of Fish and Wildlife Agencies Habitat Vulnerability Assessment, and expert opinion workshops and surveys that informed vulnerability assessments for several states across the region.

i. Nature Serve Climate Change Vulnerability Index (CCVI)

The Nature Serve Climate Change Vulnerability Index (CCVI) (Young et al. 2011) is one of the most commonly used CCVI tools, in part because it is relatively easy to use (Young et al. 2014). The CCVI is a trait-based assessment designed for use with any species of fish and wildlife. This makes it suitable for assessing large numbers of species and comparing results across both species and taxa, and it can be a useful tool for discerning patterns in the data.

The CCVI is a Microsoft Excel-based tool, and includes detailed instructions on obtaining climate data and calculating the degree of expected change in temperature, moisture, and other factors. These factors are entered as the percentage of the species' range expected to undergo change, and are considered under several magnitudes (e.g. 25% of the range is expected to experience a temperature increase of 5.1-5.5° F, and the remaining 75% of the range falls into the >5.5° F category). The remaining factors assessed by the CCVI are weighted by the magnitude of exposure, and are grouped into indirect exposure factors (including sea level rise, barriers to dispersal, and land use changes), and species-specific sensitivity factors. While the CCVI does include factors of adaptive capacity, they are often considered or presented within factors related to sensitivity (i.e., genetic variation). The CCVI also takes into account documented or modeled factors related to climate change, and historical information, as well as rarity of the species (using NatureServe Conservation Status Ranks).

Although the CCVI output includes a confidence score in addition to the vulnerability ranking, it reflects only uncertainty in the scoring of species information, and does not include the uncertainty associated with climate projections and emissions scenarios (Young et al. 2014). Other limitations of the CCVI include difficulty assessing species across their entire life-cycle, and underestimating vulnerability in species that are unusually sensitive to specific factors (Small-Lorenz et al. 2013).

ii. Climate Change Response Framework

The Northern Institute of Applied Climate Science (NIACS) and numerous partners have developed a method for assessing the vulnerability of forested ecosystems called the Climate Change Response Framework (CCRF) (Brandt et al. 2014; Handler et al. 2014a, b; Janowiak et al. 2014; Butler et al. 2015). The objective of this vulnerability assessment process is to determine vulnerability to climate change among forest community types within an ecological province (broad geographic areas that share climate, glacial history, and vegetation types). The assessment process uses a range of downscaled climate projections that are incorporated into dynamic and species distribution modeling to determine the future habitat suitability of tree species. A comprehensive literature review summarizes the effects of climate change on disturbance processes, hydrology, non-climate stressors, and associated forest species in the area. Vulnerability and levels of confidence are then determined using formal expert elicitation. A panel of experts considers the literature review in conjunction with the model results to evaluate climate change impacts on the drivers, stressors, and dominant tree species of forest communities in each ecoregion. Through a facilitated process, these projected impacts along with experts' information about the adaptive capacity of each ecological community are used to arrive at an individual vulnerability assessment. Vulnerability and levels of confidence are determined by a process where panel members come to consensus on the final determination.

Each vulnerability assessment is tailored to meet the needs of a particular region while maintaining a consistent approach and format across assessments. At the same time, all vulnerability assessments:

- Focus on forest ecosystems within a region defined by a combination of ecoregional and political boundaries;
- Address vulnerabilities of individual tree species and forest or natural community types within each region;
- Use gridded historical and modeled climate change information as well as several different approaches to modeling impacts on tree species;
- Rely on a panel of scientists and managers with local expertise to put scientific results in context; and,
- Are peer-reviewed and published by the US Forest Service Northern Research Station as General Technical Reports, with a primary audience being natural resource professionals.

Features of the CCRF determination process:

1. **Contemporary Landscape** describes existing conditions, physical environment, ecological character, and social dimensions of the assessment area.
2. **Climate Change Primer** contains background on climate change science, projection models, and impact models. It also describes the techniques used in developing climate projections.
3. **Observed Climate Change** describes trends in records of past climate.

4. **Future Climate Change** presents statistically downscaled climate projections at the regional scale.
5. **Impacts on Forests** summarizes results of modeling climate change effects on tree species distribution and forest ecosystem processes.
6. **Forest Ecosystem Vulnerability** synthesizes the potential effects of climate change on forest ecosystems and outlines key changes to ecosystem stressors, responses to those stressors, and vulnerabilities.
7. **Implications for Forest Management** describes implications for recreation, timber production, wildlife habitat, and many other secondary vulnerabilities, and ongoing research in those focus areas.

Ecosystem vulnerability (applied to habitats in this document) is assessed by a panel of experts using the same process. Experts are selected for their knowledge and experience in the ecosystems being assessed and represent a variety of disciplines, including forest ecology, hydrology, plant physiology, silviculture, wildlife ecology and management, soil science, and plant community ecology. The panel assesses vulnerability using carefully defined concepts:

- **Potential impacts** are the direct and indirect consequences of climate change on systems and could be harmful or beneficial to an ecosystem. Impacts are a function of a system's exposure to climate change and its sensitivity to any changes.
- **Adaptive capacity** is the ability of a species or ecosystem to accommodate or cope with potential climate change impacts with minimal disruption.

The panel draws upon a comprehensive literature review, results from forest impact models, and professional expertise to assess potential impacts, adaptive capacity, and overall vulnerability of forest ecosystems to climate change as well as other anthropogenic stressors (e.g., land use change, pollution). Each expert assesses vulnerability of an ecosystem based on impacts and adaptive capacity. Experts discuss these individual assessments before reaching group consensus on vulnerability and confidence in available information (**Figure 1**).

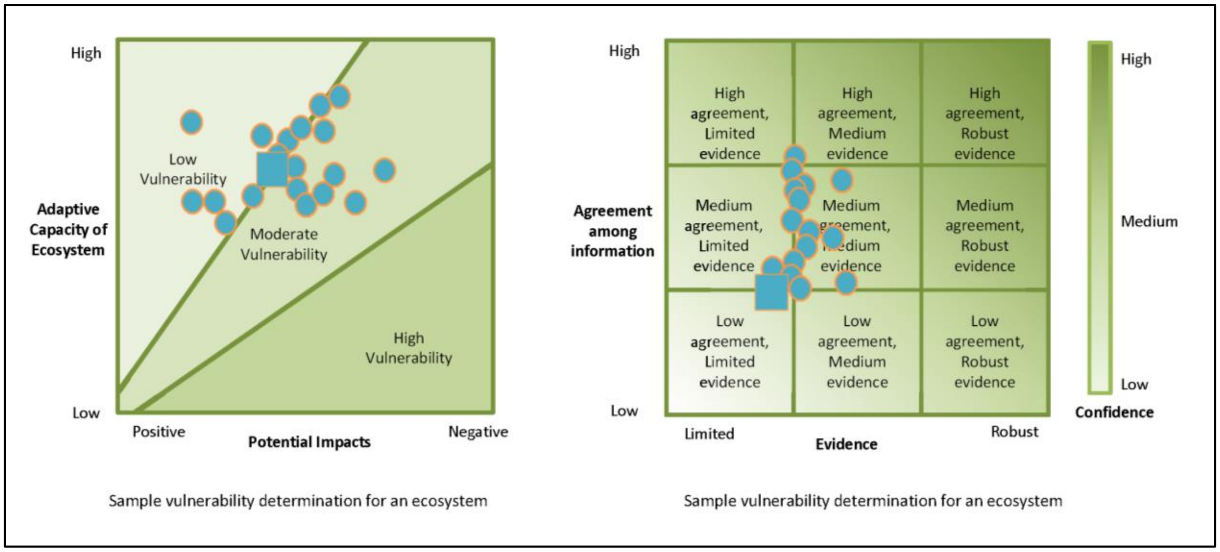

Figure 1: An example of how expert panelists assess vulnerability (left panel) and confidence (right panel) for forest ecosystems in CCRF vulnerability assessments. Each panelist provides an individual determination of ecosystem vulnerability and rate confidence in that determination (circles). The group then comes to a consensus on vulnerability and confidence through discussion (squares). Figure used with permission from P. Butler.

iii. Northeast Association of Fish and Wildlife Agencies Habitat Vulnerability Assessment

The NEAFWA Habitat Vulnerability Model was developed by the Northeastern Association of Fish and Wildlife Agencies (NEAFWA), the North Atlantic Landscape Conservation Cooperative (NALCC), the Manomet Center for Conservation Sciences (Manomet), and the National Wildlife Federation (NWF) in order to consistently evaluate the vulnerability of non-tidal habitats across all 13 states in the Northeastern United States (Manomet & NWF 2013).

The NEAFWA Habitat Vulnerability Model is based on an expert-panel approach (similarly to the CCRF method discussed above), and contains 4 modules which can be used within Microsoft Excel:

- Module 1 scores the vulnerability of non-tidal habitats to climate change based on 11 variables related to sensitivity, including location in overall range of habitat, degree of cold-adaptation, dependence on specific hydrological conditions, constraints on range shifts, and the potential for climate change to exacerbate the impact of other stressors. Adaptive capacity is included in this module as a single variable called "intrinsic adaptive capacity". Module 1 can be used alone if the goal is to identify vulnerability to climate change only, rather than overall vulnerability of the habitat.

- Module 2 includes 5 variables, and scores the current and future extent of habitats and their vulnerability to non-climate stressors.
- Module 3 combines the results of the previous two modules, and produces a vulnerability ranking and confidence score reflecting the habitat's vulnerability to climate change, to non-climate stressors, and to combined climate and non-climate stressors.
- Module 4 requires the construction of a narrative that explains the scores assigned to each variable. Because scores in Modules 1, 2, and 3 are based on expert opinion, the narrative provides a way to ensure transparency and evaluate consistency and underlying assumptions.

After the 13 states in the Northeastern United States were evaluated, results for each habitat were reviewed by an expert panel and resubmitted for evaluation if needed. The initial vulnerability assessment done using this model evaluated 13 habitat types in the Northeast region, including forests, wetlands, and grasslands. The NEAFWA Habitat Vulnerability Model has subsequently been used by the National Park Service, the U.S. Forest Service, and a number of states, suggesting that the model framework is useful and can be applied in a variety of contexts and in a number of states (Manomet & NWF 2013).

iv. Expert opinion workshops and surveys

Many regional vulnerability assessments were designed around expert opinion, either through a workshop format, or through online surveys. These assessments tended to be qualitative or mixed in nature, since they didn't include many of the quantitative attributes in the established frameworks above. Some examples of these include vulnerability assessments conducted in the states of Connecticut, Massachusetts, New Hampshire, Vermont, and Maine.

- **Connecticut** conducted a facilitated risk assessment workshop, in which the Natural Resources Working Group evaluated 18 terrestrial and aquatic habitats (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010). Experts completed a risk assessment survey to identify primary climate drivers, the likelihood, severity, and time horizon for impacts, and urgency for action. Vulnerability rankings were calculated based on average survey scores, and included narrative comments; however, data on uncertainty was not elicited. A state-wide online survey collected additional expert opinion and rankings data on wildlife.
- **Massachusetts** asked experts participating in a workshop to evaluate the vulnerability of habitats under two emissions scenarios, to identify vulnerability factors, likely ecological trajectories, and to assign a vulnerability ranking and confidence score to each habitat (Manomet & NWF 2013). The experts were broken into four discussion groups by habitat type: forested, freshwater aquatic, wetland, and coastal.
- **New Hampshire** asked experts to discuss habitats at a series of 7 workshops (New Hampshire Fish & Game Department 2013). Participants were provided with a list of stressors and how they were expected to affect the state. They constructed extensive habitat narratives, which did not include a formal vulnerability ranking or measure of confidence. Several species or groups of species were also evaluated in this way.
- **Vermont** held a workshop for experts in four areas: forest and upland habitat, wetlands, streams and rivers, and lakes (TetraTech, Inc. 2013). After being provided with information on the expected impact of climate change in the state, participants identified the likely climate stressors for each habitat, the expected impact, and potential mediating factors. Experts assigned vulnerability and confidence scores to the habitats and species assessed.
- **Maine** assessed 442 species using an online survey sent to over 100 experts (Whitman et al. 2013). Experts were asked to identify the key habitat for the species, and then assess vulnerability based on traits in six categories (with space for additional comments). Each species was reviewed by at least two (rare species) or three (common species) experts participating in the online survey. After the surveys were collected, a

workshop was held in which key regional experts reviewed the results and assigned a vulnerability ranking and confidence score for each species based on the combined score for the trait categories. Maine habitat types and sub-types were also assessed in an expert-opinion workshop format, and the results were carefully compared to similar habitat types in surrounding areas.

III. NORTHEAST AND MIDWEST REGIONAL SPECIES AND HABITATS AT GREATEST RISK AND MOST VULNERABLE TO CLIMATE CHANGE

A) OVERVIEW OF SYNTHESIS

In this section we provide information and summarize results of 21 completed or anticipated Climate Change Vulnerability Assessments (CCVAs) conducted across the Northeast and Midwest regions (**Appendix 2.1**). CCVAs were examined across two conservation targets; 1) fish and wildlife species, primarily those of Greatest Conservation Need (SGCN) and 2) habitats. For fish and wildlife species, we grouped species into major taxonomic groups including amphibians, birds, fish (freshwater and marine), freshwater mussels, insects, marine invertebrates, other invertebrates, mammals, and reptiles. Regional habitats were grouped based on similar descriptions across studies (though different names and classification schemes were often used) into seven categories including forests, freshwater wetlands, freshwater aquatic systems, coastal systems, cliffs and rocky outcrops, heathland and grasslands, and tundra. Note that some studies evaluated both species and habitats and are included in the results for sections C and D.

Two vulnerability indices were applied across multiple studies and allow for consistent metrics of comparison. NatureServe's Climate Change Vulnerability Index (CCVI) was used in six studies focused on assessing fish and wildlife species, while the Climate Change Response Framework employed by NIACS and partners was used in five studies targeting forests and other habitats. The results of the remaining vulnerability studies (referred to as "non-CCVI" when discussing fish and wildlife targets, and "non-CCRF" when discussing habitat targets) are also summarized. However, because methodologies were not consistent among non-CCVI and non-CCRF studies, comparisons among study results should be considered with the caveat that vulnerability ranking categories may not be equivalent. We encourage those interested in using the summary information presented below to consult the original reports for more detailed accounts of the climate change vulnerability ranking for a species or habitat.

B) VULNERABILITY RANKING CATEGORIES

The number and type of ranking categories varied across the 21 vulnerability assessments, with the number of rankings per method ranging from 3 - 8. The study with the greatest number of vulnerability categories (N = 8) was conducted by Manomet & MA DFW (2010); both Whitman et al. (2013) and the Adaptation Subcommittee to the Governor's Steering Committee on Climate Change (2010) had the lowest number of rankings (3 categories). Although the number of categories and ranking names varied from study to study, there were analogous rankings across studies. By creating a scale of 10 levels of vulnerability, different ranking categories can be compared. For example, six methodologies included a ranking of "Extremely" or "Critically Vulnerable", in which the species or habitat was assessed as being at risk of substantial decrease or disappearance. Nine out of ten studies included a ranking corresponding to "High Vulnerability", in which the species or habitat was assessed as being at risk of substantial decrease (e.g., defined as a greater than 50% loss within the area evaluated), as well as a "Low Vulnerability" or "Presumed Stable" category (e.g., abundance of the target species or habitat is not expected to decrease substantially).

Approximately half of the methodologies had categories in which to include species and habitats that are expected to benefit from climate change (expansion or increase in extent), and one study included a category that indicated vulnerability was uncertain (Manomet & MA DFW 2010). This synthesis groups vulnerability categories loosely across studies using a color gradient in summary figures and tables. The colors indicate: 1) Extremely Vulnerable (red), 2) High Vulnerability or Concern (orange), 3) Moderate Vulnerability (yellow), 4) Low Vulnerability (green) 5) Not at Risk or Increase or Expansion likely (blue), and 6) Least Vulnerable or Large Increase likely (purple) (**Appendix 2.2**). Two studies, Sievert (2014) and the New Hampshire Fish & Game Department (2013), did not provide vulnerability rankings and are presented separately.

C) FISH AND WILDLIFE SPECIES ASSESSMENTS

Our review identified 14 studies containing 1,524 unique assessment records for fish and wildlife species across the region (**Appendix 2.3**). Two studies are ongoing and results are anticipated by 2016. B. Zuckerberg (written communication) will focus on grassland birds, and J. Hare (written communication) will include assessments of 79 marine fish and invertebrate species. All studies assessed more than one target species. The number of targets within studies ranged from 2 – 400 species. Our review contained nine state-wide assessments (CT, WV, PA, MI, MA, ME, NY, MO, VT) and 4 regional-scale assessments (North Atlantic LCC, Atlantic coast, NEAFWA) (**Table 2**).

Birds were the most commonly assessed taxonomic group overall with 421 records. Freshwater fishes (N = 346) were the second most assessed taxonomic group across the Northeast and Midwest (note that anadromous and catadromous species were included in this group). Marine invertebrates (N = 22), amphibians (N = 56) and reptiles (N = 69) were the least assessed groups (**Figure 2; Appendix 2.3**).

Across all studies, 314 out of the 999 species (31 %) were assessed multiple times, either by location or life cycle phase[1]. Fish and wildlife species assessed in more than one study were not necessarily assigned the same vulnerability ranking even when the same framework was applied (e.g. CCVI). This indicates that vulnerability of individual species varies across their range in the Northeast and Midwest. While it is beyond the scope of the present synthesis to compare all within-species differences, we encourage those interested in particular species to compare results from different studies, and consider the specific factors affecting vulnerability in each study/region before making decisive statements about risk.

[1] Note that this number includes ongoing studies and not all results were available at the time this synthesis was conducted.

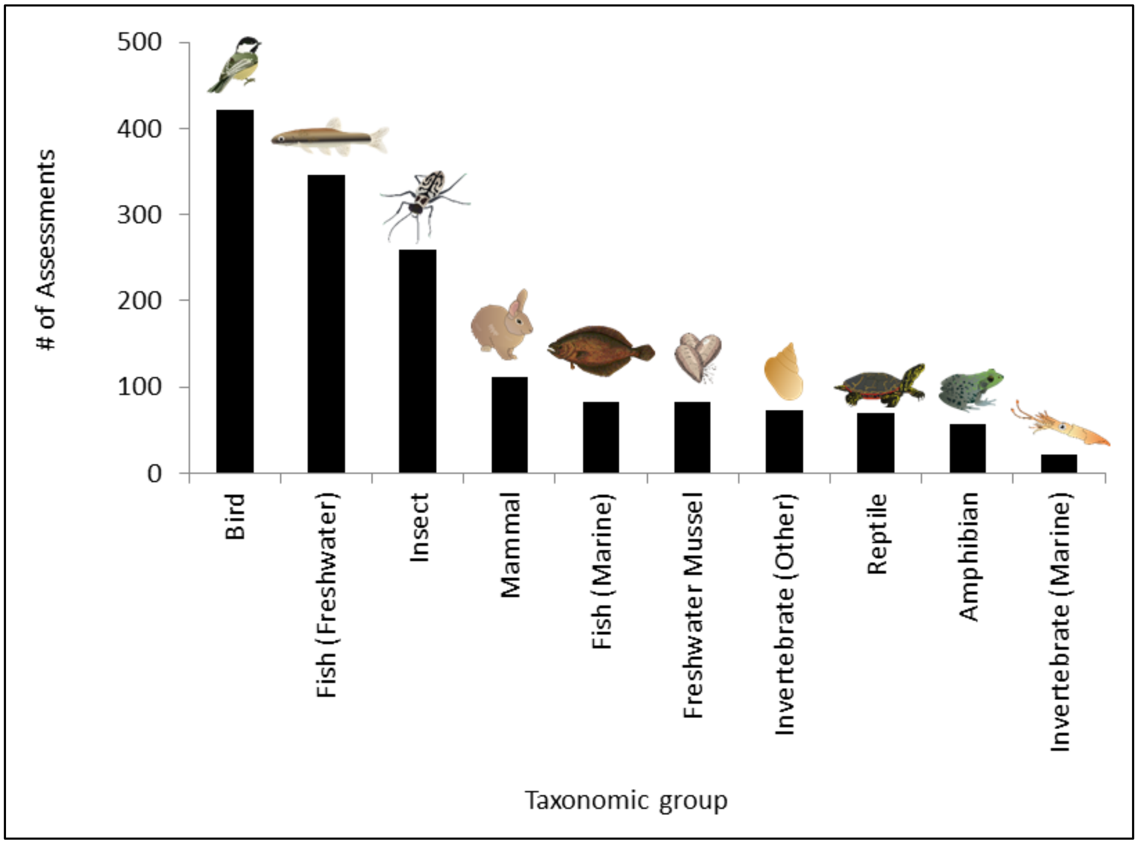

Figure 2: Number of vulnerability assessment rankings by major taxonomic groups across 16 regional studies. Icons courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

The most common CCVA framework used to assess fish and wildlife species' vulnerability to climate change across the region was the NatureServe CCVI Index. The CCVI was used in six studies, targeting West Virginia (Byers & Norris 2011), Pennsylvania (Furedi et al. 2011; Cullen et al. 2013), Michigan (Hoving et al. 2013), New York (Schlesinger et al. 2011) and the North Atlantic LCC region (Sneddon & Hammerson, 2014). Within these six studies, 842 species were assigned vulnerability rankings (**Figure 3; Appendix 2.4**). Across studies using NatureServe's CCVI framework, freshwater mussels, amphibians, and fish (primarily freshwater species) were the taxonomic groups most often ranked as extremely or highly vulnerable to climate change. Conversely, mammals and birds had the highest frequency of relatively low vulnerability rankings across studies. However, the vulnerability of birds, especially migratory species, may be underestimated as none of these assessments took the full life-cycle of migratory birds or the connections between breeding, wintering, and migratory habitat into account (Small-Lorenz et al. 2013). Species-specific vulnerability rankings across all CCVI studies can be found in **Appendix 2.4**. Please refer to the original study on which climate factors influenced vulnerability outcomes and the confidence in those rankings.

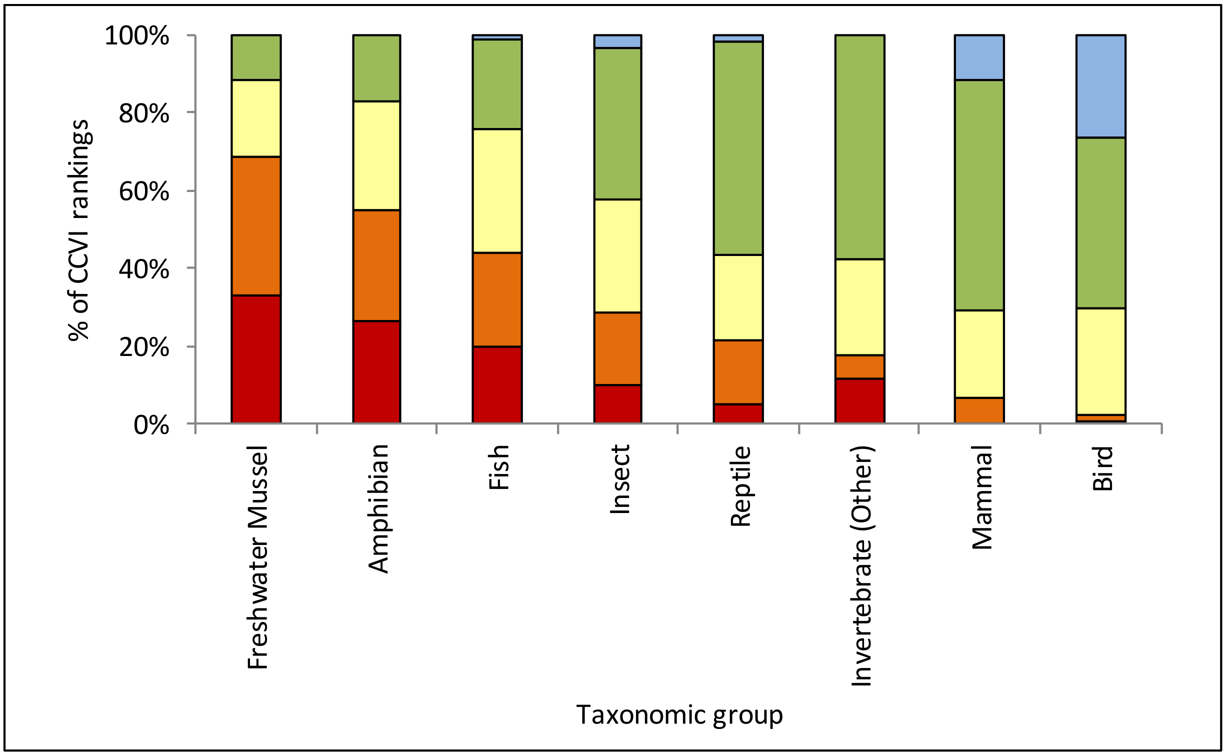

Figure 3: Count of vulnerability rankings using the NatureServe CCVI method broken down by taxonomic group. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable (orange), moderately vulnerable (yellow), presumed stable (green) and increase likely (blue). Results show combined rankings across six studies, targeting WV, PA, MI, NY and the North Atlantic LCC region (Byers & Norris 2011; Furedi et al. 2011; Schlesinger et al. 2011; Cullen et al. 2013; Hoving et al. 2013; Sneddon & Hammerson, 2014).

Vulnerability rankings were compared across four additional studies (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change, 2010; Galbraith et al. 2014; Tetratech, Inc. 2013; Whitman et al. 2013) that did not utilize the CCVI method, but rather, a combined approach of qualitative and quantitative methods that largely drew upon expert opinion to assess the vulnerability of each species. Within these four studies, there were 329 rankings of vulnerability across major taxonomic groups (**Figure 4; Appendix 2.5**). All marine fish (N = 4) and invertebrates (N = 1) were ranked as highly vulnerable[2]. Birds and mammals were the only taxonomic groups with species that were assigned rankings in the extremely vulnerable category, but the majority of birds and mammals were ranked as having moderately or low vulnerability. Please refer to **Appendix 2.5** for species and study/region-specific vulnerability rankings as well as the original source for information on which climate factors influenced vulnerability outcomes and confidence in those rankings.

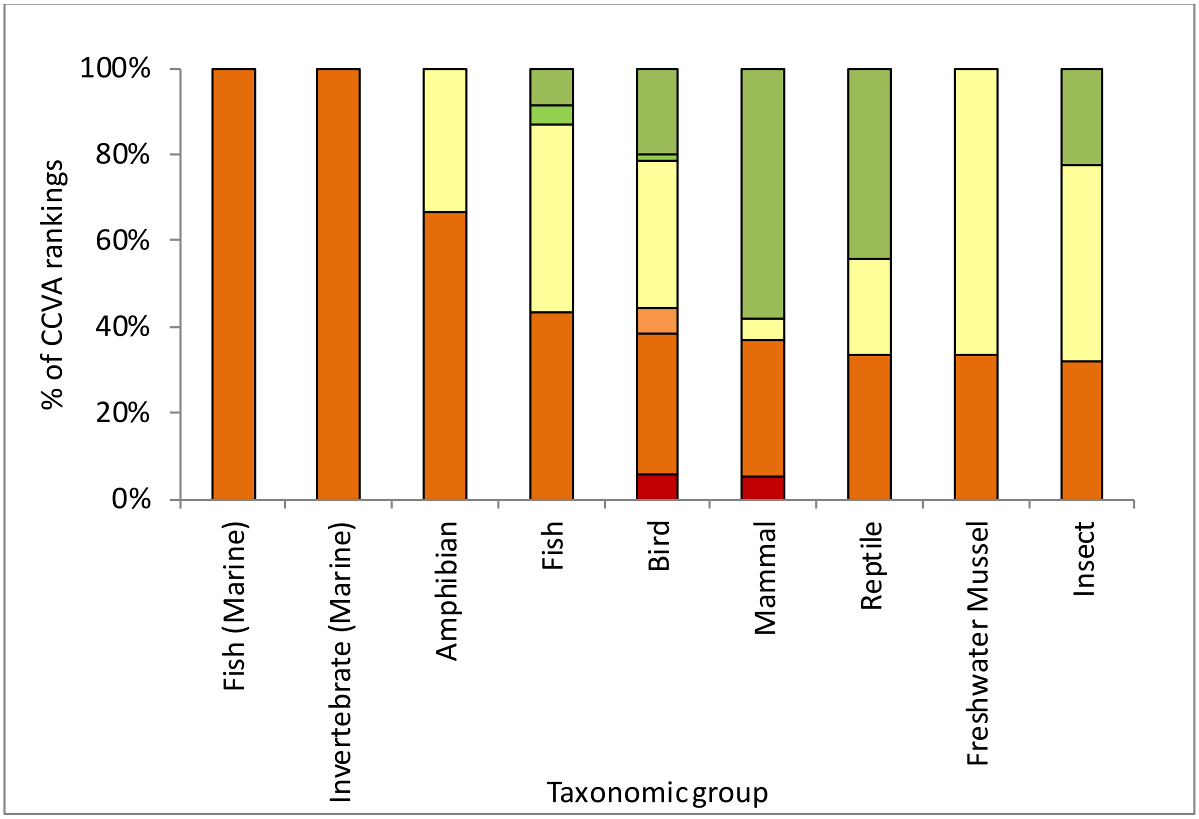

Figure 4: Count of vulnerability rankings using methods other than the NatureServe CCVI method broken down by taxonomic group. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable and high concern (orange), moderately vulnerable (yellow), low concern and presumed stable (green). No rankings were scored within studies indicating species would increase or expand their abundance. Results show combined rankings across 4 studies, targeting CT, VT, ME, and North Atlantic coastal and seabirds (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change, 2010; Galbraith et al. 2014; Tetratech, Inc. 2013; Whitman et al. 2013).

[2] Note that at the time this synthesis was completed the results of a multi-species vulnerability assessment of 79 marine fishes and invertebrates were not yet available but are anticipated in 2015 (J. Hare, written communication).

The results from Sievert (2014) are presented separately from the rest of the species CCVAs as this index ranks 133 species of freshwater fishes across two relative numeric scales. Each species received two independent scores, a "Trait-Based Score", and a "Response-Based Score". Trait-based scores were based on biological and ecological traits which have been linked to vulnerability in the literature. Response-based scores assessed species' environmental tolerances (e.g., habitat degradation, increased stream temperatures, and altered flow regimes) with measured species responses. The two scores used a similar framework but had environmental tolerance values which were derived using two different techniques. Scores enabled a comparison of relative vulnerability among 133 species of freshwater fish in the State of Missouri. Fish species were classified as vulnerable/not-vulnerable to environmental and biological factors within the framework; however, overall vulnerability thresholds and rankings (e.g., of high, medium, low) were not developed. Instead, species and trait-based scores allow for comparison of vulnerability among species included in the study. See **Appendix 2.6** for complete list of species and scores and Sievert (2014) for additional details.

D) HABITAT ASSESSMENTS

Eleven studies evaluated climate change vulnerability of terrestrial, aquatic, and coastal habitats across the Northeast and Midwest. A total of 224 unique assessment records were compiled for habitats across the region (**Figure 5**; **Appendix 2.7**). Similar to fish and wildlife CCVAs, all habitat vulnerability studies assessed more than one target habitat. The number of targets within studies ranged from 8 – 43. Seven state-wide assessments (CT, MA, VT, NH, ME, MI, MN) and four regional-scale (NEAFWA, Central Appalachians, Central Hardwoods, and Northwoods) assessments were conducted across studies (**Appendix 2.7**). Forest habitats were the most frequently assessed habitats (N = 102), followed by freshwater wetlands (N = 40) and freshwater aquatic systems (N = 40), while tundra (N = 4) and heathlands and grasslands (N = 6) were the least frequently assessed. Across all studies, 29 out of the 82 habitats (35 %) were evaluated multiple times across Northeast and Midwest.

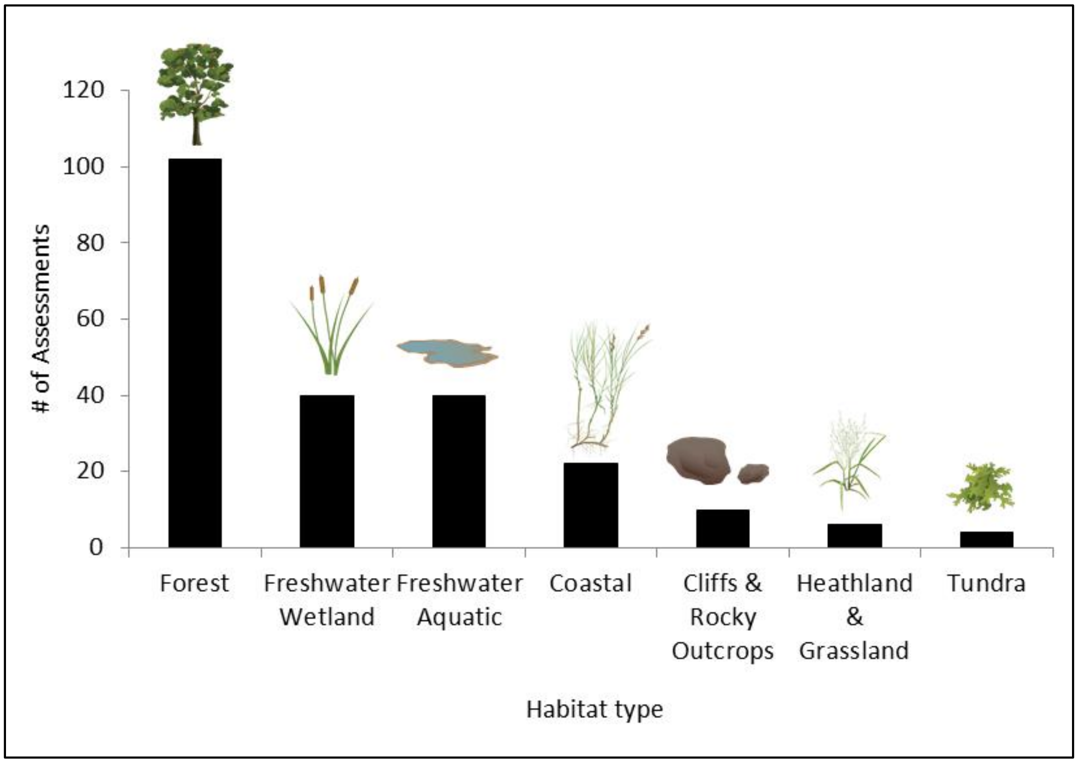

Figure 5: Number of vulnerability assessment rankings by habitat type across 11 regional studies. Icons courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

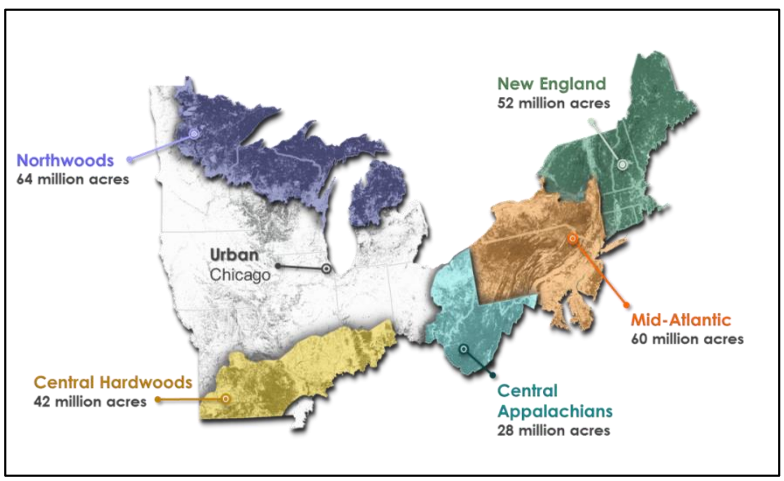

Figure 6: Areas assessed and anticipated (in 2016) for climate change vulnerability through the CCRF.

The Climate Change Response Framework (CCRF) used the same process to conduct five regional assessments of the vulnerability of forest and other habitats to climate change in the Central Appalachians (WV and Appalachian portions of OH and MD), Central Hardwoods (Southern MO, IL, IN), and Northwoods (Northern MN, WI, MI) regions (Brandt et al., 2014; Handler et al., 2014a, b; Janowiak et al., 2014; Butler et al., 2015). Assessments are currently in progress for the Mid-Atlantic, New England and Northern New York, and the Chicago area (**Figure 6**; expected 2016).

CCRF assessments primarily targeted forest habitats (N = 42), however, in a few cases they also assessed heathlands and grasslands (N = 2), and freshwater wetlands (N = 2). Habitat types assessed using the CCRF framework are organized in **Appendix 2.8** by study and region, and show the total count for each vulnerability ranking (High to Low Vulnerability) across all five studies. In addition, **Appendix 2.9** presents results as a matrix of habitat type by area/study, and provides a quick reference guide for which habitats were ranked consistently across all areas assessed by the CCRF to date.

The CCRF scored Appalachian northern hardwood, low-elevation spruce-fir, and lowland conifer forests as highly vulnerable to climate change. Freshwater wetlands, particularly bogs and fens, were also scored as highly vulnerable to climate change. Jack pine-red pine barrens, woodlands and northern oak-pine-hardwood, and central hardwoods oak-pine forests were scored as having relatively low vulnerability, as were glades (heathland and grasslands) **Figure 7**, **Appendix 2.8**). Please refer to **Appendix 2.8** for habitat and study/region-specific vulnerability rankings as well as the original source for information on which climate factors influenced vulnerability outcomes and confidence in those rankings.

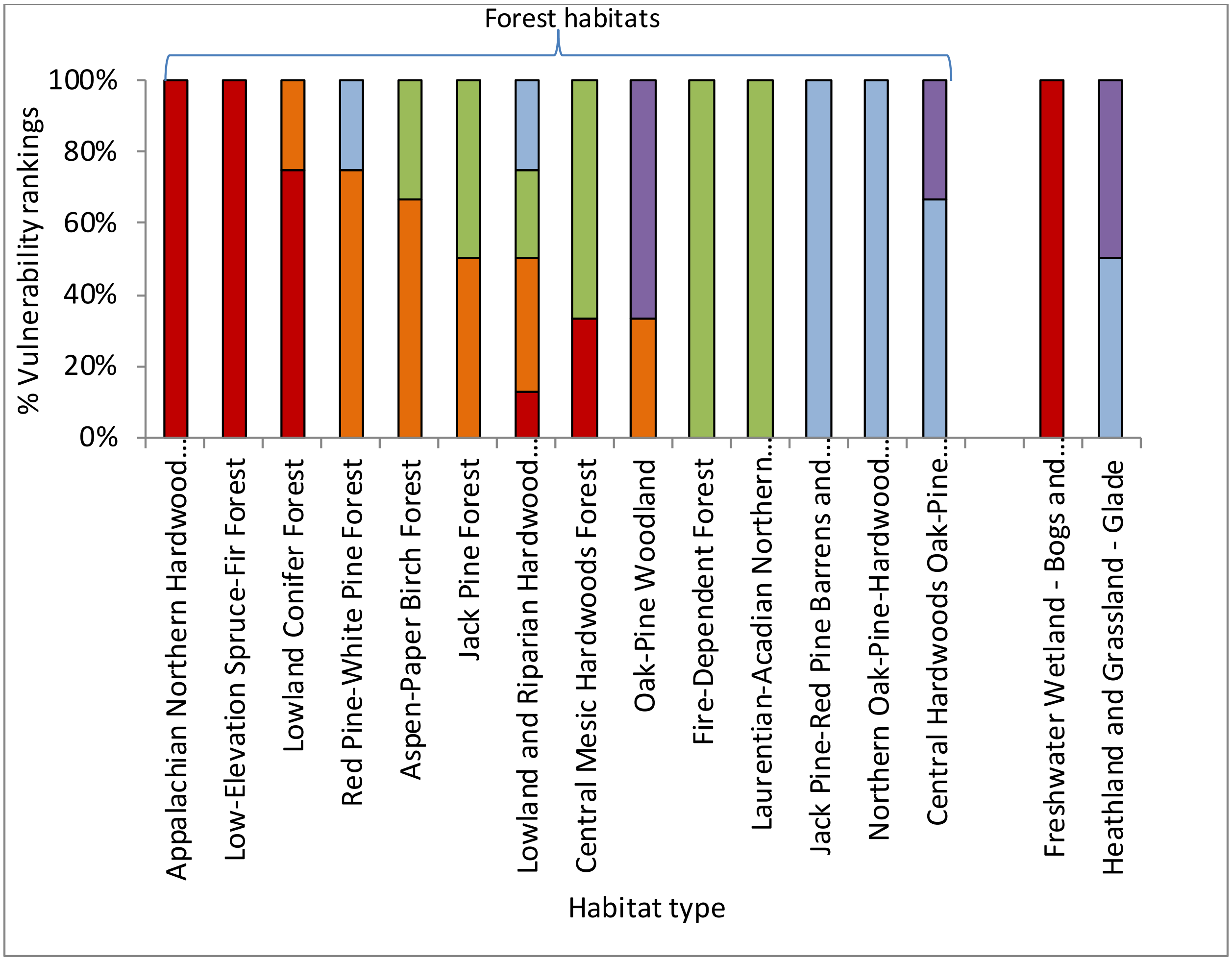

Figure 7: Count of vulnerability rankings using the CCRF framework broken down by habitat. Bars show the distribution of vulnerability ranking scores of High (red), Moderate-High (orange), Moderate (green) and Low-Moderate (blue), and Low (purple) vulnerability. Results show combined rankings across 5 studies, targeting Central Appalachians, Central Hardwoods, and Northwoods regions (Brandt et al. 2014; Handler et al. 2014a, 2014b; Janowiak et al. 2014; Butler et al. 2015).

An additional 6 studies assessed the vulnerability of terrestrial, aquatic and coastal habitats from across the region (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010; Manomet & MA DFW 2010; Manomet & NWF 2013; New Hampshire Fish & Game Department 2013; Tetratech Inc. 2013; Whitman et al. 2013). All of these assessments were qualitative with rankings developed from expert opinion gathered through online surveys and workshop panel discussions. Studies covered the geographic regions of Connecticut (Adaptation Subcommittee to the Governor's Steering Committee on

Climate Change 2010), Maine (Whitman et al. 2013), Massachusetts (Manomet & MA DFW 2010), New Hampshire (New Hampshire Fish & Game Department 2013), Vermont (Tetratech Inc. 2013), and four latitudinal zones within the New England Association of Fish & Wildlife Agencies (NEAFWA) region. Subdivisions were: Zone I (Maine, northern NH, VT, and part of NY), Zone II (Majority of NY, southern NH and VT, MA, CT, and RI), Zone III (PA and MD), and Zone IV (VA and WV) (Manomet & NWF 2013). Amassed vulnerability rankings across all habitats are organized by a) study and region, and b) vulnerability score. The total counts for each vulnerability ranking (extremely high to low vulnerability) are reported in **Appendix 2.10**.

Forest and freshwater aquatic habitats were the only groups assigned the extremely vulnerable classification across non-CCRF assessments. Generally, non-CCRF assessments ranked tundra, freshwater aquatic, and coastal habitats as highly vulnerable. Heathlands and grasslands, and cliffs and rocky outcrops were assigned relatively low vulnerability scores in about half of the studies in which they were assessed (**Figure 8; Appendix 2.10**). Please refer to **Appendix 2.10** for habitat and study/region-specific vulnerability rankings as well as the original information source on which climate factors influenced vulnerability outcomes and confidence in those rankings.

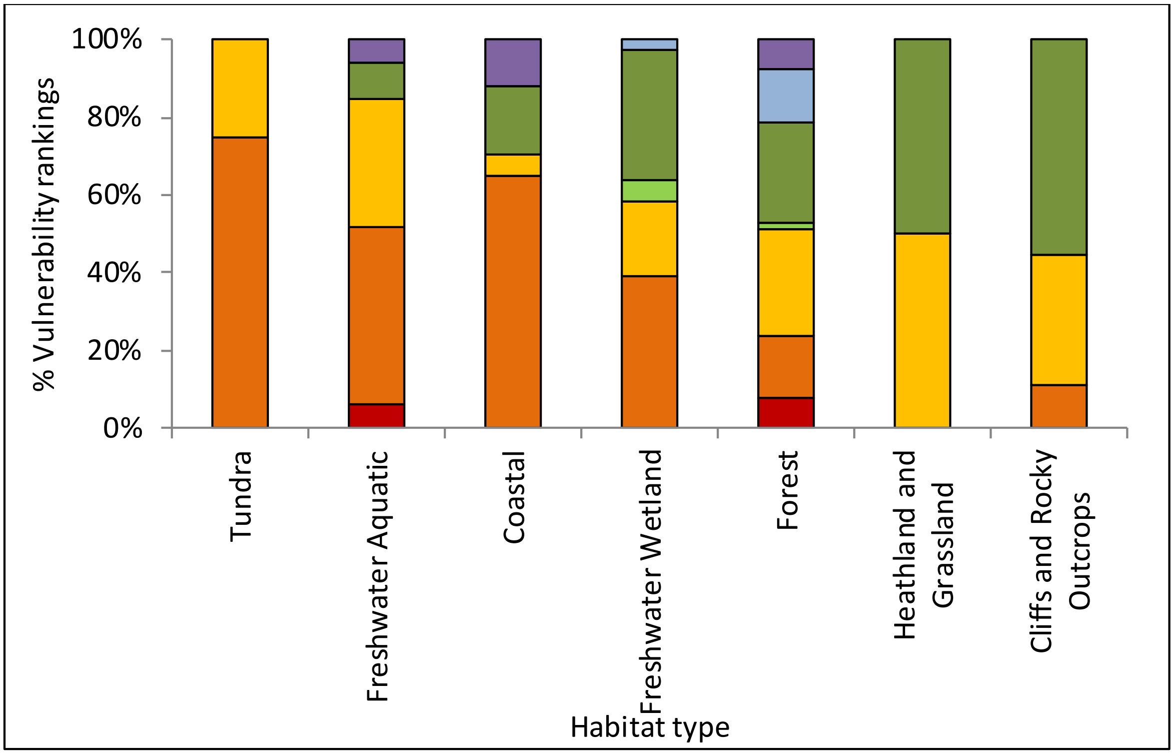

Figure 8: Percentage of counts of vulnerability rankings in non-CCRF studies by habitat type. Bars show the distribution of vulnerability ranking scores of extremely vulnerable (red), highly vulnerable and high concern (orange), moderately vulnerable (yellow), low concern and presumed stable (green), minimal increase (blue), and least vulnerable or large increase projected (purple). Results show combined rankings across 5 studies, targeting CT, MA, VT, ME, NEAFWA region (Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010; Manomet & MA DFW 2010; Manomet & NWF 2013; Tetratech, Inc. 2013; Whitman et al. 2013).

Habitats were not assigned vulnerability rankings in the New Hampshire Fish & Game Department (2013) study; instead, statements were listed in the text of the report describing how each habitat had been or was expected to be impacted by climate change. A total of 24 vulnerability descriptions were obtained from the original report and assembled in **Appendix 2.11**.

Table 3: List of climate change vulnerability assessment sources from the Northeast and Midwest regions of the United States. An expanded table of information with study-specific metadata is available in **Appendix 2.1**.

Full Citation	Overview	State or Region(s) Covered
Adaptation Subcommittee to the Governor's Steering Committee on Climate Change 2010	Assessed the vulnerability of 18 terrestrial and aquatic habitats, wildlife SGCN, state-listed plants, and some invasive species.	Connecticut
Brandt et al. 2014	Central Hardwoods forest ecosystem vulnerability assessment and synthesis.	Southern Missouri, Illinois, Indiana
L. Brandt, written communication	CCRF assessment in progress of the vulnerability of forests and associated ecosystems in the Chicago urban area. Project progress can be found at: http://www.forestadaptation.org/urban/vulnerability-assessment	Greater Chicago metropolitan area
Butler et al. 2015	Central Appalachians forest ecosystem vulnerability assessment and synthesis.	West Virginia and Appalachian portions of Ohio and Maryland
P. Butler, written communication	CCRF assessment in progress of the vulnerability of forests and associated ecosystems in the Mid-Atlantic ecoregion. Project progress can be found at: http://www.forestadaptation.org/mid-atlantic	Delaware, Maryland, Pennsylvania, New Jersey, New York
Byers & Norris 2011	Assessed the vulnerability of 185 SGCN, common, and foundational animal and plant species.	West Virginia
Cullen et al. 2013	Assessed the vulnerability of 20 forest songbirds due to climate change, historical deer browsing, and energy development (e.g., fracking).	Pennsylvania

Full Citation	Overview	State or Region(s) Covered
Furedi et al. 2011	Assessed the vulnerability of 85 priority species identified from the PA WAP to climate change, and other abiotic factors.	Pennsylvania
Galbraith et al. 2014	Assessed the vulnerability of 49 North American shorebirds to climate change.	US & Canada
Handler et al. 2014 a, b	Northwoods forest ecosystem vulnerability assessment and synthesis.	Northern Minnesota; Northern Lower Michigan and eastern Upper Michigan
J. Hare, written communication	Northeast Fisheries Climate Vulnerability Assessment (NEVA) in progress of 79 commercially and recreationally exploited marine fish and invertebrate stocks to climate change. Project progress can be found at: http://www.st.nmfs.noaa.gov/ecosystems/climate/activities/assessing-vulnerability-of-fish-stocks	Northeast U.S. Continental Shelf Ecosystem
Hoving et al. 2013	Assessed the vulnerability of 400 SGCN and game species.	Michigan
Janowiak et al. 2014	Northwoods forest ecosystem vulnerability assessment and synthesis.	Northern Wisconsin and Western Upper Michigan
M. Janowiak, written communication	CCRF assessment in progress of the vulnerability of forests and associated ecosystems in the New England ecoregion. Project progress can be found at: http://www.forestadaptation.org/new-england	Connecticut, Maine, Massachusetts, Rhode Island, New Hampshire, Vermont and Northern New York
Manomet & MA DFW 2010	Assessed the vulnerability of 20 SWAP-targeted fish and wildlife habitats to climate change.	Massachusetts

Full Citation	Overview	State or Region(s) Covered
Manomet & NWF 2013	Assessed the vulnerability of 13 non-tidal fish and wildlife habitats to climate change.	New England Association of Fish & Wildlife Agencies region
New Hampshire Fish & Game Department 2013	An amendment to the NH WAP that includes narratives of the vulnerability of 24 critical habitats.	New Hampshire
Schlesinger et al. 2011	Assessed the vulnerability of 119 SGCN.	New York
Sievert 2014	Assessed the vulnerability of 134 stream fishes to climate change, and habitat fragmentation.	Missouri
Sneddon & Hammerson 2014	Assessed the vulnerability of 64 species of plants and animals to climate change.	North Atlantic Landscape Conservation Cooperative region
Tetratech, Inc. 2013	Assessed the vulnerability of 22 upland forest, wetland, river, stream, and lake habitats as well as associated fish and wildlife species to climate change.	Vermont
Whitman et al. 2013	Assessed the vulnerability of 442 SGCN, state-listed, Threatened or Endangered wildlife and plant species, and 21 Key Habitats from the Maine Comprehensive Wildlife Conservation Strategy (ME CWCS).	Maine
B. Zuckerberg, written communication	Assessment in progress of the vulnerability of grassland birds. Project progress can be found at: http://necsc.umass.edu/projects/fitting-climate-lens-grassland-bird-conservation-assessing-climate-change-vulnerability-usi	Eastern US

IV. RESOURCES AND FUTURE DIRECTIONS FOR VULNERABILITY ASSESSMENTS

A) VULNERABILITY ASSESSMENT TRAININGS

The U.S. Fish and Wildlife Service's National Conservation Training Center (NCTC: http://training.fws.gov/) offers training courses to guide conservation and resource management practitioners in the theory, design, interpretation, and implementation of Climate Change Vulnerability Assessments. Participants also gain a perspective of how vulnerability assessments fit into the broader context of adaptation planning. Courses follow the guidelines established in *Scanning the Conservation Horizon - A Guide to Climate Change Vulnerability Assessment* (Glick et al. 2011). Generally, participants work through case-studies or modules to better understand how different factors influence vulnerability and can affect outcomes of assessments, learn about different approaches to conduct vulnerability assessments, and develop work plans and scope of work for their own systems or conservation targets.

NCTC courses are team taught by a diversity of experts and are open to government, non-profit, academic and private persons. Trainings can be taken at NCTC's campus in Shepherdstown, West Virginia, or requests can be made to hold trainings at specific institutions, and be focused on an explicit area of interest (e.g., region, tribal, habitat focus).

B) NEW RESOURCES

Climate Registry for the Assessment of Vulnerability (CRAVe)

There is currently no available method to identify existing vulnerability assessments conducted in specific regions or on specific resources. Thus, it is highly likely that new assessments are being launched without knowledge of relevant ongoing or completed assessments. Since different institutions use different vulnerability frameworks and approaches it is also likely that the data and knowledge gathered by completed assessments are not being used by managers outside the entity conducting each individual assessment.

The Climate Registry for the Assessment of Vulnerability (CRAVe) is a searchable, public registry on CCVAs. The project was initiated by the USGS National Climate Change and Wildlife Science Center (NCCWSC) as part of the work of the Interagency Land Management Adaptation Group (ILMAG); member agencies from the US Global Change Research Program Adaptation

Science Work Group, the Association of Fish and Wildlife Agencies (AFWA); several NGO's have also contributed to this new tool. The purpose of CRAVe is to make information about ongoing and completed vulnerability assessments more readily accessible and available, so that resources devoted to such assessments can be used most efficiently. The registry includes descriptions of each vulnerability assessments project.

CRAVe is hosted in two locations: 1) USGS NCCWSC (https://nccwsc.usgs.gov/crave/); and, 2) the EcoAdapt Climate Adaptation Knowledge Exchange (CAKE; http://www.cakex.org/). In the future, the registry will likely create a link to or be otherwise integrated into the evolving USGCRP-led Global Change Information System (GCIS; https://data.globalchange.gov/).

Users of CRAVe can enter basic information about a vulnerability assessment, including project location and scale, assessment target or endpoint, contact information, managing agency and partner agencies, vulnerability assessment components (exposure, sensitivity, adaptive capacity), type of climate, sea level rise or hydrological change projections, methods for determining the impact of threats, and the purpose of the vulnerability assessment. CRAVe users may also upload abstracts that provide additional details on their projects, and links to websites and other documents. The assessments housed in CRAVe include studies pertaining to species and ecosystems, built environments and infrastructure, cultural resources, and socioeconomic systems. Users can access CRAVe to conduct searches across all vulnerability assessments to find necessary information for decision making.

Contact: nccwsc_crave@usgs.gov

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